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Master of Science degree in Automotive Engineering

Master Thesis

Digital Twin at Urban Scale for a Master Plan in the Area of the CEBU Airport (Philippine)

Supervisors **Candidate**

Prof.ssa Anna Osello **Ma Fanshu**

Prof.ssa Francesca Maria Ugliotti

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Time flies quickly, five years of study almost finish. Looking back on the five years of study and life, I have deep feelings and rich harvest.

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Abstract

In the view of the current traffic situation of Metro Cebu in recently years, the problems of urban air pollution have become more and more serious, the pollution problems caused by the operation of urban motor vehicles has become prominent. At the same time, digital twin, IoT, big data, artificial intelligence, virtual reality, and other new generation information technologies are deeply integrated and developed with the cities. This case study through the modelling of the proposed mobility Hub, the interactive driving simulator, and the traffic data visualization management center with the help of digital twin dashboard to provide a methodology to optimize the Metro Cebu traffic situation and improve the government management efficiency. The main research work of the thesis is the macroscopic traffic analysis, microscopic traffic analysis of Cebu metro to make decision of the mobility hub location, the emission and energy analysis of the electric vehicles in the future, finally based on the 3D models of digital urban and using the interactivity of the Unity3D platform to design a data visualization management system. Given the rapid development that cities are experiencing in terms of population, size and energy consumption, the methodological Digital Twin supplied aims to enhance citizens life quality with the help of industry 4.0 technologies. This objective is pursued addressing some of the seventeen sustainable development goals by the UN 2030 Agenda.

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Chapter 1: Introduction

1.1 Background

Currently, Global demand for transportation is gradually rising, and estimated to increase by 45% by the year of 2050. Most mobilities are powered by fossil fuels (such as gasoline, diesel, or liquefied petroleum gas). These fuels are non-renewable resources and will be used up within one day. The main pollutants which come from the automobiles are Carbon dioxide (CO_2), carbon nitrogen oxides (NO_x) , hydrocarbons (HC), particulate matter (PM), and monoxide (CO). In the atmosphere of cities, 82% carbon monoxides, 48% of nitrogen oxides, 58% of hydrocarbons, 1.3% of sulfur oxides, and 8% of particulate matter, all these come from vehicle emissions. Thus, the still increasing demand for transportation combined with the growing world economy is driving the air pollution to the limits while threatening our daily lives with this elevated pollution levels. How to intelligently control traffic in urban areas and reduce environmental pollution has become a very important matter. Our world is constantly changing and rapidly developing into digital world. With the new technologies such as cloud computing, machine-learning (ML), internet of Things, Big-Data, Real-Time Interaction AI growth and the advent of the 5G era, human connection technology has reached an unprecedented height. With the closer connection between the cloud and the end, more data is collected, and new technologies begin to emerge, Digital twins are becoming a hot topic. The digital twin technology realizes the bidirectional mapping by establishing between the physical object and the physical object's digital twin model. It has been applied to product development, design, manufacturing, and other areas, and is being expanded to business operations, urban governance, and other areas to improve efficiency. At the same time, it will promote the creation of digital-based innovation models. Commercial production operations and urban governance.

Digital twins are abstracting and modelling everything, it can improve business processes, reduce risks, optimize operational efficiency, and use automation to predict results to enhance decision making capabilities. Though the combination of information and models, digital twins provide indispensable help to optimize the traffic situation and friendly protect the environment of the world.

1.2 Environmental Effect of Urban Traffic

The global economy, science and technology and other aspects are in rapid development. At the same time, the size of the city is also growing, led to the population increase rapidly, increase in the scale of facilities, improvement of service efficiency and the scale of urban transportation network is gradually expanding. Large urban transport networks can provide better quality, more efficient service, but there are also many disadvantages such as air pollution, noise pollution, lack of resources caused by traffic problems (fuel consumption and traffic jams) have plagued us for a long time. In the previous studies about the field of transportation, most of the research concern the work only focus on increasing traffic flow, reducing traffic congestion, saving travel time and so on, but ignored traffic pollution and other environmental issues. Traffic pollution refers to pollutants such as harmful substances produced by vehicles during operation. And under natural conditions, the atmosphere cannot completely purify pollutants therefore causing serious environmental pollution problems. In the past ten years, urban smog has become more and more serious, which is already an environmental problem that needs attention. The number of vehicles is growing rapidly, the emission of vehicle exhaust pollutants has become the main cause of urban environmental degradation, especially the impact on the air. The main reasons for the increase in traffic exhaust emissions are the increase in the total number of motor vehicles, the traffic jams, and the low-speed drive.

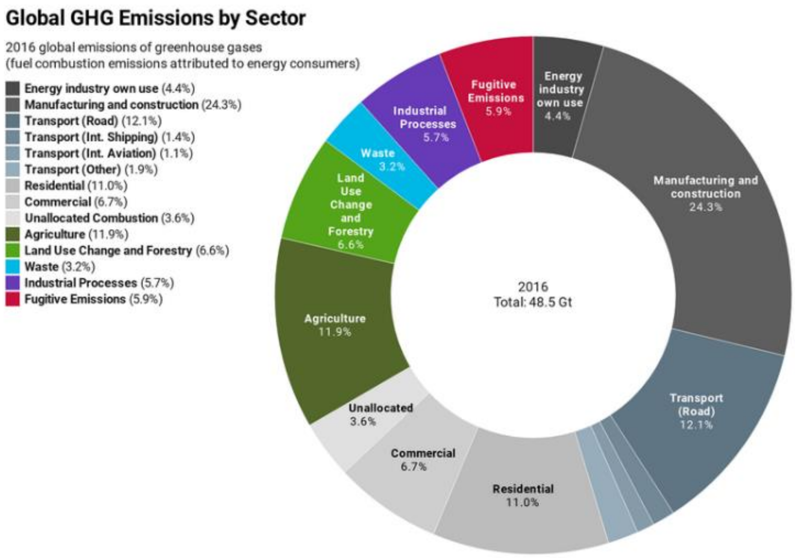


Figure 1.1 Chart showing 2016 global greenhouse gas emissions by Sector.[3]

As we can see from the **Figure 1.1**, Environmental pollution caused by Transport (Road) takes up a large proportion. The world Resource institute's Climate Data Explorer provides data from CAIT on the breakdown of emissions by sector. In 2016, global CO2 emissions (including land use) were 36.7 billion tons CO_2; emissions from transport were 7.9 billion tons CO_2. therefore accounted for 7.9/36.7 = 21% of global emissions. The IEA looks at CO_2 emission from energy production alone in 2018 it reported 33.5 billion tons of energy – related CO_2. [hence, transport accounted for 8 billion / 33.5 billion = 24% of energy-related emissions[1].

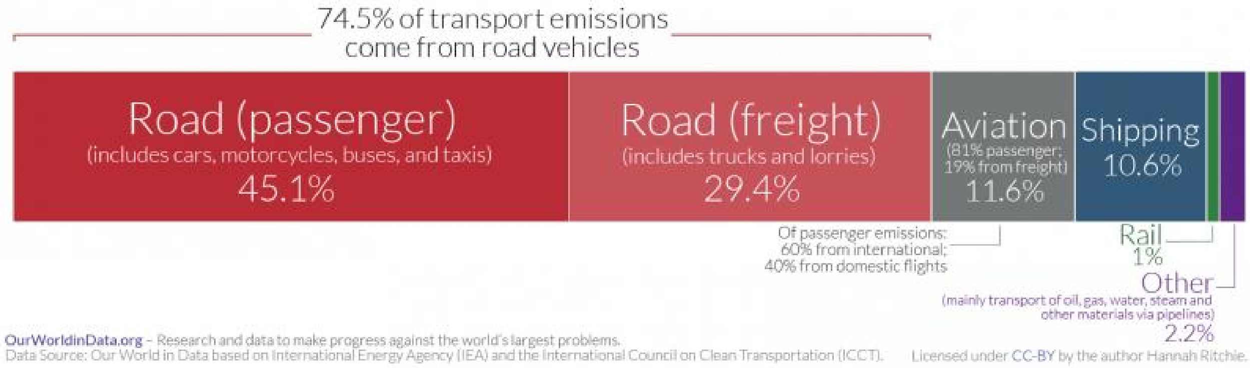


Figure 1.2 Global CO_2 emissions from transport

In the **Figure 1.2** we can see the share rate of different transportation method. The transportation emission comes from passenger cars has occupied a large percentage with almost 50%. Therefore, we can realize that the most transport emission comes from road transport [1]. High level of air pollution affects all organs of the human body, leading to various diseases as shown in **Figure 1.3**.

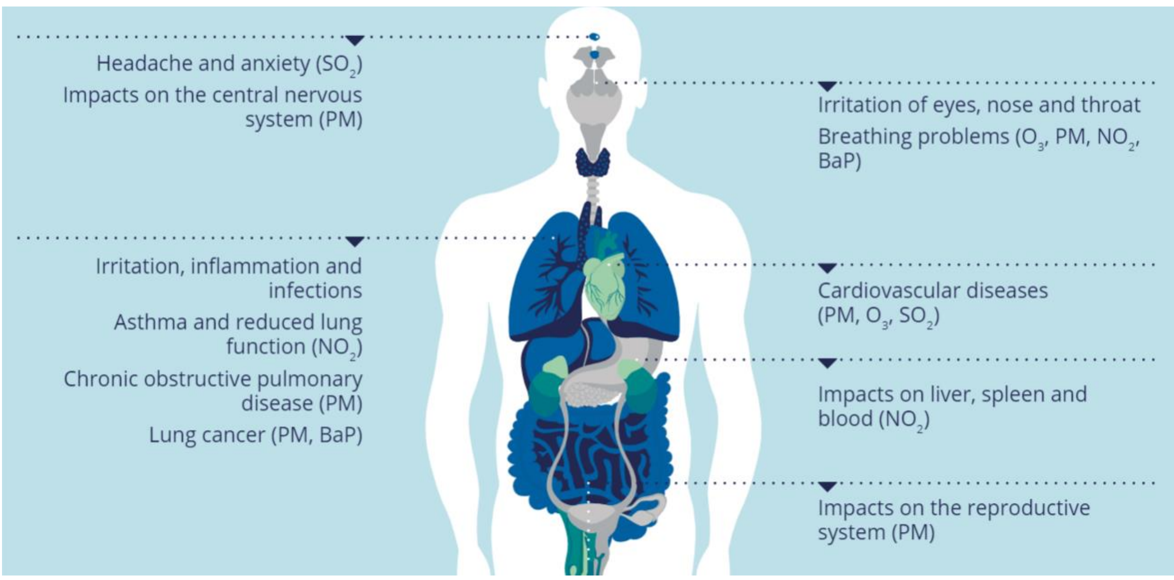


Figure 1.3 Health impacts of air pollution[4]

Since most motor vehicles run in densely populated areas, they are harmful to the human body. Among them, CO is the highest concentration component of all harmful emissions from mobilities. The same concentration of carbon monoxide enters the lungs will induce the lung cancer. And after being absorbed by the blood, it combines with the hemoglobin in the body to form carbon monoxide hemoglobin, which will cause different degrees of harm to the human body. The main hazard of lead pollution to young people is that lead in car exhaust is generally distributed in the young people-s breathing zone about 1 meter from the ground.

1.3 Problem definition and Goal of the Study

Transportation is the lifeblood of the national economy, social development, and people's lives. Modern transportation mainly includes five major field: road transportation, railway transportation, water transportation, air transportation and pipeline transportation. With the rapid development of information technology, the internet, communications, and satellite navigation Development and the integration and promotion of various technologies have greatly improved the functions of information systems. The functions of the traffic information management system and vehicle information management system based on satellite navigation are getting stronger and stronger, which greatly improves the management level of transportation and the transportation efficiency of various vehicles. The Philippines is a multiethnic archipelago country in Southeast Asia. The domestic transportation is mainly road and sea transportation. Road transportation is the most developed. Road transportation accounts for 90% of the country's total transportation volume. in the recent years, the population of the Philippines continues to increase, the number of vehicles continues to increase, and management becomes more and more difficult. Improving transport system is critical important for reduce emission and enhancing economic growth. This paper by studying the traffic around the Cebu airport (Philippine), build center mobility hub and uses digital twin's visualization management system technology to monitor and improve traffic condition and reduce emission.

1.3.1 Current state and Problems of traffic in Philippines

The Philippines has 210,528 kilometers of roads, with only 65,101 kilometers of road paved (concrete and/or asphalt), almost 20% being paved and 80% being unpaved [10], as shown in **Figure 1.4**; indicate that only 14 percent of the country's roads is paved, while 86% is unpaved. Most of the country's unpaved roads are in rural areas. These are mainly roads from the farm to the market. These roads are most important to the economic life of rural communities because they are usually far away from the main roads and are entrusted to the local government in terms of resources and technical capabilities, therefore they are often ignored, it is easily damaged and destroyed by natural factors such as rain and flood. [11]. Republic Act (RA) No. 917 or the Philippine Highway Act, classifies roads into National, Provincial, City, Municipal and Barangay Roads. As of December 2018, the road network consists of 15% National roads, 13% Provincial roads, 12% City and municipal roads and 60% Barangay (village) roads. Even some parts of the national road are unpaved, and it is used by regular transport vehicles in **Figure 1.6**. However, despite the construction of a large-scale road network across the country, most of the road network is still in poor condition, accounting for only 20% of the road network. The ADB-DILG Policy Framework Report has mentioned that among the ASEAN countries, Philippine has the highest road density but the lowest paved ratio. In **Figure 1.5** provides a comparative analysis of this situation among selected countries in Southeast Asia.[12] All in all, Traffic is a significant issue facing the country, especially within Manila and Cebu.

Classification	Paved	%	Unpaved	%	Total
National	16,029	57	11,868	43	27,897
Local	23,287	14	148,501	86	171,788
Total	**39,316**	**20**	**160,369**	**80**	**199,685**
Local Roads					
Provincial	5,825	20	22,678	80	28,503
City	4,048	70	1,719	30	5,767
Municipal	5,394	34	10,422	66	15,816
Barangay	8,020	7	113,682	93	121,702
Total	**23,287**	**14**	**148,501**	**86**	**171,788**

Figure 1.4 Road Inventory, Philippine (in km) [11]

Country	Road Density (Km/Km^2)	Paved Ratio
Philippines	0.67	0.21
Indonesia	0.19	0.47
Malaysia	0.20	0.82
Thailand	0.42	0.35
Vietnam	0.46	

Figure 1.5 Road Density ratio and Paved ratio [12]

Figure 1.6 Unpaved national roads used by regular transport vehicle (Jeepney)

We take the capital of the Philippines (Manila) as an example to show the current traffic condition in the Philippines. In the **Figure 1.8** shows the recent traffic conditions in Manila. With the COVID-

19 under travel restrictions conditions, the traffic conditions in Manila and the Philippines are still very unsatisfactory. Traffic has been a big issue in Philippine. With a bad traffic condition will affect a lot of Philippines. Due to the frequent stop-and-go traffic and narrow intervals, bends and collision are more common. Because you cannot improve work efficiency in traffic jams it will cause opportunity cost or wasted time, thus reducing the economic health of the region. Traffic on major roads often overflows onto secondary roads, many of which are residential roads. This will create lots of noise and it will affect the peace and lives of the neighborhood, and even has a negatively effect of the real estate prices. Due to heavy traffic, it is common to see that goods are late, students are late, and employees are late. The worst example is the delayed response time of emergency services such as firetruck and ambulance, because if these response times are delayed, it will lead to health. Also, bad traffic will affect the economics of Philippines. According to the Japan international Cooperation Agency (JICA), if the traffic problem is not resolved, Philippines Cebu will lose 3.5 billion pesos a day. JICA's 2018 study said that Philippines will lose 5.4 billion to traffic daily by 2035 id no interventions are made. Currently, metro Manila loses about 3 billion pesos every day. More importantly, the impact on the environment due to the huge traffic volume and traffic congestion cannot be underestimated. For example, old model jeepneys become the main contributor to air pollution. Jeepneys contributes to greenhouse gas emission of about 12.49 – 17.48 tons of CO_2 per year. Therefore, it is particularly important and urgent for the Philippines to solve the traffic problem. There are many factors that have contributed the bad traffic conditions in Philippines.

WORLD RANK	CITY	COUNTRY	CONGESTION LEVEL	
1	Bengaluru	India	71%	
2	Manila	Philippines	71%	
3	Bogota	Colombia	68%	↑5%
4	Mumbai	India	65%	0%
5	Pune	India	59%	
6	Moscow region (oblast)	Russia	59%	↑3%
7	Lima	Peru	57%	↓1%
8	New Delhi	India	56%	↓2%
9	Istanbul	Turkey	55%	↑2%
10	Jakarta	Indonesia	53%	0%

Figure 1.7 TomTom's list of 10 most Worst traffic cities

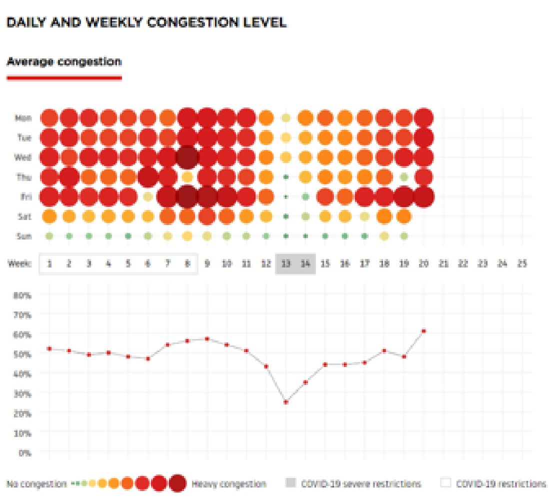


Figure 1.8 Daily and Weekly congestion level

1.3.2 Current state and Problems of traffic in Metro Cebu

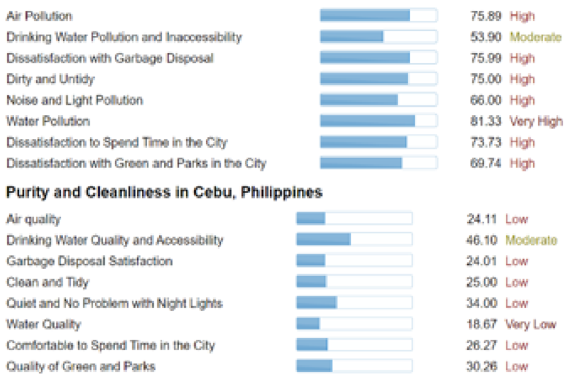
Cebu City is located on the eastern coast of Cebu Province. Cebu is the second largest city in the Philippines, Cebu covers an area of 340 square kilometers and has a population of seven hundred thousand. Cebu City, Mandaue City and Lapu-Lapu form the Cebu, the total population is 1.24 million, and is the economic center of Visayas region. The urban core of Cebu Province is Metro Cebu, which is located along the central eastern portion of the province and includes the nearby Mactan Island. The main island of Cebu Province about 225 kilometers from north to south. The total length of the road network include city, municipal and barangay roads is 1398.2 km. According to the Japan international Cooperation Agency (JICA), most of roads are usually very narrow with two lanes even for some sections of highway. Through the research of Cebu Road study, almost 46% of roads are unpaved, barangay roads occupied large amount of part as shown in the **Figure 1.9**.[13]

Road Classification	Length (km)
National Primary Road	121.0
National Secondary Road	191.0
National Tertiary Road	105.6
Provincial Road	112.5
City Road	171.1
Municipal Road	66.4
Barangay Road	630.6
Total	1,398.2

Source: JICA Study Team

Figure 1.9 Road Lengths in Metro Cebu by Road Classification

Cebu Public Transport system is mainly combined by jeepneys, buses, taxis, and tricycles. Same as Manila or other cities of Philippines, Cebu is facing with traffic problems: increasing congestion; a rise number of traffic accidents; local and noise pollution; growing fossil fuel consumption, and a rising level of greenhouse gas emission. Firstly, the traffic congestion is very serious in Cebu, travel speed in Cebu city ranged from 4 to 18 kph, the average speed is almost 10 kph were surveyed by CITOM in 2005. This indicated that **the traffic congestion seriously** at all times of the days. In Recently years, traffic congestion occurs on many roads and intersections not only during peak hours, but also off – peak hours. As the population increased and vehicle flow growth, Cebu traffic congestion more and more seriously. the main public transportation in Cebu is Jeepney, since its rear door is open, passengers and drivers can easily get on and off, therefore they can stop anywhere and loading and unloading passengers in the middle of the street, blocking traffic, and risking the safety of passengers. Jeepneys contributes to greenhouse gas emission of about 12.49 – 17.48 tons of CO2 per year. This is also considered to be the main source of urban air pollution. Secondly, **the number of traffic accident is high**, which occur in Cebu is 1235 per month which is quite high. Traffic accident always happened on congested roads. Due to the traffic congestion, Cebu accidents numbers increased steadily. In the view of bad traffic **increasing air pollution**, according to the latest statistics on Cebu's air condition in Cebu in **Figure 1.10**, in all kinds of pollution, air pollution is the most serious one, and in the data about the Purity and Cleanliness in Cebu, the air quality is in low level. Through Air pollution data from World Health Organization, PM pollution level is high. In the **Figure 1.11** shows that the emission rate of Philippines which we can realize that the transport emission is occupied the large part of air pollution.



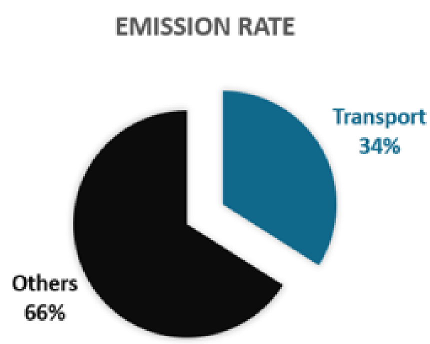


Figure 1.10 Air Condition in Cebu

Figure 1.11 Emission rate of Philippines

In the view of the problems about **fossil fuel consumption growing**, the total amount of primary energy provided to Cebu City is 21.8 billion MJ, or 6 billion kWh, approximately 20.4% is in the form of electricity, while 79.6% is in the form of petroleum products, and very small amounts of natural gas are also imported into the city. Therefore, the reliability of energy supply is an important consideration for future energy planning. In the **Figure 1.12**; we found the transportation is the largest energy user in Cebu city, consuming 51% of Cebu City's primary energy and accounting for most of the fuel loss.[12]. As we can see in the Philippine the renewable energy grows slowly in the **Figure 1.13**, if we want to save energy, improve the air quality and reducing emission on traffic, we should more use the renewable energy.

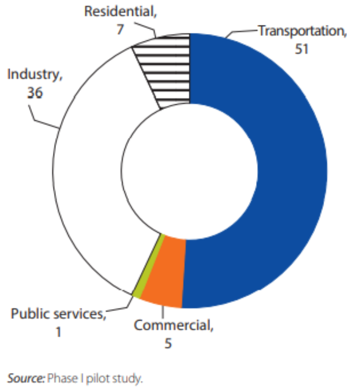
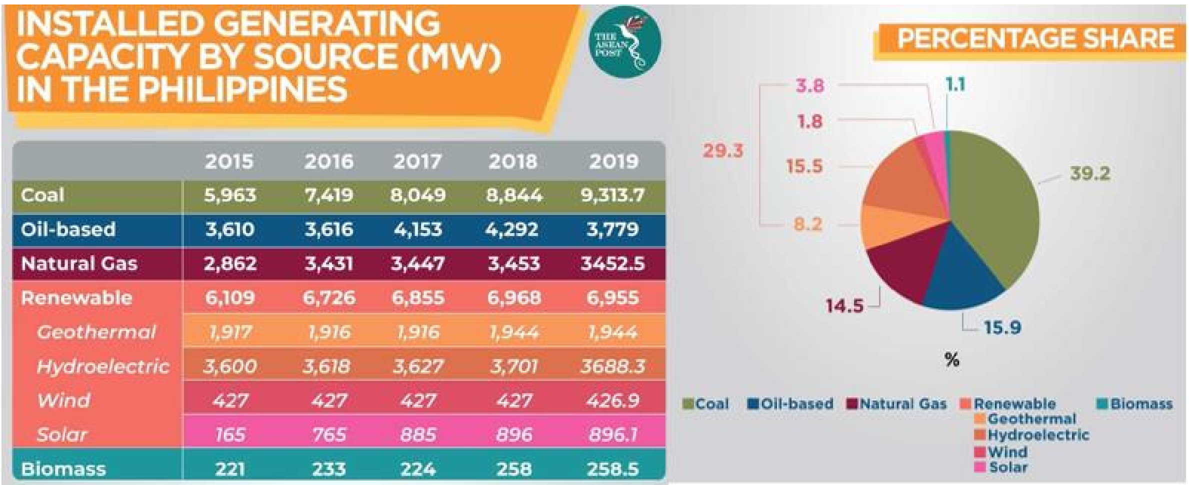


Figure 1.12 Cebu City Energy Consumption



	2015	2016	2017	2018	2019
Coal	5,963	7,419	8,049	8,844	9,313.7
Oil-based	3,610	3,616	4,153	4,292	3,779
Natural Gas	2,862	3,431	3,447	3,453	3452.5
Renewable	6,109	6,726	6,855	6,968	6,955
Geothermal	1,917	1,916	1,916	1,944	1,944
Hydroelectric	3,600	3,618	3,627	3,701	3688.3
Wind	427	427	427	427	426.9
Solar	165	765	885	896	896.1
Biomass	221	233	224	258	258.5

Figure 1.13 Distribution of energy source

Causes of Worse Traffic Conditions

Population Grows Fast

Now the population of Philippine is 110,870,506. It ranks number 13 in the list of countries (and dependencies) by population. The population density in the Philippines is 368 per Km^2 As a research “the 25 cities with the highest population density in the world”, Cities in the Philippines dominated the list with six in the top 25. Through the JICA Group study, the population of Metro Cebu is expected to increase from 2.55 million in 2010 to 5 million in 2050 due to rapid urbanization. There are three metropolitan areas in Philippines: Metro Manila in Luzon, Metro Cebu in Visayas and Metro Davao in Mindanao. In 2015, Manila population is 12.9 million, Metro Davao is 2.5 million and Cebu is 2.8 million. Although Cebu ranks seconds on the population, and the population is less than Manila, but its population growth rate is higher. Cebu Metro has a highest population growth rate in Philippines as shown in the **Figure 1.14**.

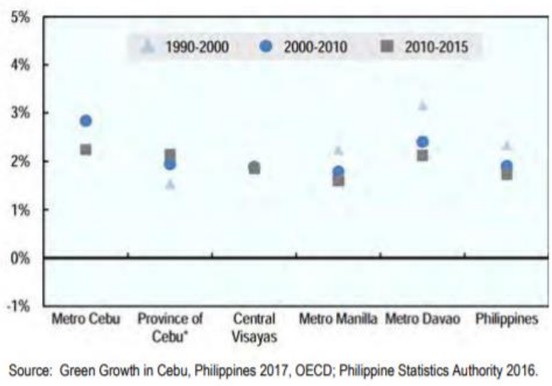


Figure 1.14 Population Growth in Cebu 1800-2020

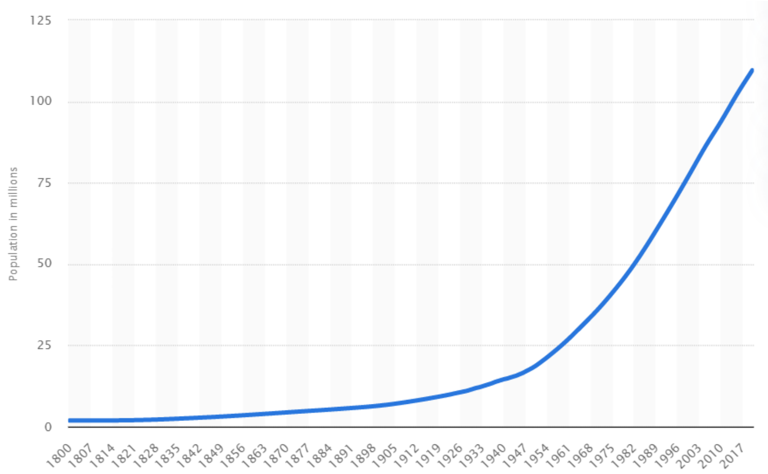


Figure 1.15 Population of Philippines

The increasing population has a great influence on traffic system. A proper tool to investigate complex dynamics of variables in a system is the CLD (Causal Loop Diagram).[17] Through the **Figure 1.16**. we can see the relationship between population and traffic system. As the population continues to increase, traffic congestion will gradually increase. Regarding the current population growth in the Philippines, traffic congestion will become more and more serious.

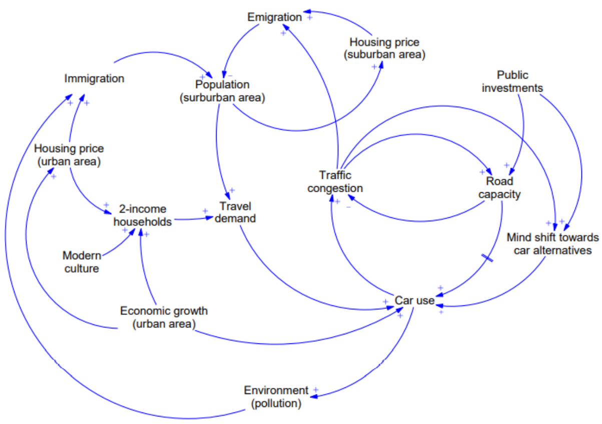


Figure 1.16 CLD of traffic dynamics

Traffic Volume Increase but Limit Road Capacity

In Philippines, More and more people are going to work in cities, since their workplace is far away from their home and they have enough incomes to buy cars, almost all the long-term residents have their own cars. It can be said that cars like Toyotas Viols, Mitsubishi Mirage are in small size, and the prices is low, these young people are very interested in these kinds of vehicles. Therefore, the vehicle volume increases rapidly these years, Also the public transport system has a lot of problems, such as cannot find the bus station, the taxis driver arbitrary charges and Jeepney can stop any place in the middle of roads. These factors induce more people buy their own transport tools. Thereby increasing the traffic volume. In 2020, the total volume of registered private vehicles in the Philippines amounted to about 1.1 million units as shown in **Figure 1.17**. Serious traffic congestion often occurs at major roads and intersections in Metro Cebu. And the roads between Cebu and Mactan island (first and second Mactan bridge) and the roads between Lapu-Lapu city hall and Cebu international airport. The main reason of serious traffic congestion is traffic volume is increasing rapidly but the roads in Philippines are narrow and worse, the roads capacity reaches limit point. Thus, it induces traffic congestion and serious traffic congestion lowers the vehicle speed less than 10 km/h at main road and some certain identified roads. In the **Figure 1.18** As a research of Cebu Road capacity study from JICA Group, the first and the second Mactan Bridges connect the city center of Cebu and Mactan Island, 2 lanes of the first Mactan Bridge is already over capacity at 45000 PCU/day (PCU: Passenger Car Unit) and 4 lanes of the second Mactan Bridge is almost over capacity at 48000 PCU/day. [13] We can see the first bridge in the **Figure 1.18** is already over saturated and the second bridge is almost saturated. (VCR: Volume Capacity Ratio).

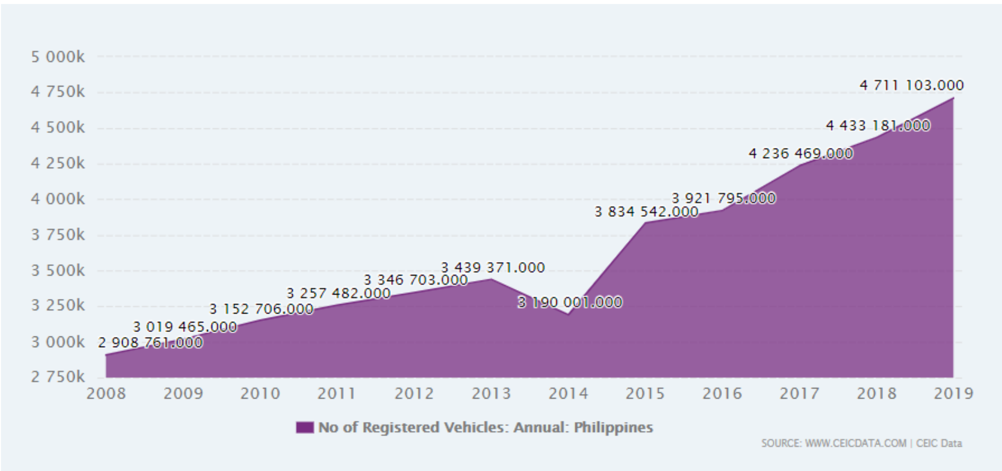


Figure 1.17 Philippines's Number of registered Vehicle

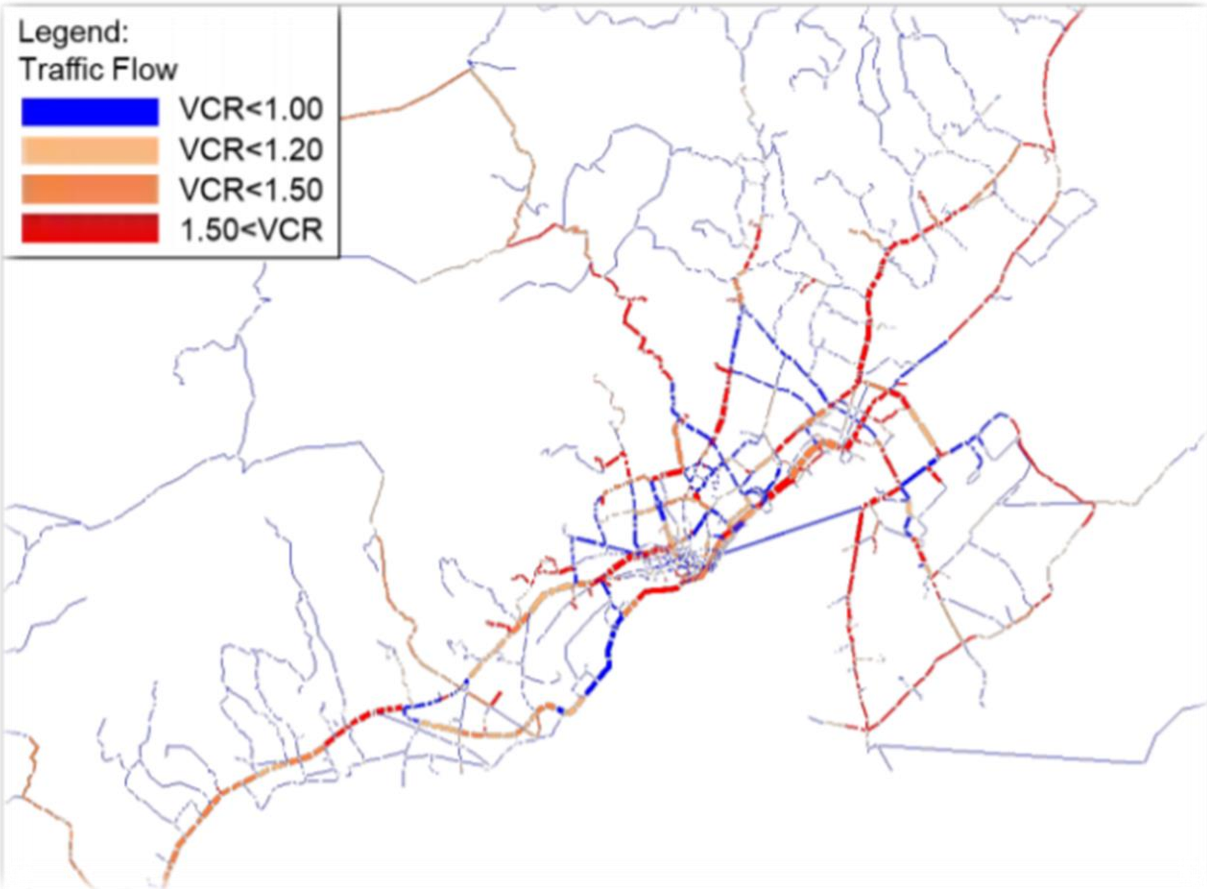


Figure 1.18 Volume Capacity Ratio in Cebu

The Utter Lack of Quality Infrastructure and Insufficient Public Transport Services

One of the fundamental causes of traffic congestion in the Philippines is the low quality of the infrasturcture such as roads, public transport terminals and railways. The public routes in Mactan island are shown in **Figure 1.19.** The World Economic Forum's (WEF 2010) Executive Opinion Survey, published in its Global Competitiveness Report (GCR) 2010 – 2011, ranked the Philippines 113th out of 139 countries in the overall quality of its infrastructure. More specially: 112th in air transport infrasturcture, 114th in road infrastructure 97th in road infrastructure and 121st in port infrastructure [19]. The overall quality of Philippines infrastructure is poor. As a news published: Due to fire damage one of the power transformers, LRT Line 2 temporarily closed its other three westbound stations. This accident affects approximately 200,000 commuters. And the maintenance time is so slow so it induces these stations will closed for 3 months. Many research has found that Philippines still not have enough trains and tracks to ferry commuters. The Dominant public transport is jeepneys, buses, taxis, and tricycles. The public transport survey conducted by Department of transportation in 2011 showed only 130 PUV routes (public utility Vehicles) routes served by 9252 units.[13] in the research of JICA Group, 695 PUVs are operating on 38 routes in

Mactan Island with 450,000 people. That is a ratio of 1 PUV for every 647 persons or nearly 20 PUVs per Km2, the ratio of Cebu city is approximately 10 PUVs per Km2. From commuter's view, the average travel time in 60 min in Lapu-Lapu. More than 30% of the travel time is due to waiting for the public transport in the station. Also, we cannot ignore the dominant of public transportation: Jeepneys; many jeepneys drivers do not have a good habit. They are stopping in the middle of road to pick up or take off passengers, and they do not have a certain stop position.

Figure 1.19 Mactan Island Public Routes

Inadequate Traffic Management

The number of traffic accidents increase rapidly in Philippines, according to the Philippines Statistics Authority, traffic accident in the Cebu, Mandaue, and Lapu-Lapu Cities is quite high per month. Traffic Accident always happens at main roads and intersections. When happens traffic accident, not only the human life safety is threatened, but also it will block the whole traffic system, and paralyze the traffic. Large part of traffic congestion is induced by traffic accident. Since traffic safety is always a major topic needed to attention, so manage the traffic and control the traffic flow is very important work need to improve in Philippine and in Cebu. Strengthening the management of traffic can not only reduce the traffic congestion, reduce traffic accident rate. The current state of the traffic management in Philippines is not very consummate. From previous Roadmap study, there are 20 intersections listed for improvement with measures as flyovers or underpasses. The average Cycle length of these 20 intersections is about 300s, it is longer than the standard cycle length. The Cycle length should be changed by times of day and hour and need a consummate system to actuate the signal control. In the Cebu City, the city's Traffic control system controls all traffic signals at 70 intersections. The center is built in 1991, and most of the equipment is very old as shown in **Figure 1.20**. And the system has several fixed cycle lengths for each intersection and cycle time changes by time of day.[13]

Source: JICA Project Team

Figure 1.20 Traffic Control Center

1.3.3 Goals of this study

This study is focus on the area of the Cebu airport in Lapu-Lapu City. Mactan-Cebu international Airport (MCIA) in the **Figure 1.21** is the second busiest international airport in Philippines. It is in the city of Lapu-Lapu on Mactan Island. [20] Lapu–Lapu is a famous tourist city. In the past 15 years, the international passenger flow of Mactan – Cebu International Airport has increased by an average of 21% per year. And the domestic passenger flow has increased by an average of 5% per year. The terminal can accommodate 4.5 million passengers. It is the main trade center in the southern Philippines. Currently it can provide 602 commercial flights per week and transport 10223 passengers per day. It is the main entryway to Cebu and the traffic is continually increase rapidly. The master development plan said that in 2024, the estimated annual passengers for the international and Domestic flights are 4.127 million and 11,654 million passengers, for years 2039, around 8.068 million passengers in the international flights, and about 20.244 million passengers for the Domestic flight. [21] As the Figure shown in the 1.21 right, the passengers increase year by year. According to the "General Situation of Lapu-Lapu City", the total road length of Lapu-Lapu City is 115.757 kilometers, and almost 72% are Barangay roads. It is estimated that each lane leading to the Mactan-Cebu international Airport can accommodate 1400 to 1500 vehicle per hour.

According to the forecasts, optimize the traffic in Mactan -Cebu international Airport is important to ensure and maintain the efficiency of traffic flow.

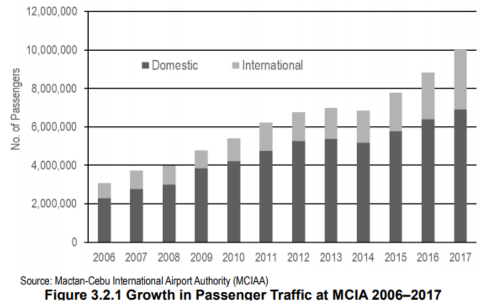


Figure 1.21 Mactan-Cebu international Airport (MCIA) and passenger growth trend

As shown in the **Figure 1.18**, the traffic volume is extremely high along Central Nautical Highway, the road between 1st and 2nd bridges and the region around Lapu-Lapu city hall. Through **Chapter 1 the problem definition in Cebu metro**, we realize that improve the traffic condition and reduce the environment pollution is most important. The goal of this study is using Digital twin at urban scale technology to develop master plan to reduce the traffic congestion and reduce environmental pollution in the area of Mactan – Cebu International Airport and Lapu-Lapu city, this master plan is established by a multi-disciplinary group. the members are civil engineering Daniele Iunti, automotive engineering Zhang Zheyuan and automotive engineering Ma Fanshu. through our cooperation, we propose a master plan which more convenient to optimize the traffic situation in Lapu-Lapu city and provide the environment friendly transportation methods for the passengers exits from Mactan-Cebu International Airport reach the center of city and the passengers from the city center to other destinations.

1.4 Structure of the Thesis

This thesis is based on the traffic analysis, emission analysis and energy analysis of Lapu-Lapu city to discover the current traffic condition Then through analysis results and data collection to make the choice of working area, the location of establishing mobility hub and propose a master plan which is based on the digital twin technology to establish a data visualization management system to reduce pollution and traffic congestion in Lapu-Lapu city.

The **Figure 1.22** show the structure of the thesis. The main chapters of this thesis are arranged as follows:

Chapter 1 Introduction: Mainly introduce the global environment effects by the urban traffic and the current traffic situation and problems in Philippines and Cebu metro. Explain the significance and background of our case study. And according to the current problem definition to determine our case study target.

Chapter 2 State of Art: Mainly the theoretical and technical basis of this case study. Firstly, introduce the concept of smart transportation and smart city, explain the relationship between them and the positive role of smart transportation in smart city. Secondly, discusses the related theory and technology of digital twin from the aspects of the concept of digital twin, the basic composition of digital twin, the application filed and value of digital twin. Then introduced more detail about the important role of digital twin in the information visualization management system. At the end, introduce the concept and advantage of MaaS (Mobility as a service).

Chapter 3 Methodology: Firstly, overview the whole project and introduce the entire workflow of this case study. Then describe the methodology and workflow of macroscopic traffic analysis. Through the result of the macroscopic traffic analysis to provide one basis for the choice of working area (Lapu-Lapu city hall). After determining the working area, microscopic traffic analysis of the work area. The microscopic simulation results as an input database of emission and energy analysis. Through the emission and energy analysis to prove the rationality and feasibility of our proposal: instead of the traditional motor vehicle into electric mobilities and use solar energy as the electric vehicles charging energy resource will reduce the emission and air pollution significantly. In the last part of chapter 2 is mainly introduce the establish process of digital twin data visualization management system and detailed describe the implementation methods of various functions of the system. Through this system can visualize the data in 3D scene which convenient for managers to control and monitor traffic, energy state, mobility hub to realize the decongestion of Lapu-Lapu city.

Chapter 4 Conclusion and Future development: in this chapter summarize the overall case study and prospect the future development direction of the digital twin in smart cities.

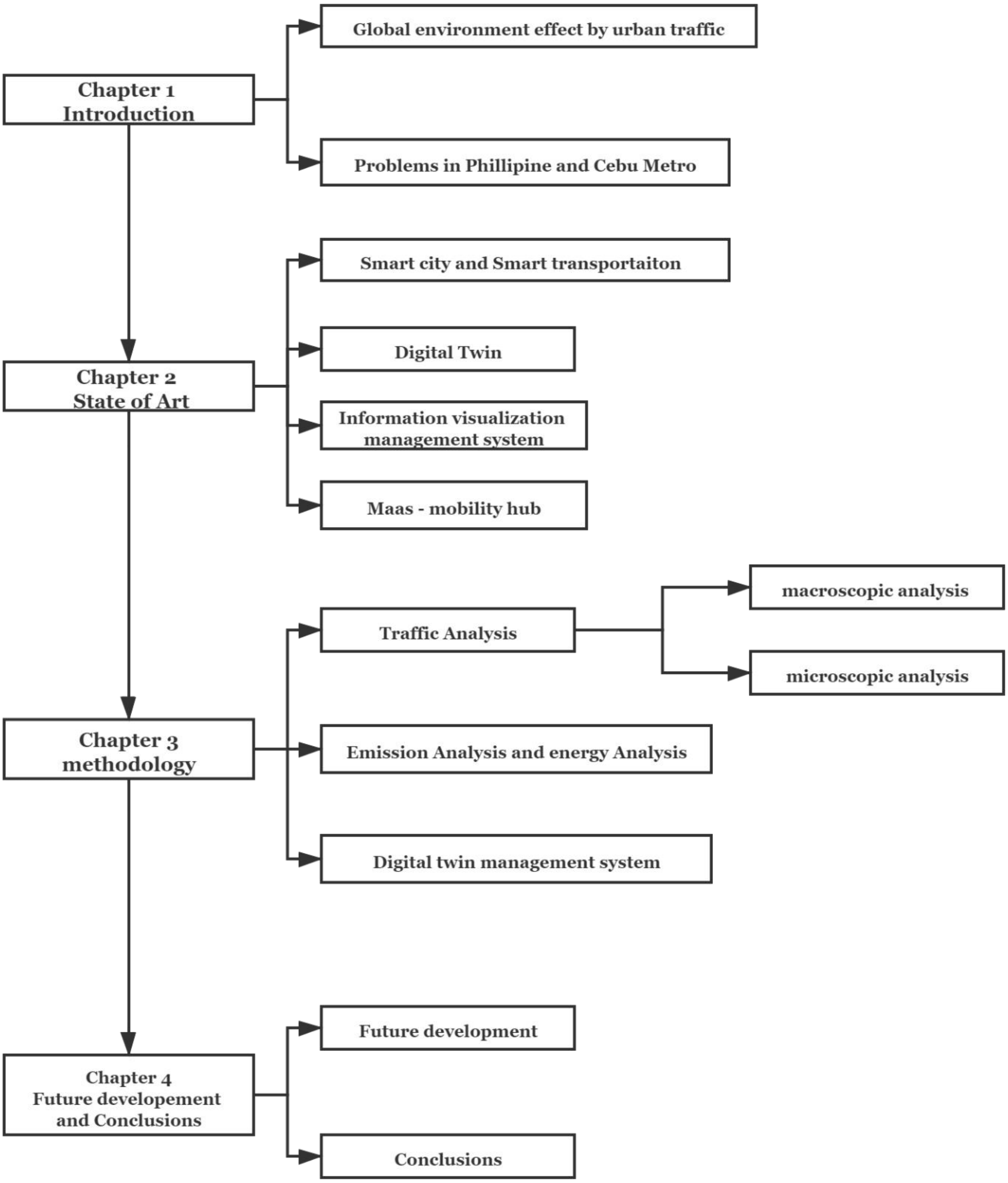


Figure 1.22 Structure of this thesis

Chapter 2: STATE OF THE ART

2.1 Smart City and Smart Transportation

Smart cities have become a new concept of urban development on a global scale. High efficiency, sustainability, and low carbon are important characteristics of smart cities. Smart cities' key significant is to provide the accurate information to citizens, city managers [5]. The development of the smart city can help to improve the quality of life for citizens and reduce the time and resources needed for information gathering, urban planning, solution testing etc. in order to facilitate the urban management process. From **Figure 2.1** shows the development of smart city is able to influence the management decision making and the citizens behavior, a good management can encourage the good behavior of citizens lifestyle, and this improvement can make the city environment more sustainable.

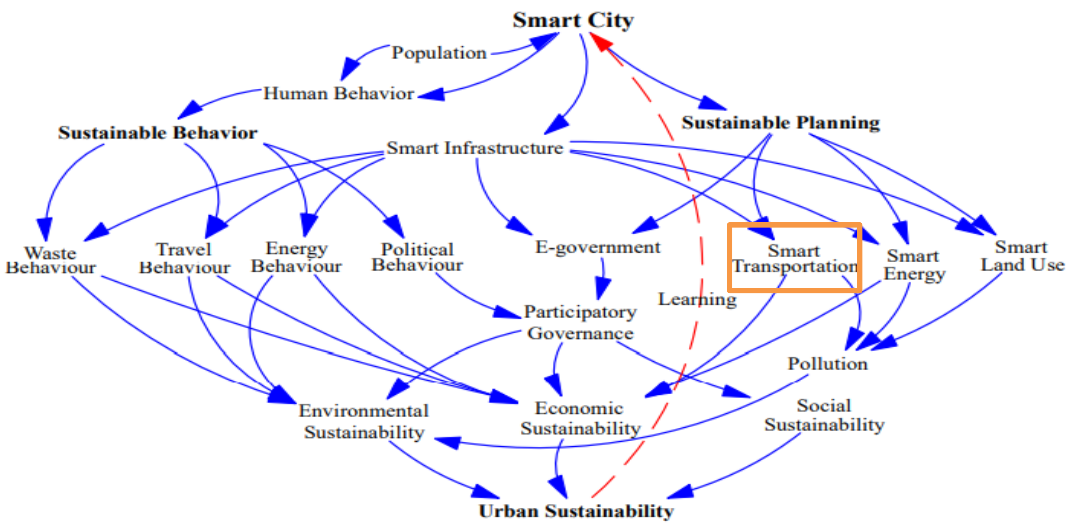


Figure 2.1 The process of achieving urban sustainability[4]

Smart transportation is one of the core parts of a smart city. Among them, Intelligent transportation System (ITS) is the technical core of intelligent transportation. It integrates several real-time traffic relevant data such as weather, congestion, parking etc. to the passengers and drivers trip process, in order to reduce the time and resources consumed by travel, decrease the traffic congestion and relative emission. Additionally, this information can help the traffic management center to control the urban transportation operation in a fast, low delay, no local limitation way. In general, the intelligent transportation system (ITS) is a low carbon development of urban transportation and makes the traffic method available met the continuously growth of the traffic demand.

2.1.1 The Positive Role of Smart transportation in Smart city

The smart city driven by the IOT, and big data technology has become a new solution for the fast population growth caused by rapid urbanization. Traffic congestion, traffic safety in cities and environmental pollution improve the efficiency of residents' travel and reduce travel carbon emissions is currently the key issues to build a low-carbon smart city.

Figure 2.2 Intelligent Transportation System

Smart transportation has a very large amount of impact on traveling. The main manifestations are potholes in the pavement and traffic accidents. As shown in **Figure 2.2**, not only passively receive the data from sensors, but also uses these data to have an overview of the traffic aspect then control the traffic flow by traffic signal, road gate etc. to improve travel efficiency and traffic safety. As the same time, through ITS technology can guide the passengers and drivers choose the best property route in time. In terms of urban transportation demand management, smart transportation can use information systems according to the vehicles entering the central area of the city to implement standardized fees, using technical management measures and control the flow of traffic. At the same time provide travelers with diversified services, through the ITS technology primary can obtain the real time information of smart parking area, then send the information to the drivers to help driver find the parking lot. As a manager, ITS will optimize the decision making by obtaining the detail vehicle information such as the license plate. Also, managers can optimize the traffic signal time which will solve the existing road problem. The relative positioning of all 15 priorities is outlined in **Figure 2.3** and a clear shift can be seen between current and future ITS priorities. The clear priority of climate and environmental impacts is low in current strategies and as shown these two factors will increase in the future.[6]

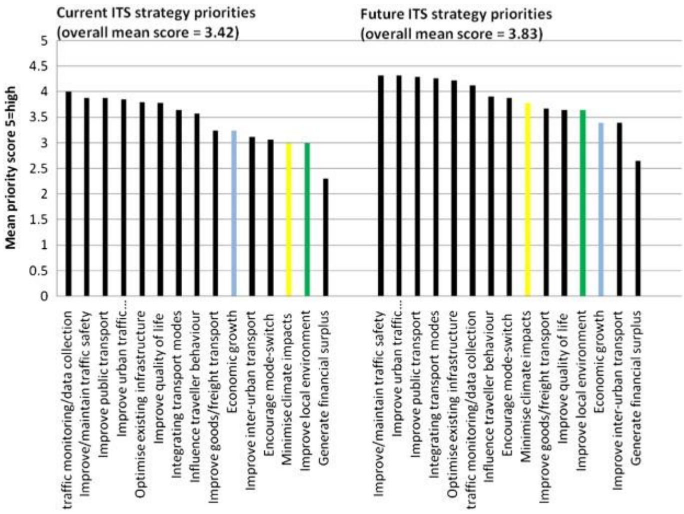


Figure 2.3 ITS Strategy priority [6]

In addition, improving energy efficiency and reducing emissions have become key principles for smart city investment. In fact, energy saving, and reduction of greenhouse gas emissions is seen as a major benefit through smart transportation monitor. As we said before, the transportation sector accounts for about one-fifth of the total global energy use, and passenger road transport occupied a major part, in most urban traffic demand management, the solutions supported by Intelligent transportation system are regarded as the main solutions to mitigate climate change.[7] With the sustainable development of the environment (energy conservation, emission reduction and climate change mitigation) intelligent transportation system has become a more important role.[7]

The development of smart transportation can effectively reduce the energy demand for transportation, achieve the purpose of energy saving, and greatly reduce the cost of environmental pollution control. Several studies have shown that smart transportation and smart travel can improve the environment and reduce pollution. Evidence of impact can be collected from actual implementation field studies or through simulation and laboratory tests in the **Figure 2.4** The results show that 5% to 20% of carbon can be saved; the fuel saved can reached up to 20%.[6]

Study	ITS scheme	Data collection method	Study location/ context	Reported benefits
[30]	Teleworking	Review of studies and modelling	UK	2.4% of carbon emissions from cars in UK may be reduced due to teleworking by 2050
[29]	Teleworking	Expert review	UK	Inconclusive and recommendation that more detailed research is needed.
[30]	Personalised travel planning	Field trial	Japan	A personalized travel planning system helps commuters choose environmentally friendly routes and modes; reduces carbon dioxide emissions by 20%
[43]	Transport management system: Electronic charging	Observed	London Congestion Charge	a) Between 2003 and 2006, a reduction in carbon emissions in the central congestion area of 16% b) western extension zone introduced in 2007 led to a reduction of 6.5% by 2008
[44]	Transport management system: hard shoulder running and variable speed limits (VSL))	Simulation and observation	UK Motorways (M42 and M25)	M42: most vehicle emissions reduced by between 4% and 10%. Fuel consumption reduced by 4%. Similar findings obtained from two other studies of VSL on M25
[28]	Eco-driving: In-vehicle control and performance systems	On-board monitoring	USA, Denver, normal driving conditions.	5% fuel saving with no feedback/coaching, 10% fuel saving with feedback/coaching. Assumes carbon saving equivalent to fuel saving.
[30]	Eco-driving	Review of studies	Field trials	Average 10% reduction in carbon emissions
[45]	Eco-driving: in vehicle (overridable) speed control	Field trial using instrumented vehicles and emissions models	UK (Leeds and Leicestershire), different road types	Motorway — average 6% benefit on CO_2 Other road types — little benefit or small disbenefit on low speed urban roads. 20% difference in CO_2 emissions between lowest and highest emitting drivers
[46]	Eco-driving: dynamic systems that utilise RTTI	Simulation	Simulated environment	Reduction in carbon emissions and fuel consumption by 10%–20% per cent without a significant increase in journey time. Real world experiments showed similar but slightly lower findings
[30]	Eco-driving	Field trial	Netherlands, 1999–2004	Fuel consumption reduced 0.3%–0.8%
[47]	In vehicle technology and other measures	Review of studies	Europe	5% to 25% carbon saving with 10% generally agreed
[48]	Platooning and road-trains	Laboratory testing of vehicles	Motorways	Fuel consumption and carbon emissions. Approx 20%

Figure 2.4 indicative evidence on carbon fuel and emission impacts[6]

2.2 Digital Twin

Digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object process[22]. Digital twin is to use physical model, sensor update, operation history and relative data, integrate multi-disciplinary, multi-physical, multi-scale, multi-probability simulation process to complete the mapping of virtual space, thus, to reflect the entire life cycle of the corresponding physical equipment process. Digital twin is a concept that transcends reality and can be seen as a digital system map of one or more important and interdependent device systems. Saying in a simple way, Digital twin is using digital methods to create virtual entities of physical entities, using historical data, real-time data, and algorithm models to simulate, verify, predict, and control full life cycle process of physical entities. Digital twin refers to the use of the operating elements and dynamics of IoT devices throughout the life cycle to form a digital copy, and data analysis and processing techniques to create active digital simulation models, so that the models changed and updated as their physical objects change. The deeper application lies in learning system formed by the combination of digital twin technology and artificial intelligence. The digital simulation model continuously learns and updates itself from multiple sources to express its near real-time status, working status or location. This learning system can be derived from itself, using sensor collects data that conveys all aspects of its operation conditions, or from human experts, such as engineers with in-depth and relevant industry domain knowledge; or from a huge exist system. The digital twin also integrates historical data used by machines in the past into its new digital models as new system. For the operation and maintenance of the system and manufacturing process. Digital twin technology is a forming technology of the industrial IoT, which can make physical objects live virtually and interact with other machines and people. As shown in **Figure 2.5** digital twin can be applicated in many fields such as the aerospace, automobile, smart industry, smart city, agriculture, architecture and so on[27]. with the continuous development of new technologies, digital twins will be applied to more fields and bring us a more convenient and efficient world.

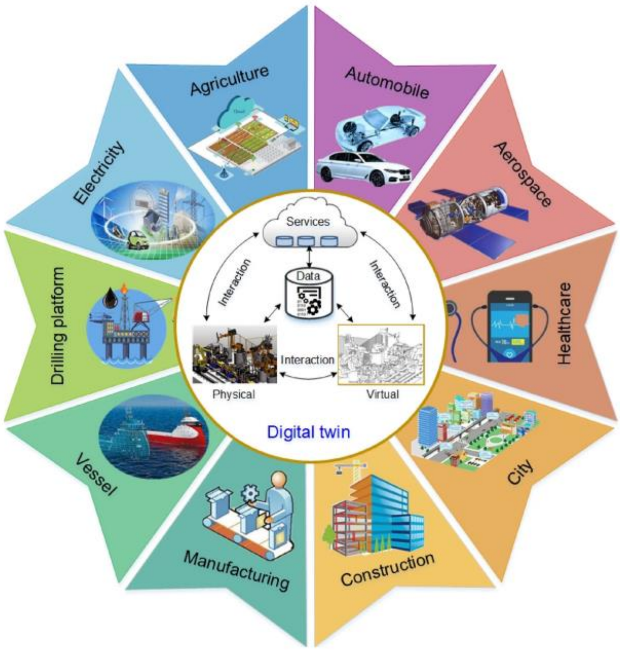


Figure 2.5 Digital Twin in All Field [27]

2.2.1 Digital twin development background and concept

Digital twins were first be foreseen by David Gelernter in his book –- Mirror Worlds which is published in 1991. Digital twin technology was first proposed by Professor Grieves of the University of Michigan in a PLM (Product Life Cycle Management) course in 2003, and it is defined as three-dimensional model, including physical products, virtual products, and the connection between them as shown in the **Figure 2.6**; But due to the limitations of technology and cognition at that time, the concept of digital twin was not taken seriously. Until 2011, the Structural Mechanics Department of the US air Force Research Laboratory gave a speech with the title "Condition based Maintenance Plus Structural Integrity (CBM + SI)) & the Airframe Digital Twin" proposed the idea of designing digital twins for future aircraft which is the first time clearly define the Digital twin. And they defined that digital twin are a highly integrated multi-physics, multi-scale and multi-probability simulation model of an aircraft or system. The physical models, sensor data and historical data can be used to reflect the function, real time statis and performance of the entity corresponding to the model. After that, the digital twins have indeed attracted people's attention. Another company: The General Electric Company of the United States realized that the digital twin has a strong practical significance, General Electric Company provided the F-35 joint fighter solution to the US Department of Defense, they discovered the value and significant of the digital twin. Later, NASA applied the concept of digital twins in the Apollo program in **Figure 2.7** and developed and designed two identical space vehicles to reflect the conditions of space on Earth for training and flight preparations. Some scholars have supplemented and improved the concept based on the concept proposed by NASA. In 2016, digital twin was applied in Industry 4.0 by Siemens. In January 2017, Tao Fei of Bei hang university and others first gave the definition of workshop digital twin from the perspective of workshop composition, and then proposed the composition of workshop digital twin. In 2018, five-Dimensional Digital twin was proposed by them. The history of the digital twin is shown in the **Figure 2.8**. Gartner, the world's most authoritative IT research and consulting company lists digital twins is one of the ten most important technologies in the future, Gartner believes that by 2021, more than half of large industrial companies will use digital twins, as a result, the work efficiency of these organizations has increased by 10%.

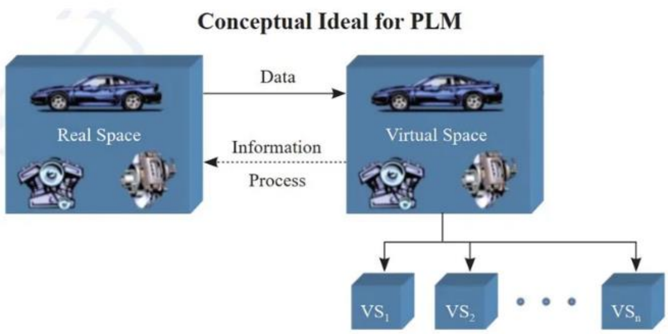


Figure 2.6 Conceptual assumptions in PLM

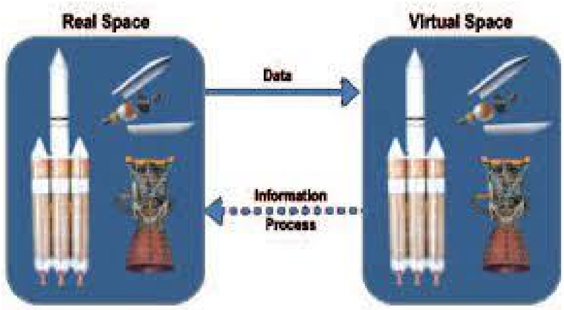


Figure 2.7 NASA Digital Twin proposal

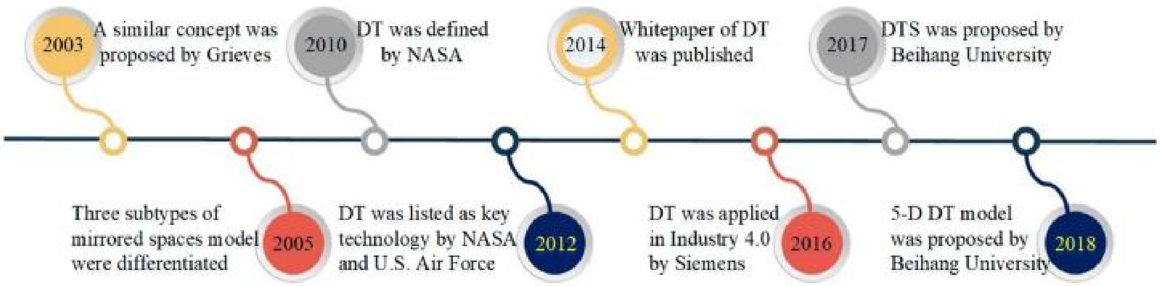


Figure 2.8 History of Digital twin[27]

2.2.2 Values of Digital Twin in different fields

Digital Twin in Intelligent Industrial Manufacturing

Manufacturing processes are becoming increasingly digital. [23]Digital twin plays an important role in the industry 4.0 revolution. Because Digital twin enables reproduce products and production system in cyberspace and make the digital space model and physical space model of the product and production system always interact in real time. The two parts can know each other's dynamic changes in time, and respond in real time, which provides a strong guarantee for realization of intelligent manufacturing, and at the same time, it has further accelerated the integration of intelligent manufacturing with industrial internet and IoT. In recent year, digital twins are mainly used in the manufacturing sector as shown in **Figure 2.9**. International Data Corporation stated that 40% of larger manufacturers are now using this virtual simulation technology to model production processes. Digital twins have become the key for manufacturing companies to move towards Industry 4.0 solution. American Parametric Technology Corporation (PTC) provides customers with efficient product after – sales services and support based on digital twins [24]. Through digital twin technology, Siemens is committed to help manufacturing processes in the information spaces through digital twin technology and realized the digitization of the whole process from product design to manufacturing execution in the physical space.[25] General Electric, Siemens and ANSYS have launched a series of platforms for building digital twin. Now the technology has been implemented in the aerospace, wind turbine power stations and the automotive industry to improve performance and predict operating inefficiencies. GE has established a pair of digital jet engines in **Figure 2.10**, which can realize the power optimization, monitoring and diagnosis of jet engines. DXC technology builds the Digital twin for the manufacturing process of hybrid electric vehicles to predict the performance of previous vehicles and make changes during the manufacturing process. In addition, some technology companies are developing 3D experience platforms based on this technology. In 2020, there will be 21 billion connected sensors and terminals serving the digital twin, and there will be billions of digital twins soon.

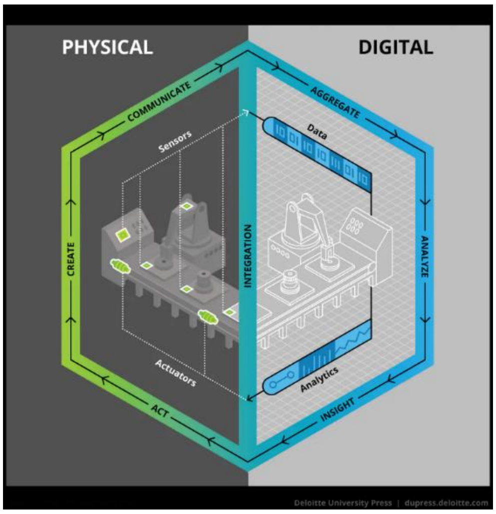


Figure 2.9 Manufacturing process digital twin model [23]

Figure 2.10 digital jet engines

Digital Twin in Smart City

Except digital twin using in the industrial manufacturing, digital twins are also related to 5G and Smart Cities. City is an open, huge, and complex system with the characteristics of high population density, complex infrastructure, subsystem coupling and so on. How to realize real – time monitoring of various types of data and information in the city is quite a difficult problem. Around the design, planning, land use, construction, operation, safety, and people's live style, how to efficient manage the city is the core of modern city construction. As ICT (information, communication, technology) has become the main driving force for the development of smart cities, mobile communications, the internet, cloud computing, sensors, artificial intelligence, and quantum communications have all been widely used in smart cities. The technological development in various fields such as global perception, digital simulation, and deep learning are also rapidly increase, which makes the digital twin of the city more and more popular. Today our city is full of various sensors and cameras and so on. With the help of IoT technologies which transmit the data collected from various sensors such as tempera meter, camera, inductive loop, radars etc. through low delay wireless data exchanging technology such as 5G to the digital twin data cloud. Powerful technical capacities such as automated perception, networked connections, intelligent control, and platform-based services can make the smart digital city model more significant, as a twin body that runs in parallel with the physical city make the virtual and real world contains unlimited space to dream and realize as shown in **Figure 2.11**.

Figure 2.11 City Digital Twin

The city managers, based on these data and city models, build digital twins to manage the city more efficiently. The Singapore government has cooperated with Dassault to establish a digital twin city to monitor everything from the bus station to the buildings in the city, to realize the graphical monitoring of the city, monitoring simulation, optimization, planning, decision- making and other functions. [28] Cityzenith build a "5D smart city platform" for city management system.[29]. IBM Watson demonstrated how to use digital twins in urban buildings to control and monitor HVAC systems, and through digital twin to assist in energy management and failure prediction and provide technical personnel with maintenance, control, and other service support. In China, Alibaba Cloud Research Center proposes to establish a digital twin city, based on clou computing and big data platforms, and use the IoT, AI and other technical to realize the vital signs of urban operation, public source allocation, macro decision-making command, and event prediction and warning in time and so on. It is equivalent to give the city a smart brain.

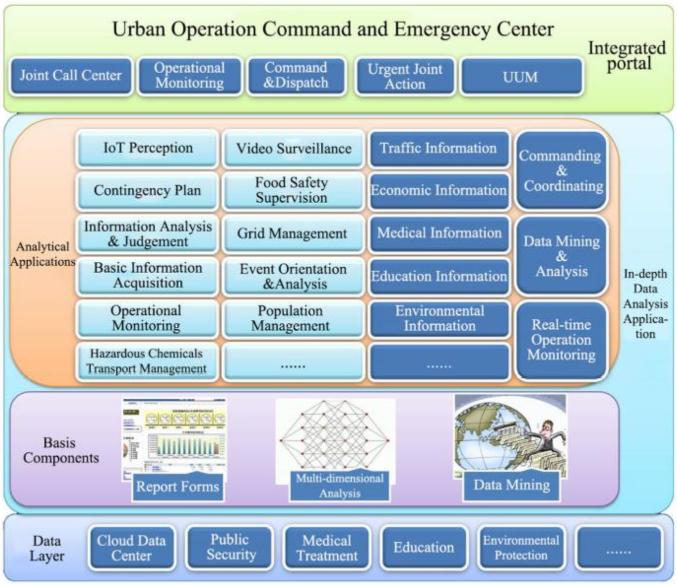


Figure 2.12 schematic of the structure of smart city based on Digital Twins[30]

The Figure 2.12 shows an example of the structure of the digital twin system, this layered structure is composed by data layer (includes the data collected from the sensors and transmitted to the data base of different field through IOT technology), basic component (includes the big data analytic and visualization technologies), Application layer (different services and functions generated from previous layer) [30]. With the help of digital twin technology, the total city will be greatly changed, the city management decision will be coordinated and intelligent to ensure the safe and orderly operation of the city. At the same time, it will reduce the cost of urban informatization projects and its maintenance, minimize the cost of government affairs, makes city life and environment change better.

Digital Twin in Smart Transportation

The transportation problem is one of the important issues related to the development issues related to the development of the country, the use of digital methods to analyze the causes of traffic problems, study the laws of traffic operation, grasp the characteristic of traffic travel, predict traffic development trends, and use them in various links of traffic management, decision-making and services will help solve complex traffic problem and promote High quality development of the transportation industry. The concept of intelligent transportation based on digital twins mainly refers to the construction of a mapping models of the actual transportation system in the digital acquisition system, a networked transmission system and an intelligent application system, and promote the digitalization of traffic elements, visualization of traffic operation, and traffic management. Intelligent and personalized transportation services. With the help of traffic simulation, model deduction, data analysis, iterative optimization and other means, data-driven, intelligent decision-making traffic management and services are realized, and the digital transportation system can operate simultaneously and interact with each other. A new form of transportation system that realizes the improvement of comprehensive transportation efficiency. The concept of digital twins provides new development space for transportation planning, construction, operation, management, and services, and will become a new direction for development of transportation system in the future. For example, digital twin technology in improving the efficiency of self-driving system has a great help. Currently, the intelligent research center is carrying out research on the intelligent self-driving virtual training system to provide an open virtual test and training platform for the road driving safety and intelligent driving ability of the self-driving algorithm. The goal of the project is to reproduce real-life traffic scenarios in the digital space, create extreme environments and critical high-risk scenarios for self-driving vehicles through generalized derivative technologies, and greatly improve the efficiency of self-driving training. Build a digital twin analysis and experimental environment for real traffic operation is also a favorable way for traffic development. Through data collection, processing, correlation, identification, analysis, insight, prediction, and feedback control of real traffic operation scenes, take the people, vehicle, road, and environment in traffic operation scenes are migrated from the physical world to the digital world and connected Real traffic scenes and digital scenes. Changes in the real traffic operation scene in real time, and the insights and prediction results of the digital twin scene are fed back to the real traffic scene in time. Through this iterative interaction of “integration of virtual (VR) and virtual control of reality”, the ability to analyze and solve complex traffic problems is improved, in the **Figure 2.13** shows the digital twin construction and congestion problem of a certain traffic operation scene.

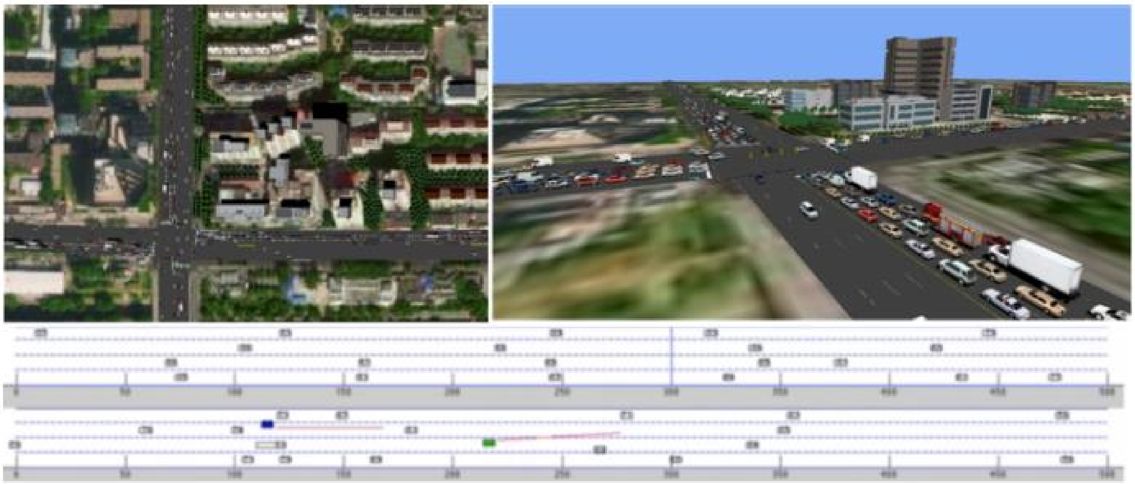


Figure 2.13 An example of digital twin construction and congestion problem analysis in a traffic scene[31]

2.3 Information visualization management system on Digital Twin

Information visualization

In short, it is scientific and technological research on the visual representation of data. It mainly refers to use of graphics and visualization technology to process basic information, through real time rendering of three-dimensional scenes and data visually, displaying real time data achieving visual interaction. Data visualization is closely relative to information graphics, information visualization, scientific visualization and statistical graphics, information visualization, scientific visualization, and statistical graphics.

Data visualization to realize digital twin information management system

Digital twin emphasizes simulation, modelling, analysis, and decision-making assistance as shown in **Figure 2.14** . It focuses on the reproduction analysis, decision-making of physical world objects in the data world, and what data visualization does is the true reproduction of the physical world and analysis planning. The field of digital twin visualization development continues to increase, there are many ways to show, and the method of expression is constantly changing. With the continuous development and expansion of digital twin visualization, real time display data effects and user interaction use have been added. At present, advanced technologies such as the IoT, cloud computing, machine learning and big data are used to realize 3D digital twin visualization; 3D virtual reality technology, and these technologies are used to build a 3D digital twin visualization application management system. Combining video surveillance system, video analysis system, network information technology, scanning sensor, data storage and other technologies, presents the data online visualization 3D digital twin management mode. The digital twin information visualization system solves the problems of the traditional mode, such as the amount of information is small, the transmission speed is slow, the equipment status has problems, emergencies cannot be solved and fed back in time, and other serious security risks, etc.

Data visualization, IoT, digital twin combines cloud computing data analysis and IoT technology into the digital twin, digital twin performs efficient data collections, analysis, processing, and real-time display; it provides managers with real time display of remote equipment operating status, real-time positioning of personnel, real time supervision of the monitoring system and other services and provides timely feedback and solutions through real time data display. the digital twin management system uses IoT technology, which is mainly reflected in the level of digitization and intelligent transformation, digging the values of original equipment data, and improving the coordination ability between equipment. Most important thing is the digital twin data visualization can process, analyze, locate, and display the information to the administrator in time, so that the administrator can better control the status, the working environment, and the safety of people.

Application of management system in smart transportation

In the intelligent traffic control field, digital twin management will realize real-time collection of traffic data, synchronized visualization of traffic operation. In terms of data collection, through intensive sensing terminals, such as smart information poles, collect road or other public area's meteorological data and video surveillance data, then through embedded sensing terminals, such as sensors installed inside buildings, roads, bridges, etc. through independent sensing terminals such as road monitoring, RFID, sensor nodes, phones, autonomous vehicle, and other personal equipment to collect personal travel, running vehicles, movement trajectory and other data. In terms of data presentation, data modeling is realized based on 3D, and data presentation is realized based on technologies, such as data loading, visualization, and comprehensive rendering. Finally, the digital twin model can be synchronized and visualized. Therefore, through digital twin technology and collect the data about road network, dynamic vehicle position, road running speed can be quantified to realize the real time warning of road network and improve traffic situation.

Application of management system in smart city

The digital twin smart city management system is based on infrastructure, through simulation and reflection of real physical space in the digital world, and simulation experiment and analysis and prediction in the digital world, it provides decision-making basis for the issuance of city management instructions and the further optimization of the process system, and finally gives the city the ability to realize smart management and scientific decision-making. To build a smart city visualization system, the most important the display of the entire city space, and comprehensive and accurate monitoring of large-scale city operations. The traditional two-dimensional flat map display method carries limited information, which cannot visually present the spatial situation of the entire city, and it also increases the difficulty of information identification. The smart city visualization management system is constructed based on 3D situation map technology, combined with real urban spatial data, loads, and displays high-precision terrain data, 3D building structure data, and visually displays information about the distribution of urban buildings, road networks, topography, and other elements. It also presents complete and detailed information in the fields of resources and environment, infrastructure, transportation, social governance, population and people’s livelihood, industrial economy, social public opinion, public security etc., and reproduces the overall situation of the city’s operation. All monitoring objects have a panoramic view, assisting managers to comprehensively control the city's operation situation, and improve supervision and administrative efficiency.

Figure 2.14 Application of Digital Twin management system

2.4 MaaS -- Mobility Hub

To better solve urban traffic problem, with the advent of the era of big data, traditional urban transportation planning be replaced. Government realized the need to establish a public and shared transportation network to provide travelers with feasible and personalized services. However different shared transportation has different payment methods, booking platform, and operator platforms. The lack of uniformity makes the concept of “sharing” not fully developed. Therefore, integrating different modes of transportation to provide personalized services for travelers is the primary task of promoting shared transportation. Based on shared information technology, a new transportation concept has emerged in the city, that is “Mobility as a service” (MaaS).

The concept of MaaS first appeared in Sweden in 2014 [32]and became a popular topic at ITS World Congress in 2015, and then the MaaS Alliance was established in Europe.[33]. The definition of MaaS of Wikipedia is: MaaS is a transportation system that integrates travel services of various modes of transportation to meet various travel needs. For users, they can access programs that provide travel service through one account and pay through one payment channel. MaaS solves the inconvenience of personal travel and even the entire transportation system by individual needs. The biggest feature of MaaS is to integrate various optional travel methods, and at the same time allow users to pay through an account. The existing MaaS platform can support multiple transportation modes in **Figure 2.15**, including car-sharing, car-rental, bike-sharing, parking-sharing, subway, bus, taxi, etc. Fast and convenient payment through the reservation system software, real-time traffic information, MaaS users can purchase suitable travel services according to their needs. There are many advantages of MaaS. MaaS can collect data of the traveler's habit and then base on the different passenger to provide different services. MaaS usually applicate in the share platform. Such as share bikes, share vehicles, and share motorcycle and so on. Also, MaaS can assistant the managers and government to obtain the resource of the citizens' demands.

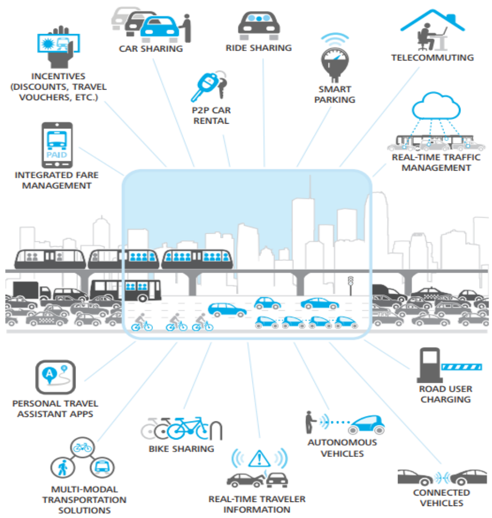


Figure 2.15 multiple transportation modes[34]

Chapter 3: METHODOLOGY

3.1 Project Overview

In the **1.3 Problem definition and Goal of the Study** we have realized that there are many traffic problems in Lapu-Lapu. The passenger flow of Mactan-Cebu-International Airport is increasing rapidly these years, and the traffic volume is rapidly increase but it is limited by the road capacity. There are so many factors induce the traffic problems in Lapu-Lapu: most of the roads in Lapu-Lapu are unpaved, the insufficient public transport service and the inadequate traffic management system and so on. Our goal is through intelligent method to improve this area traffic condition and reduce the air pollution which comes from traffic. This case study is a multidisciplinary project between civil-building engineering study course and automotive engineering study course. For the Civil building engineer field (orange part in **Figure 3.1**), Daniele is focusing on the design of smart parking hub and moving walkway, problem definition and Geographical Information System (GIS) analysis. For automotive engineering part, we divided in two directions. Zheyuan was focusing on traffic scene building, low polygon building batch generation, real time data exchange between software, and VR application to the driving scene (light blue part in **Figure 3.1**). Fanshu was focusing on the road network data perception, traffic analysis, emission analysis and data visualization management system (dark blue in **Figure 3.1**). Our case study target is to reduce traffic pollution and traffic congestion of the area of the Mactan – Cebu International Airport. The walkway which is designed by Daniele is directly connected between the airport and the city hall, passengers can go from the airport to the city center (city hall), walkway will be zero emission cheaper and faster, higher capacity, convenience for passenger go from airport to city hall. When passengers come out of the walkway, arrive in the city hall, there is the mobility hub includes (smart Parking area, shared-electric micro-mobility area and the entry and exit port of Walkway) will give the passenger many travel choices, Zheyuan focus on the interactive driving simulator of city hall which will improve the efficiency of driverless training and analysis the traffic accident, and then Fanshu has created the data visualization management system which can show the information of energy use, building, traffic and mobility hub information which will help managers easier gain the real time information and control the traffic and population of this city.

3.2 Workflow

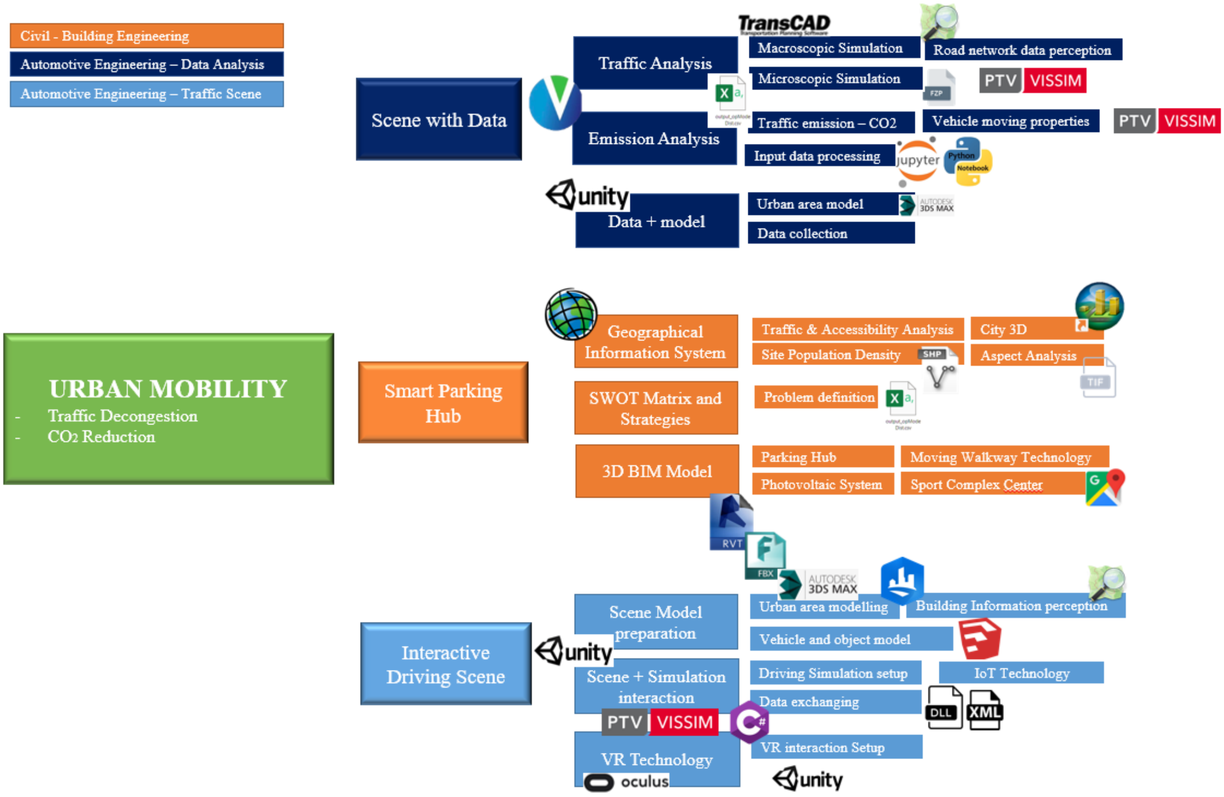


Figure 3.1 Workflow diagram

As shown in the **Figure 3.1**, this is the whole case study workflow. At the beginning, to have a deep understanding of the site, the civil engineering student Daniele focused on spatial data management, concerning traffic and accessibility analysis, site population density, and the 3D as build of the city. simultaneously, the automotive engineering student Fanshu focused on the macroscopic data analysis about traffic by using TransCAD which the map source from OpenStreetMap (OSM). Having understood the potential and drawbacks of the site, using the strategic planning tool of swot analysis, the project attention was drawn on urban mobility, on the traffic decongestion and CO2 emission reduction issues.

Throughout the entire case study, we decided to first to focus on the choice of working area, the location of establishing the mobility hub, taking advantage of macroscopic simulation results by TransCAD, accessibility analysis, swot analysis, spatial analysis outcome and an aspect analysis about solar radiation in GIS, we choose Lapu-Lapu city hall as our working area. then for automotive area, it was realized a microscopic simulation of the intersection of the M.L. Quezon National Highway by VISSIM, and an emission analysis by MOVES which the traffic data outcome from VISSIM simulation. Simultaneously the setup of BIM model of the parking area for civil building field. These two parts served as input for the driving scene setup and for the scene with data building. At the same time, Zheyuan prepared the urban area model by 3dsMAX and the vehicle models by Sketchup.

By using the vehicle model, Urban area model, Parking hub model together and from the microscopic simulation set up by VISSM, Zheyuan can built the connection between the simulation data from VISSIM and the scene in Unity to make the interactive driving traffic scene in the digital world.

Finally, each working sector was further investigated separately. For the Daniele's part, focusing on the parking hub energy requirement and the energy production of photovoltaic system, and a deep understanding of the state of art of the moving walkway technology. For the Fanshu's part, based on the BIM models of mobility hub, traffic scenes and the various data sources such as building information, energy analysis and so on, Fanshu established a digital twin data visualization management system, which is merging and showing the data and the scene model. For the Zheyuan part, Zheyuan established the scene with driver's first perspective with VR devices which allow to drive in the interactive scene.

3.3 Traffic Analysis

This case study is focus on traffic analysis of the Area of the CEBU Airport (Philippine). As said before, CEBU international airport is located on the city of Lapu-Lapu on Mactan Island. This part will mainly analysis the traffic of Mactan Island. First through TransCAD to analysis the traffic in macroscopic to find and predict where the traffic volume is relatively large part in Mactan Island, and then choose the large traffic volume area to simulate the microscopic traffic analysis by VISSIM. Through microscopic traffic analysis, we can collect data about numbers of vehicles, average speed, travel time, delay time, traffic length, environmental condition and so on which is as an input of emission analysis. Through the macroscopic analysis, we can determine the Lapu-Lapu transportation center, thus, this important area will become the core area that we will study for next steps.

3.3.1 Macroscopic Simulation

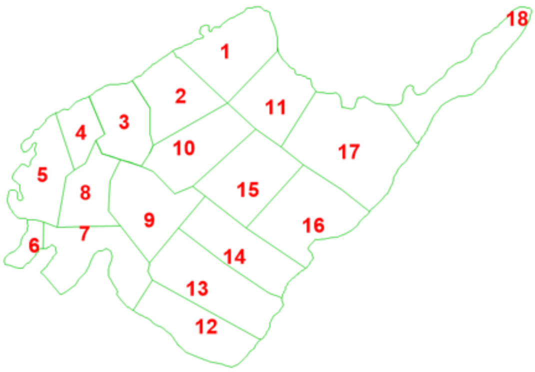
Macroscopic traffic simulation is a very important method to know the traffic situation of a large area part, compare to the microscopic traffic simulation, it will more focus on the analysis and predict of traffic volume, population growth, traffic distribution, traffic demand forecast, public transportation effect etc. In this study, we are using the software TransCAD to do the macroscopic simulation of Mactan island, therefore, to find out the traffic volume large part. The basic idea of using TransCAD to analysis traffic volume distribution is: First, investigate the study area's background information, determine the research scope, and then divide the study area into different traffic districts. Second, use the current traffic volume to infer the Original – Destination matrix (OD matrix) between each traffic districts, calibrate traffic distribution of each traffic district from the inverse OD matrix. Third, divide the OD traffic volume of each district and allocate it to the road network within the study area, and observe and gain the final result of traffic distribution.

TransCAD overview

The existing geographic information system (GIS) technology is becoming more and more mature. GIS analysis uses computers to calculate, compare and describe the contents of the database, and can access raw data, perform clustering and reclassification and decomposition for further analysis. Currently hundreds of professional software have been applied to various fields of transportation planning. Among them, TransCAD, CUBE, INRO and VISUM are often used in the field of transportation analysis. In term of graphic analysis, TransCAD is the only transportation software fully integrated with GIS so far. The TransCAD software developed by Caliper Company of the United States, which integrates GIS and traffic model functions, specially designed for traffic planning and transportation management industries. TransCAD software consists of road network analysis model, traffic planning and transportation demand prediction model, route selection and logistics model, zoning, and positioning model, and has powerful spatial analysis functions and GIS development tools. In term of graphic analysis, TransCAD is the only transportation software fully integrated with GIS so far. It has powerful GIS analysis functions, convenient data import, and can realize various traffic analysis. In terms of road network analysis, TransCAD has more comprehensive models and methods, flexible invocation, and accurate analysis. In terms of traffic impact assessment, TransCAD has sufficient model, powerful graphics analysis capabilities. Moreover, TransCAD has a GISDK secondary development function which similar to the BASIC programming language. Due to the powerful functions of TransCAD, using TransCAD to analysis macroscopic traffic will be more scientific and efficient.

Divide traffic districts

in order to do macroscopic analysis, the traffic, it is necessary to divide the traffic districts of our study area, which helps to transform individual travel into point-to-point travel. The division of traffic districts is generally affected by factors such as land types, planned land types, and planned road networks. The Lapu-Lapu city are subdivide into 18 areas as shown in **Figure 3.2**, we download this area shapefile from internet [35], then import the traffic districts into TransCAD. In TransCAD, the surface layer is used to represent the traffic area, and the centroid is used to represent the mass center for next processing.



Dataview1 - lapulapu_cebu

ID	Area	NAME
9	0.92	Buaya
2	2.00	Mactan
14	1.31	Maribago
15	1.06	Agus
11	1.13	Pajac
5	0.91	Looc
16	1.12	Babag
6	0.21	Canjulao
12	0.71	Gun-Ob
13	1.11	Basak
1	1.03	Subabasbas
17	1.40	Marigondon
18	0.80	Pajo
10	0.94	Pusok
7	1.15	Ibo
3	0.41	Poblacion
19	0.00	
4	1.04	Bankal
20	0.00	
8	1.03	Punta Engano

Figure 3.2 Divide 18 traffic areas in Lapu-Lapu

Establish road network

The study is located at the Lapu-Lapu City of Mactan Island, and the surrounding road network is relatively complicated. There are usually many methods in TransCAD for establishment of road networks. TransCAD's own drawing tool can import the background image in "*.tif" format for manually drawing, also we can use AutoCAD deal with the road network and import the file in TransCAD, also we can use ArcGIS save the map and imported in a format recognized by TransCAD. We should save ArcGIS files "*. Shp" map format before they can be imported into TransCAD. Because the Lapu-Lapu's area is almost 60km2 and the road network is relatively large and complicated. We choose the method which is save the "*. Shp" file from ArcGIS.

We download the road network information from the OpenStreetMap (OSM) as shown in **Figure 3.3**, OSM is a free, open source, editable map service jointly created by the internet public, like Wikipedia in the map field. OSM uses the collective power and unpaid contributions of the public to improve map-related geographic data. The elements of OSM mainly include three types: Nodes, Ways and Relations. These three primitives constitute the entire map screen. Among them, Nodes defines the position of a point in space; Ways defines a line or area; Relations defines the relationship between elements. Through the OSM, we can easily download the road network of

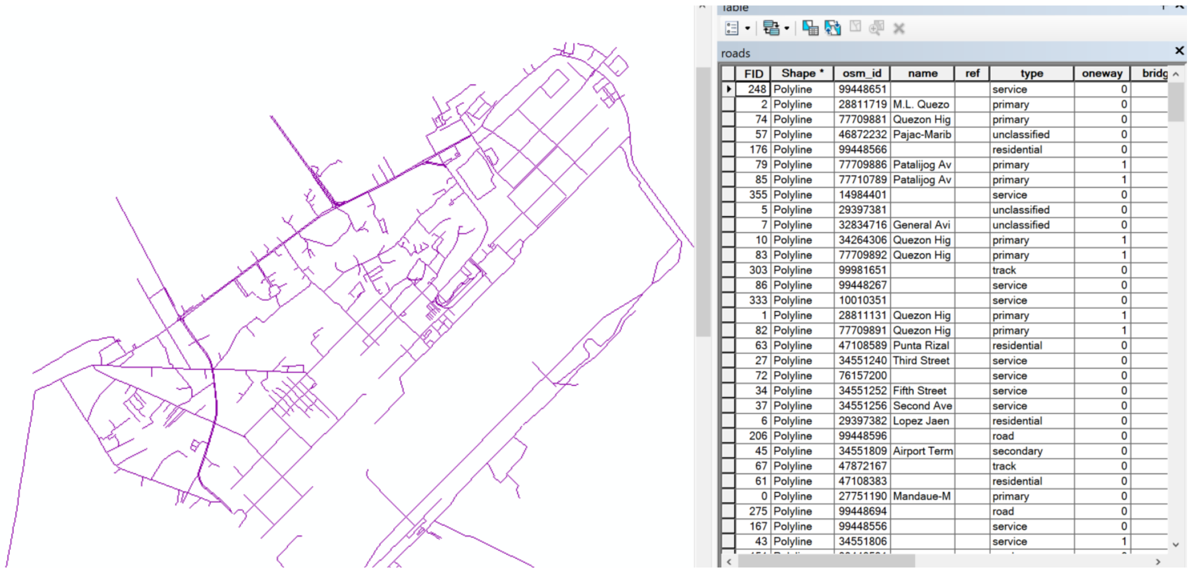
Lapu-Lapu city.

Figure 3.3 OSM Data Source

Figure 3.4 JOSM version

We import the map file into JOSM where we can visualise the road detail information as shown in **Figure 3.4**. The information of road network on OSM are edited and uploaded by someone who familiar with the local area, this information includes the road layout type, number of lanes, Max Speed, is one-way or not and so on. These information are playing an important role in the macroscopic analysis.

The road network export from OSM is in format “. osm” which are supported by the ArcMap, as the **Figure 3.5**, we can use ArcMap to edit and visualize all the roads information and the change the map file format from “. osm” to “.Shp” (shapefile). Then import the shapefile of road network to the TransCAD as our road network.



FID	Shape *	osm_id	name	ref	type	oneway	bridg
248	Polyline	99448651			service	0	
2	Polyline	28811719	M.L. Quezo		primary	0	
74	Polyline	77709881	Quezon Hig		primary	0	
57	Polyline	46872232	Pajac-Marib		unclassified	0	
176	Polyline	99448566			residential	0	
79	Polyline	77709886	Patalijog Av		primary	1	
85	Polyline	77710789	Patalijog Av		primary	1	
355	Polyline	14984401			service	0	
5	Polyline	29397381			unclassified	0	
7	Polyline	32834716	General Avi		unclassified	0	
10	Polyline	34264306	Quezon Hig		primary	1	
83	Polyline	77709892	Quezon Hig		primary	1	
303	Polyline	99981651			track	0	
86	Polyline	99448267			service	0	
333	Polyline	10010351			service	0	
1	Polyline	28811131	Quezon Hig		primary	1	
82	Polyline	77709891	Quezon Hig		primary	1	
63	Polyline	47108589	Punta Rizal		residential	0	
27	Polyline	34551240	Third Street		service	0	
72	Polyline	76157200			service	0	
34	Polyline	34551252	Fifth Street		service	0	
37	Polyline	34551256	Second Ave		service	0	
6	Polyline	29397382	Lopez Jaen		residential	0	
206	Polyline	99448596			road	0	
45	Polyline	34551809	Airport Term		secondary	0	
67	Polyline	47872167			track	0	
61	Polyline	47108383			residential	0	
0	Polyline	27751190	Mandaue-M		primary	0	
275	Polyline	99448694			road	0	
167	Polyline	99448556			service	0	
43	Polyline	34551806			service	1	

Figure 3.5 Lapu-Lapu road network in ArcMap

After importing the road network shapefile in TransCAD as shown in **Figure 3.6** right, we should check the connectivity of the line layer, execute Tool – Map Editing – "Check Line Layer Connectivity" command as shown in the **Figure 3.6** left, if there is a problem with road lines connectivity, the macroscopic simulation result will inaccurate, and the final OD reverse matric is abnormally. If the connectivity has problem, use the map toolbox to modify it. Our Lapu-Lapu road network has no problem with connectivity. The solid points in the **Figure 3.6** left mean that the connectivity of the road network is good.

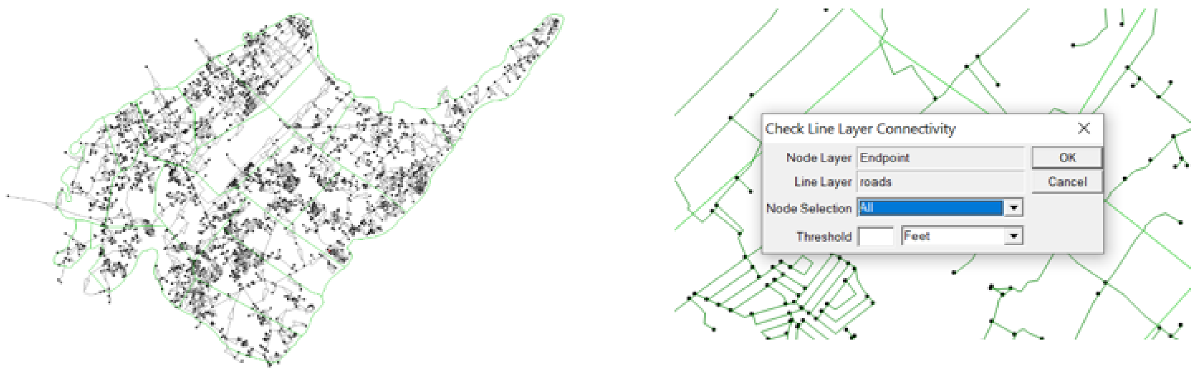


Figure 3.6 Road network in TransCAD

After the road network is built completed, we will set the properties of the road network. For macroscopic simulation, the properties need to be established are shown in **Figure 3.7**. there are 15 properties in this table: the road index, the length of road, the direction of road, the name of road,

road type, the flow of A to B, the flow of B to A, the road capacity of A to B, the road capacity of B to A, the travel time from A to B, the travel time from B to A, the number of road lane, the population density of the road, road is one-way or not, and the max speed of the roads.

Dataview3 - Table Structure: roads

Field_Name	Type	Width	Decimal
ID	Integer (4 bytes)	10	0
Length	Real (8 bytes)	10	2
Dir	Integer (2 bytes)	2	0
name	Character	16	0
type	Character	16	0
Type:1	Integer (2 bytes)	2	0
AB_Count	Integer (4 bytes)	8	0
BA_Count	Integer (4 bytes)	8	0
AB_Capacity	Integer (4 bytes)	8	0
BA_Capacity	Integer (4 bytes)	8	0
AB_Time	Real (8 bytes)	10	2
BA_Time	Real (8 bytes)	10	2
Lane	Integer (2 bytes)	2	0
popDensit	Real (8 bytes)	10	2
oneway	Integer (2 bytes)	6	0
maxspeed	Integer (2 bytes)	6	0

Figure 3.7 Road Network Properties

Data Collection of Lapu-Lapu Road network

These are the information we used to estimate the traffic flow distribution on the road as shown in **Figure 3.7** and also the type of these information, the most important factors are traffic count and road capacity, Since we don't have the real traffic data of each roads in Lapu-Lapu, also there are thousand road segments, it is not possible to get the count one by one, so we collected some data from internet, the research from a masterplan made by one Japanese group – JICA and also generate some data by functions and so on. Through the OSM file, we can directly get the data of each road name, every road length, every road type, the number of lanes, is one-way or not. For the other data such as count, capacity, time, max speed, and population density, we should calculate and then write them into this road network properties table. **OSM** divide all roads into Motorway, Trunk, Primary, Secondary, Tertiary, Unclassified, Residential, living street and so on. The whole road classification is in the OSM official site.[37] trunk, primary and secondary, these three kinds of road are most important in a country's system, and the least important through roads in the country's street is unclassified roads, i.e. minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties.[37], the residential roads which serve as an access to housing, without function of connecting settlements, often lined with housing. OSM website has already classified the road type for Lapu-Lapu city, OSM file contains the road type information, we use these data for our simulation. the **Max Speed** information for different type of road from different countries are provided by Wikipedia Street map as shown in **Figure 3.8**. this information will help us to estimate the time of vehicles stay on each road segment.

		Maxspeed in km/h, driving a motorcar														
		Motorway		Trunk		Primary		Secondary		Tertiary		Unclassified		Residential		Living street
Country			link	outside place=	inside place=	outside place=	inside place=	outside place=	inside place=	outside place=	inside place=	outside place=	inside place=	outside place=	inside place=	
Armenia		110	90	90	60	90	60	90	60	90	60	90	60	90	60	20
Austria		130	130	100 (*7)		100 (*7)		100 (*7)		100 (*7)		100 (*7)		50 (*7)		5.4 (*8)
Azerbaijan		110	80	80	50	80	50	80	50	80	50	70	50	50	50	20
Belgium	Flanders	120		70	50	70	50	70	50	70	50	70	50	70	50	20
	rest of country			90		90		90		90		90		90		
Brazil		110	80	80	80	80	60	60	60	60	40	60	30	30	30	30
Philippines		100 (some 60-80)	40	80	40 (*16)	80	40 (*16)	80	40 (*16) (*17)	30	30	20	20	20-	20	

Figure 3.8 Default speed limits by country

Road capacity is a kind of information to react each road limit number of vehicles. We do not have the road capacity for each road, so we through each road's number of lane and road width (we classified the width id each street according to different types of roads as shown in **Figure 3.9**) and then using the road capacity graph from JICA group as shown in **Figure 3.10**, by using linear interpolation method to estimate each road traffic capacity.

Category	Colour	Width	Opacity	Colour
motorway	Red	15	0.8	
motorway_link	Red	15	0.8	
trunk	Red	15	0.8	
trunk_link	Red	15	0.8	
primary	Red	15	0.8	
primary_link	Red	15	0.8	
secondary	Orange	15	0.7	
secondary_link	Orange	15	0.7	
tertiary	Yellow	10	0.6	
tertiary_link	Yellow	10	0.6	
road	Yellow	10	0.6	
service	Brown	6	0.4	
services	Brown	6	0.4	
steps	Brown	2	0.4	
track	Brown	2	0.4	
bridleway	Brown	2	0.5	
path	Brown	2	0.5	
pedestrian	Brown	2	0.5	
residential	Green	8	0.4	
cycleway	Blue	4	0.8	
living_street	Blue	8	0.8	
unclassified	Blue	4	0.4	
footway	Cyan	4	0.5	
proposed	Black	8	0.4	

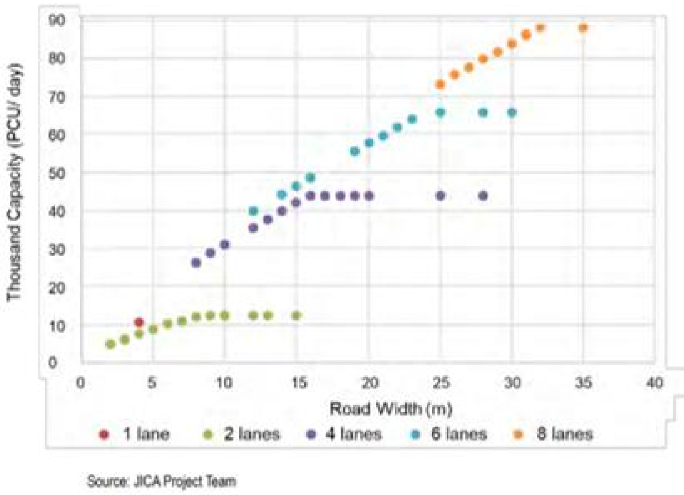


Figure 3.9 OSM classification road width

Figure 3.10 Road traffic capacity of Lapu-Lapu

Road count is depending on many factors, since we do not have real data of the traffic count, we estimated it depending on the population density of the region roads belongs to and the road capacity. There is a close positive correlation between higher population density and higher traffic volume. The fundamental problem is that as the population density increases, the use of vehicle also increases. [38]The traffic volume at a typical density trends to increase the population density growth rate by at least 80% as shown in **Figure 3.11** which is the relationship between population density and traffic density. this means that if a certain area experiences a 100% increase in population per square mile, the number of vehicle miles per square mile is expected to increase 80%. [38] Also, higher road capacity means better road condition and surface which make them more attractive to the people in trip.

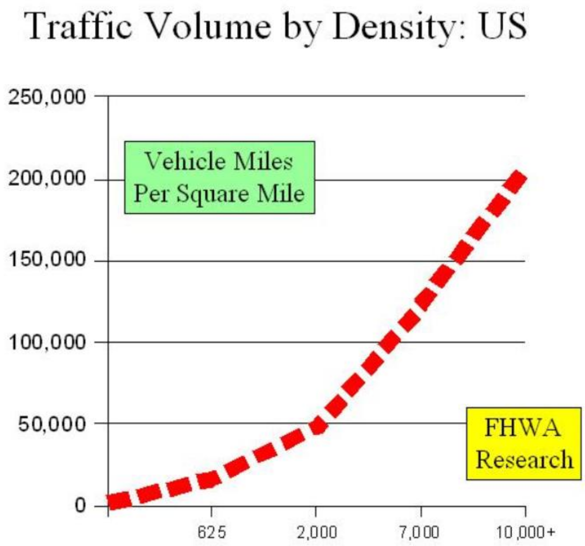


Figure 3.11 relationship between traffic volume and population[38]

In the **Figure 3.12** is the population density of different regions in Lapu-Lapu. Through these two factors we can estimate each road counts in Lapu-Lapu.

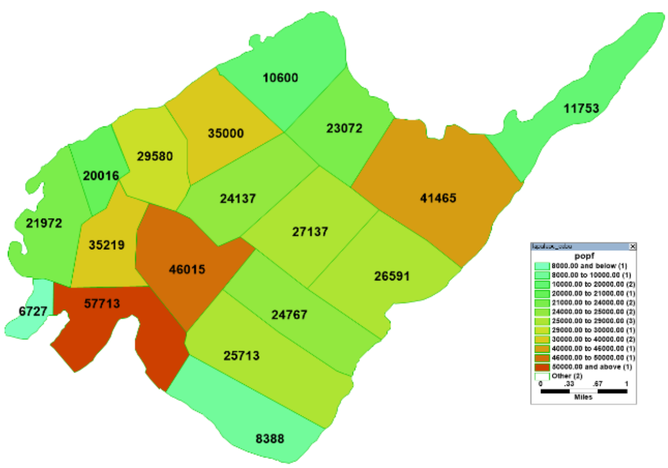


Figure 3.12 Population distribution of different region in Lapu-Lapu[39]

Travel time for each road is easy to calculate. The travel time is calculated by formula: the road length divided by the road max speed. We have gotten each road length and max speed before. The part of the final table of all data about Lapu-Lapu all roads is shown in the **Figure 3.13**.

ID	Length	Dir	name	type	[Type:1]	AB_Count	BA_Count	AB_Capacity	BA_Capacity	AB_Time	BA_Time	Lane	popDensit	oneway	maxspeed
3	2389.00	0		primary	1	37	37	45	45	2.39	2.39	6	15767.00	0	60
4	243.00	0	to Hadsan	unclassified	7	3	3	9	9	0.73	0.73	2	15767.00	0	20
9	5067.00	0	M.L. Quezc	primary	1	37	37	45	45	5.07	5.07	6	16072.00	0	60
95	345.00	0		residential	5	3	3	9	9	1.03	1.03	2	15767.00	0	20
99	2372.00	0	Mactan Air	unclassified	7	5	5	9	9	7.12	7.12	2	33465.00	0	20
100	690.00	0		residential	5	5	5	9	9	2.07	2.07	2	33465.00	0	20
108	1852.00	0	Bankal So	residential	5	3	3	9	9	5.56	5.56	2	17402.00	0	20
114	2938.00	0	Basak-Ca	residential	5	3	3	9	9	8.81	8.81	2	16072.00	0	20
117	2904.00	0	Pajac-Mar	unclassified	7	3	3	9	9	8.71	8.71	2	17402.00	0	20
205	86.00	1		service	6	3	0	7	0	0.26	0.26	1	16591.00	1	20
206	87.00	1		service	6	3	0	7	0	0.26	0.26	1	16591.00	1	20
616	785.00	0		track	8	2	2	7	7	4.71	4.71	1	16072.00	0	10
1273	31.00	0		residential	5	3	3	9	9	0.09	0.09	2	16591.00	0	20
1274	84.00	0		residential	5	3	3	9	9	0.25	0.25	2	16591.00	0	20
1425	49.00	0		residential	5	3	3	9	9	0.15	0.15	2	17402.00	0	20
1429	183.00	0		residential	5	3	3	9	9	0.55	0.55	2	17402.00	0	20
1430	110.00	0		residential	5	3	3	9	9	0.33	0.33	2	16591.00	0	20
1437	164.00	0		residential	5	3	3	9	9	0.49	0.49	2	16591.00	0	20
1438	88.00	0		residential	5	3	3	9	9	0.26	0.26	2	16591.00	0	20
1440	313.00	0		residential	5	3	3	9	9	0.94	0.94	2	16591.00	0	20
1441	384.00	0		residential	5	3	3	9	9	1.15	1.15	2	17402.00	0	20
1454	123.00	0		road	4	6	6	9	9	0.21	0.21	2	33465.00	0	35
1470	231.00	0		track	8	2	2	7	7	1.39	1.39	1	16072.00	0	10
8	3288.00	0	Patalijog /	primary	1	54	54	45	45	3.29	3.29	6	59873.00	0	60
20	3019.00	0	Benedicto	unclassified	7	4	4	9	9	9.06	9.06	2	31219.00	0	20
119	1787.00	0	Fuentes St	residential	5	3	3	9	9	5.36	5.36	2	15767.00	0	20
228	4080.00	0	Quezon Hi	primary	1	36	36	45	45	4.08	4.08	6	14800.00	0	60
256	69.00	0		residential	5	3	3	9	9	0.21	0.21	2	15767.00	0	20
263	448.00	0		residential	5	3	3	9	9	1.34	1.34	2	15767.00	0	20

Figure 3.13 Final all roads in Lapu-Lapu attribute table

stablish road network file

First, we should import the traffic districts file and road file in the TransCAD as shown in **Figure 3.14**. And then connect the traffic district's mass center to the road file to make the centroid connecting rods to establish the whole road network. In the menu bar, click on the "Networks/Paths – Create" then we choose the link fields as shown in **Figure 3.15**: "AB_Count/BA_Count", "AB_Capacity/BA_Capacity", "AB_Time /BA_Time" then click ok, our road network is established.

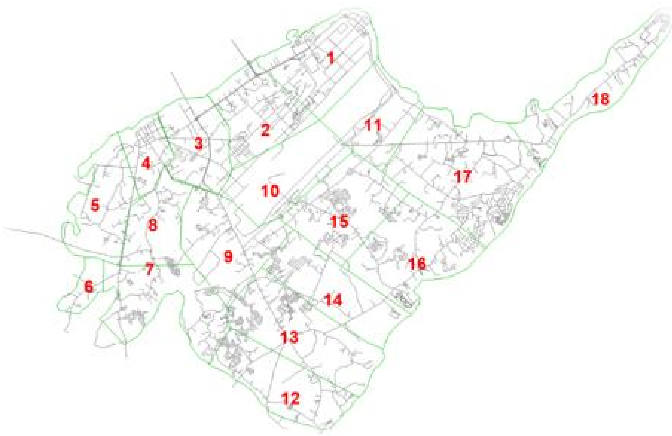


Figure 3.14 import Road and district

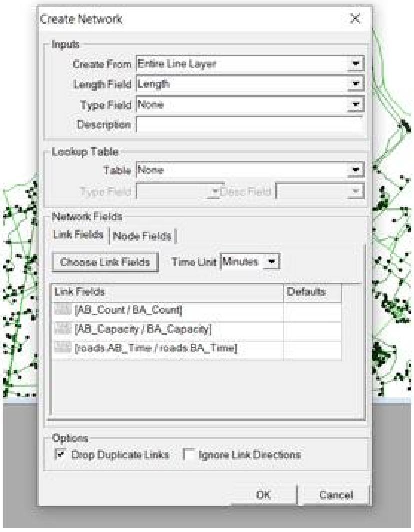


Figure 3.15 Create Network

OD Matrix inversion based on TransCAD

The OD matrix is a matrix in which all traffic partitions are sorted by row (Starting traffic area) and column (end traffic area), and the number of residents or vehicle trips (OD amount) between any two partitions as elements of OD matrix. This matrix can distinguish the travel volume of two sections in different directions. All the element in the matrix means the traffic flow from area A to area B, which is equivalent to the degree of congestion on your path from one place to another. Because there are thousands of roads need to survey, this is a huge workload, waste a lot of time, and the cost is very expensive to count the actual OD matrix, it is difficult to guarantee the accuracy of the result.

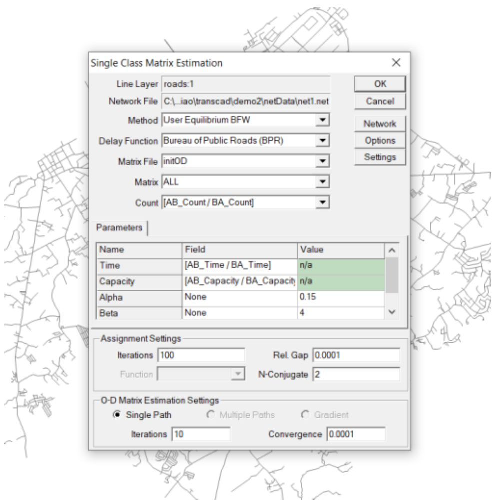


Figure 3.16 Single Class Matrix Estimation

Therefore, the OD inverse technique is used to solve this problem. The OD matrix inverse technique is used to estimate the OD matrix by combining the effectively collected road network traffic flow, part of the OD data and some available traffic information based on the area research. TransCAD provides a scientific and reasonable process for OD matrix. we need two files to establish OD matrix: road network file and initial matrix file. Then we find Planning in the menu and click "OD Matrix Estimation – Single Class Matrix Estimation" , and we will see in the **Figure 3.16**, we enter our initial OD matrix as shown in **Figure 3.17**, and then through road network file and initial OD matrix, using OD matrix inverse matrix to get the current traffic volume distribution OD matrix. the final result of OD matrix is shown in the **Figure 3.18**. in this matrix, shows us the traffic volume distribution between each district.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
11	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 3.17 part of initial OD Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	15.19	2.26	2.18	1.63	1.41	1.00	1.00	1.00	1.00	0.96	0.29	1.20	1.16
2	16.54	1.00	3.06	2.82	1.90	1.67	1.00	1.00	1.00	1.00	1.23	0.41	1.46	1.92
3	1.87	2.65	1.00	1.92	0.50	0.36	1.00	1.00	1.00	1.00	0.14	0.05	0.24	34.50
4	1.94	2.57	2.32	1.00	0.58	0.44	1.00	1.00	1.00	1.00	0.21	0.08	0.32	7.54
5	1.25	1.47	0.47	0.53	1.00	13.16	1.00	1.00	1.00	1.00	9.18	0.39	10.24	0.32
6	1.08	1.30	0.35	0.42	12.80	1.00	1.00	1.00	1.00	1.00	8.28	0.17	8.34	0.22
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00
11	0.71	0.92	0.16	0.21	7.70	6.58	1.00	1.00	1.00	1.00	1.00	0.00	6.08	0.08
12	2.87	3.26	0.56	0.66	0.87	0.73	1.00	1.00	1.00	1.00	0.46	1.00	0.60	0.28
13	0.92	1.13	0.25	0.32	9.67	7.73	1.00	1.00	1.00	1.00	8.77	0.04	1.00	0.14
14	0.92	1.62	32.58	6.65	0.33	0.21	1.00	1.00	1.00	1.00	0.06	0.02	0.12	1.00

Figure 3.18 the Final part of OD matrix

OD matrix is distributed to the road network and Visualize

Through the OD matrix, there is no way to intuitively reflect the traffic situation of the Lapu-Lapu city. If we want to observe the traffic distribution of the entire city more intuitively, we can assign the OD matrix on the road network and make the data visualize in the road network. First, we can find Planning in the menu bar, and then execute "Static traffic Assignment – traffic Assignment" as shown in **Figure 3.19**. then it will create a table about the assignment traffic distribution of the road network. Then find Planning in the menu bar and execute "Assignment Utilities – Create Flow Map" as shown in **Figure 3.19 right**. we can choose AB flow to observe the current traffic distribution in Lapu–Lapu city.

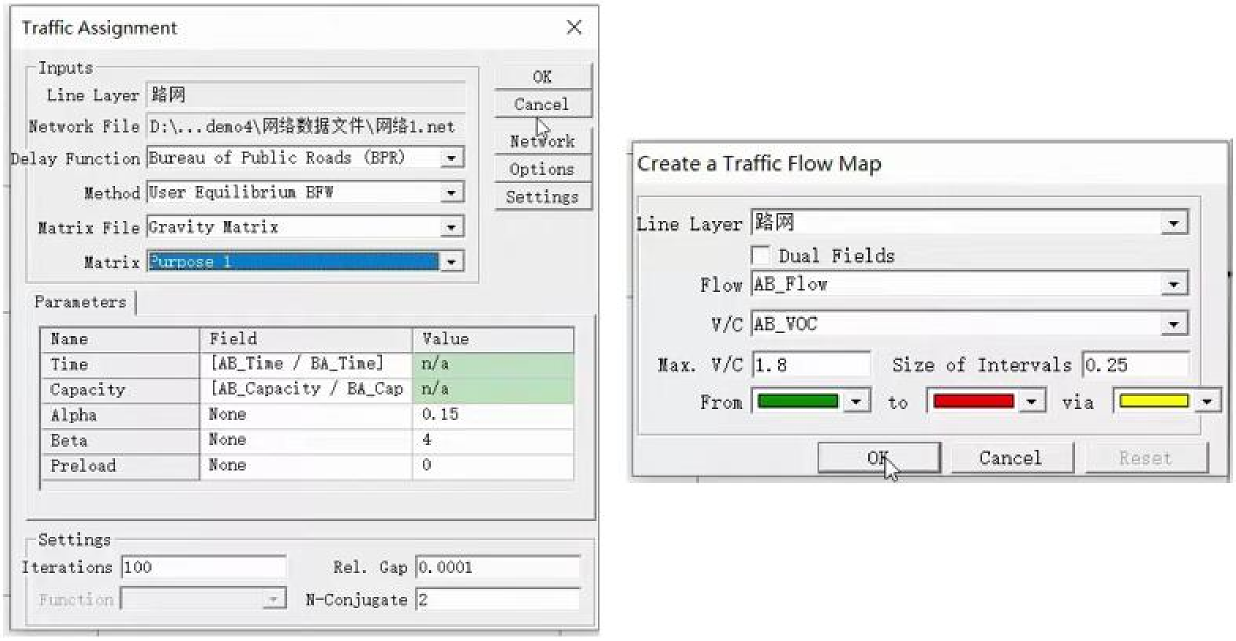


Figure 3.19 Traffic Assignment and flow visualize

Finally Result

In the **Figure 3.20**, this is the simulation result of TransCAD, it shows the traffic volume distribution. As we can see, the main road between two bridges and the road segment toward the airport line and the marigondon road have a higher traffic volume, due to the traffic count is based on the hypothesis, so it may cause inaccuracy. In the **Figure3.20**, we chose the intersection of the M.L. Quezon National Highway which between main road and the Lapu-Lapu city hall as our main study area. This part traffic volume is higher and most of government services office is positioned there. It is the main traffic center of Lapu-Lapu city.

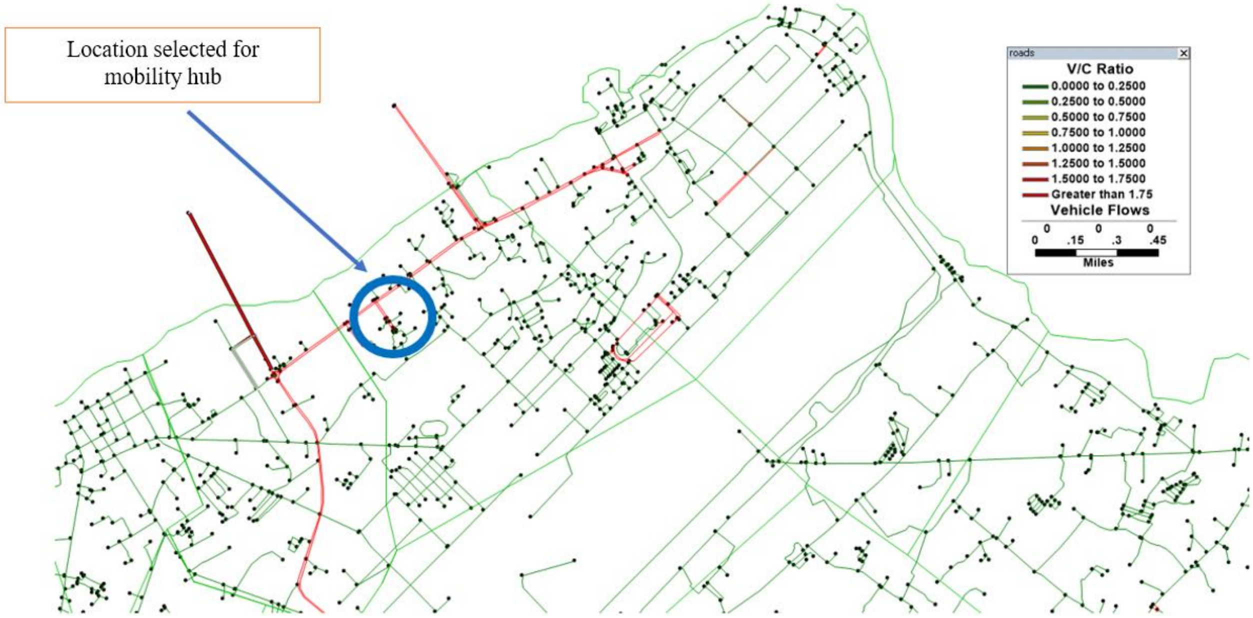


Figure 3.20 Traffic Volume Distribution in Lapu-Lapu

3.3.2 Microscopic Simulation

Determine Simulation area

As saying in the 3.2 Workflow, the case study working area, the location of establishing the mobility hub, taking advantage of macroscopic simulation results by TransCAD, accessibility analysis, swot analysis, spatial analysis outcome and an aspect analysis about solar radiation in GIS, from Daniele's study results, we choose Lapu-Lapu city hall as our working area as shown in the **Figure 3.21**. This area is at the middle of the 1st bridge and 2nd bridge, which means that the vehicles from this area can reach these two bridges easily. This area includes the intersection of the M.L. Quezon National Highway, which is one of the highest traffic density roads, and there are many government service offices around this area. We research the video about this area traffic flow from local people videos[44][45], we observed that there are many jeepney and large commercial vehicles travel around here. Therefore, this city hall area a transportation center of Lapu-Lapu city. In this part, we do the microscopic simulation of this area by VISSM. Zheyuan focus on the microscopic simulation scene set up by VISSIM. Through the microscopic simulation, we can outcome the information about the number of vehicles, each vehicle speed, acceleration, travel distance, the amount of CO_2 and other pollutant production and many traffic information. VISSM has the emission calculation function but which the pollutant type of emission measurement is less, and the accuracy is low, so the VISSIM simulation outputs file (*.fzp) will be used into the emission analysis in the MOVES and collect all kinds of useful data to establish the visualization data management at the end.

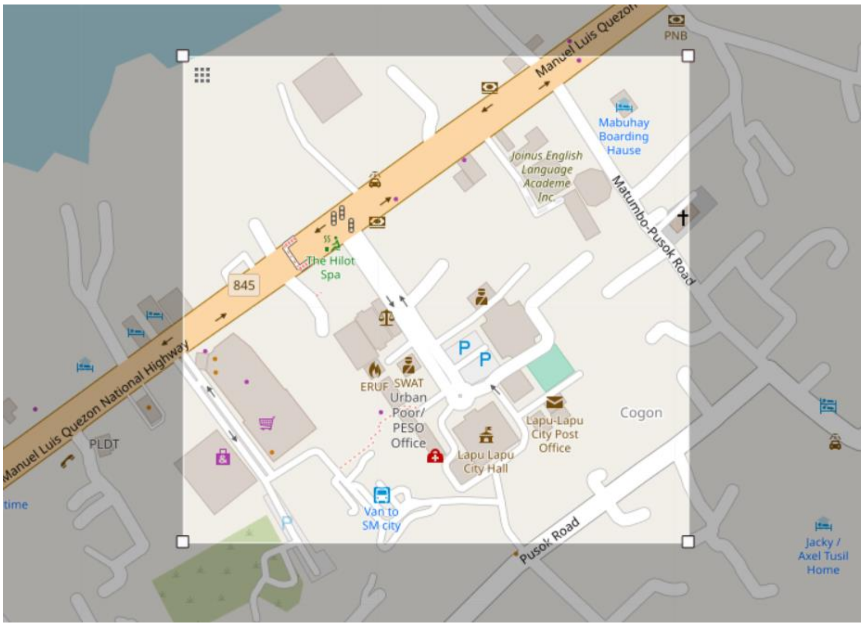


Figure 3.21 Lapu-Lapu City Hall

VISSM overview

VISSM simulation software is a microscopic traffic flow simulation software developed by German PTV company[86].VISSIM can analyze the operation status if urban traffic and public transportation under various traffic conditions (such as lane setting, traffic composition, signal timing, bus stops and routes decisions, etc.), It is an effective tool for evaluating traffic situation, emission calculation and traffic planning tool. There are two parts of the traffic simulator and the signal state generator inside, through Application Programming Interface (API) exchanging detector data and signal status information. The traffic simulator includes a car-following model and lane-changing model to form a traffic flow. The signal state generator is a signal control software used to realize the logical control of the traffic flow. The accuracy of the traffic simulation model mainly depends on the quality of the vehicle simulation model, including the two important models: the car following model and the lane changing model. The car following model is the most important model in traffic simulation. The car following model used by this software is a psycho-physiological driving by Wiedemann, which is mainly used for the operation and analysis of the traffic system. Driver's driving behavior is a complex process that is influenced and interacted by various factors such as environment, physiology, and psychology. This simulation model is closer to the reality, also, this car-following model best describes most common driving behaviors. The lane-changing model is used to describe that the driver adjusts his own driving habit according to the surrounding environment information such as the speed and clearance of the surrounding vehicles, adjust its own driving strategy and complete the integrated process of the strategy. VISSIM simulation software is mainly used in vehicle operation modeling and analysis of vehicle operating conditions under various traffic conditions.

Road Network Establish in VISSM

The road Network establish by Zheyuan in the VISSM. In his thesis will describe how to build the road network in detail. In this section will roughly introduce the establishment of the entire road network in VISSM. First, we should establish the basic road segments composition by observing the road composition in the reality map. VISSM uses two basic components to establish the road network: Link and Connector. Combining these two components to describe a continuous path and connect all the path together will establish the entire road network. **Link:** Link represent each road segment in the whole road network. The simulated road network should be based on Link. on the ordinary road section, if multiple lanes have the same function, they can be represented by a multi-lane link. When establish this kind of road section, we just enter the numbers of how many lanes in this road section. If the functions of the two lanes are different and the vehicle cannot change lanes with each other, we should establish two Links to present. And through the research we can set each Link's Lane number and the width of each lane. **Connector:** connector is to connect Links. Only when the link attributes such as the number of lanes, speed limit, road channelization changes, Connector is needed to connect different links. Vehicles are not allowed to change lanes on the Connector. Two important thing needs to be avoided: avoid setting too long connectors on the main road and the overlapping part of the Connector and Link should not be too long which will cause the distortion of the simulation results and the failure of the rule setting. Our working area is a T-shaped intersection. When establish the road section in the intersection, the turnings of vehicles at the intersection are generally not allowed to change lanes or overtake, we use the Connectors to establish the turning path. Through the Links and Connectors, the basic road network was established. Secondly, we should input this area's **Vehicle Composition**. Traffic composition is a component of VISSIM's input of traffic flow, and it needs to be defined before input traffic flow. The traffic composition in our work area includes **Cars, HGV, Bus, Jeepney, Pickup, Motorcycle, and Light trunk.** Since in this area there is some road which the HGV cannot enter, so we classified the vehicle composition in two types. The vehicle composition should define each kind of vehicle's types and their relative proportions of the whole traffic flow and each kind of vehicle's speed distribution. Third, we should define each road segment **Vehicle Input**. Our basic road network has seven vehicle input Links. We should define the volume (how many vehicles enter this road) and the vehicle composition (which kind of vehicles will enter) for each vehicle input Links. Fourth, Create **Car Park**. In our case study, we have established a Parking area in this working area, the parking area is located in front of the DTI Negosyo Center Lapu-Lapu City; we should define the number of car position and vehicle composition to enter this park area, the vehicle speed, vehicle stay time in the parking area (DirChgDurDistr) and other parking information. Fifth, we should define the **Vehicle Routes.** the meaning of vehicle routes is the vehicle should go in which paths. we used two kinds of route decision in this study. One is the static route; another one is the partial route for parking area. Static route has one start link and one end link. In each route decision of static route, we should define the vehicle class and the relative traffic flow. In the parking area, as we know it is not possible that every vehicle passes the road which connect with the park entry road that wants to enter the parking area. So, we use the partial route to define the route decision, And the partial route has one start link and multi end links, we can proportionally define different traffic flow on each route decision. Finally, we should set up the **Signal Control**.

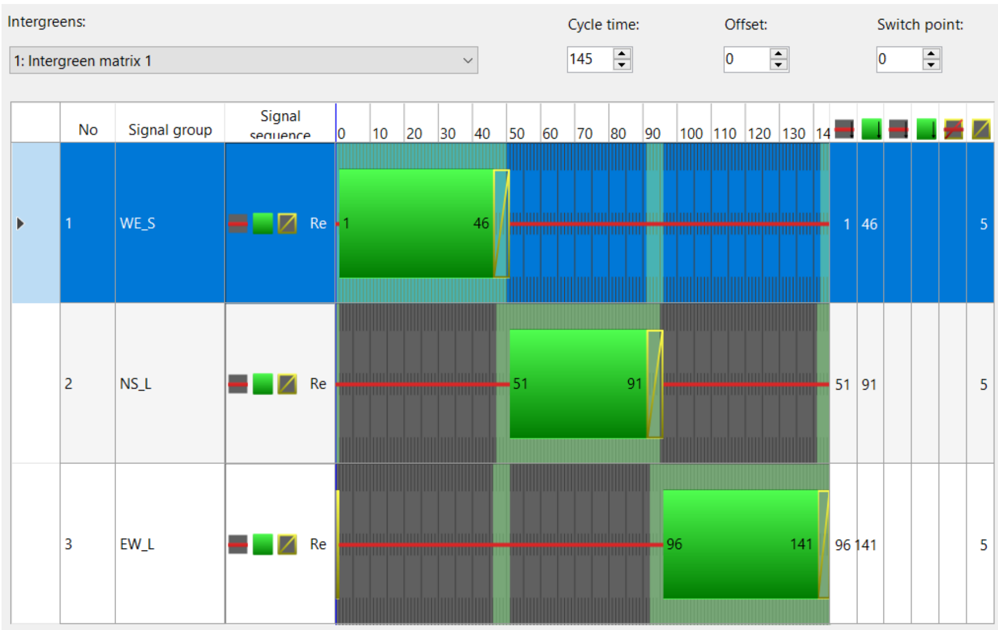


Figure 3.22 Signal Controller

In our study area, there are three groups of signal controller in the intersection. Each signal controller has its own signal time. Through observing the signal lights times from local people videos[44][45], we establish each group signal controller time as shown in **Figure 3.22**. until now, the whole establish road network is finished as shown in **Figure 3.23**. All the preparations of simulation are finished, we can click on the playing to start simulating. The simulation is shown in **Figure 3.24**.

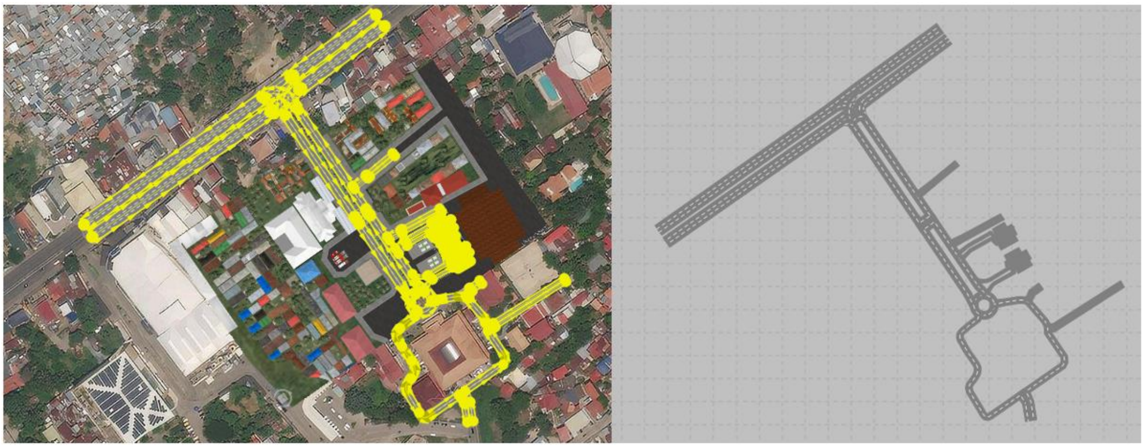


Figure 3.23 whole road network

Figure 3.24 Microscopic simulation

VISSM Simulation result evaluation

VISSIM provides multiple types of evaluation functions. Evaluation data can be displayed during the simulation operation or output as a "*.fzp" file. In the case study, we will do the emission analysis about this area in the MOVES. Therefore, we choose the output as a "*.fzp" file. Before the simulation, we should set up which kind of data we need through the microscopic analysis. In the MOVES, we need an excel file which named "operation mode distribution", this will be mentioned below in the emission analysis. For the emission analysis in MOVES, we need each vehicle's speed, simulation second, Acceleration, travel distance, Vehicle type, and vehicle number post-simulation through VISSIM simulation as shown in the **Figure 3.26**. In the VISSIM, we can find the "evaluation" in the menu bar and execute the "Configuration". And then the interface appears as shown in **Figure 3.25**, we click “More…” to select the attributes of the simulation output.

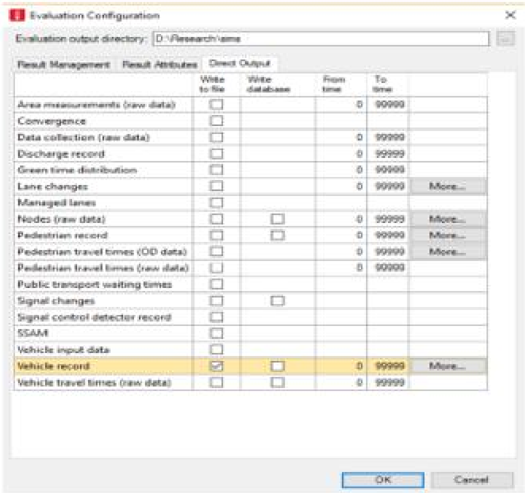


Figure 3.25 Direct Output

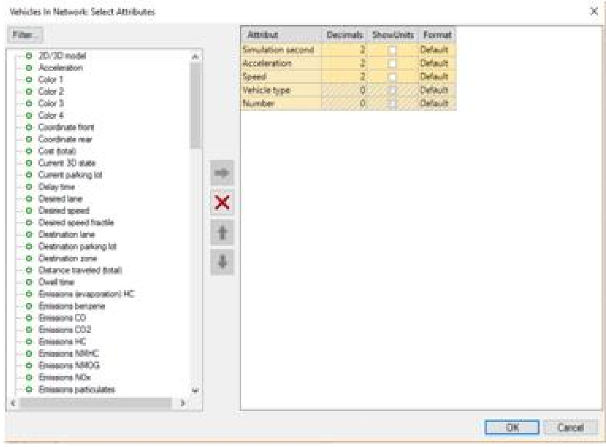
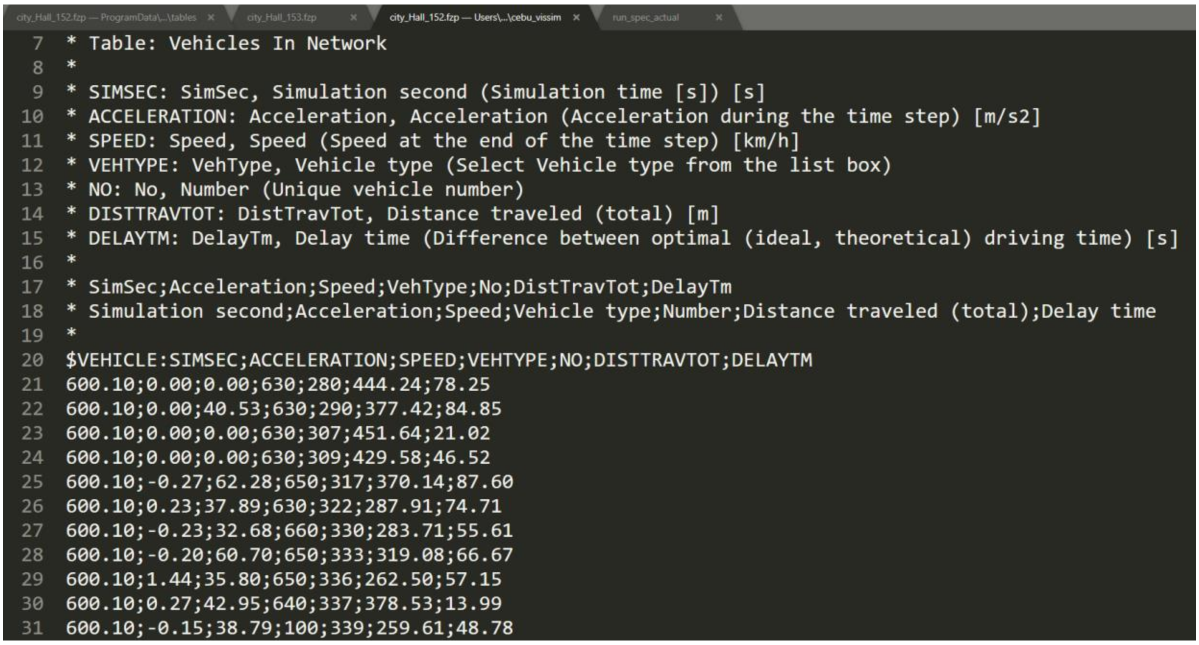


Figure 3.26 Select Attribute

After setting up the Evaluation, we can start playing the simulation. The output result of microscopic analysis will directly write into the “*.fzp” file, which contains more than hundred thousand rows of data, and the partial part of the file as shown in **Figure 3.27**. then we will organize the output data from microscopic simulation as an input of emission analysis in MOVES.



```
* Table: Vehicles In Network
*
* SIMSEC: SimSec, Simulation second (Simulation time [s]) [s]
* ACCELERATION: Acceleration, Acceleration (Acceleration during the time step) [m/s2]
* SPEED: Speed, Speed (Speed at the end of the time step) [km/h]
* VEHTYPE: VehType, Vehicle type (Select Vehicle type from the list box)
* NO: No, Number (Unique vehicle number)
* DISTTRAVTOT: DistTravTot, Distance traveled (total) [m]
* DELAYTM: DelayTm, Delay time (Difference between optimal (ideal, theoretical) driving time) [s]
*
* SimSec;Acceleration;Speed;VehType;No;DistTravTot;DelayTm
* Simulation second;Acceleration;Speed;Vehicle type;Number;Distance traveled (total);Delay time
*
$VEHICLE:SIMSEC;ACCELERATION;SPEED;VEHTYPE;NO;DISTTRAVTOT;DELAYTM
600.10;0.00;0.00;630;280;444.24;78.25
600.10;0.00;40.53;630;290;377.42;84.85
600.10;0.00;0.00;630;307;451.64;21.02
600.10;0.00;0.00;630;309;429.58;46.52
600.10;-0.27;62.28;650;317;370.14;87.60
600.10;0.23;37.89;630;322;287.91;74.71
600.10;-0.23;32.68;660;330;283.71;55.61
600.10;-0.20;60.70;650;333;319.08;66.67
600.10;1.44;35.80;650;336;262.50;57.15
600.10;0.27;42.95;640;337;378.53;13.99
600.10;-0.15;38.79;100;339;259.61;48.78
```

Figure 3.27 Output of Microscopic Simulation

3.4 Emission and Energy Analysis

3.4.1 The composition and harm of motor vehicle exhaust pollutants

Motor vehicle's engine can be divided into gasoline engines and diesel engines, which have different combustion mechanisms, the components of their exhaust pollutants are also different. The main pollutants are also different. The main pollutants of gasoline engines are carbon monoxide (CO), hydrocarbons (HC), Carbon dioxide (CO2) nitrogen oxides (NOx). Diesel engine pollutants mainly include hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM). Motor vehicle exhaust pollutants can harm human health and the plant growth in different levels. Through the research, in the air of cities, harmful gases 87% CO, 61% HC, 55% NOx etc. come from automobile exhaust .

Carbon monoxide (CO)

Carbon monoxide is a product formed when the air supply is insufficient, and the fuel is not completely burned. It is an odorless, colorless, and odorless flammable and toxic gas. When the vehicle is under heavy load, running at a slow speed or running in neutral gear, the CO content in the exhaust gas will increase significantly because the fuel cannot be fully burned. In general, the level of CO in the city is harmless to plans, but it is harmful to the human body, because after CO enters the human body from the respiratory tract, it is easy to combine with hemoglobin in the blood to form carboxyhemoglobin. Experiments have shown that the binding capacity of hemoglobin and CO is 200 to 300 times higher than its binding capacity to oxygen, which will cause the blood's oxygen-carrying to decrease, causing symptoms such as dizziness, headache, and accelerated heartbeat. Higher CO concentration can damage the central nervous system can even suffocate people to death. In addition, CO can also cause fetal growth impairment or mental retardation, and it is more harmful to patients with heart disease, anemia, and respiratory diseases. The impact of different content of CO on human health. At intersections and busy roads in cities, high levels of CO pollution often occur. Therefore, strengthening urban traffic management will help reduce the CO content in the city's air.

Hydrocarbon (HC)

HC is a product formed by incomplete combustion or cracking of fuel lubricating oil. There are more than 200 kinds of HC in the exhaust gas of motor vehicles. About 60%HC comes from exhaust gas emissions from internal combustion engines, 20% to 25% of HC comes from crankcase blowby gas, and the remaining 15% to 20% of HC comes from evaporation of the fuel system. It is causing direct harm to humans. HC is a volatile organic compound. HC includes unburned and completely burned fuel oil, lubricating oil, and some of the oxidation products after cracking, such as alkanes, alkenes, cycloalkanes, aromatics, aldehydes, ketones, organic acids, and other components. These components are causing direct harm to humans. Aromatics have an aromatic smell and are dangerously toxic. Benzene may cause leukemia at higher concentrations and damage the liver and central nervous system. Polycyclic aromatic hydrocarbons and their derivatives have carcinogenic effects. The main aldehydes from exhaust emissions are formaldehyde, acetaldehyde and acrolein. They all irritate the eye film, larynx, and bronchi, are toxic to the blood, and may also have genetic toxicity and carcinogenic activity. It becomes the second public nuisance of car exhaust emission.

nitrogen oxides (NOx)

NOx is produced in the cylinders of internal combustion engines. They are the products formed by the products formed by the combination of remaining oxygen and nitridation in the process of high temperature fuel combustion. Its emission depends on factors such as combustion temperature, time, and air – fuel ratio. The main component of NOx is NO and NO2. The NO emitted by motor vehicles is easily oxidized in the air to form the secondary pollutant NO2. Because the higher daytime temperature is conducive to the conversion of NO, the concentration of NO2 is higher during the day. The NOX content in motor vehicle exhaust is less, but it is very toxic, and its toxicity is three times that of sulfur oxides. NOX can irritate people's nose, eyes, lungs, and throat, and increase the probability of virus infection. NOX can also adversely affect the growth of plants. It is also an important source of photochemical smog. It also produces acid rain and causes climate change.

Carbon dioxide (CO2)

CO2 is a colorless and non-toxic gas. The greenhouse effect formed by the absorption of infrared heat radiation causes the global temperature to rise and the north and south poles to melt. The **Figure 3.28** shows the relationship between global temperature and the amount of CO2 emitted. We know the CO2 is the main factor to induce global temperature increase. In turn, the sea level has risen, and the trend of deserts in the hinterland of the continent has intensified, destroying the ecological environment on which humans, animals, and plants. The proportion of vehicle exhaust emission in urban air pollution has exceeded 70% which about 30% of CO2 emissions come from vehicle exhaust. CO2 us not hurt people but it is a greenhouse gas emitted from combustion.

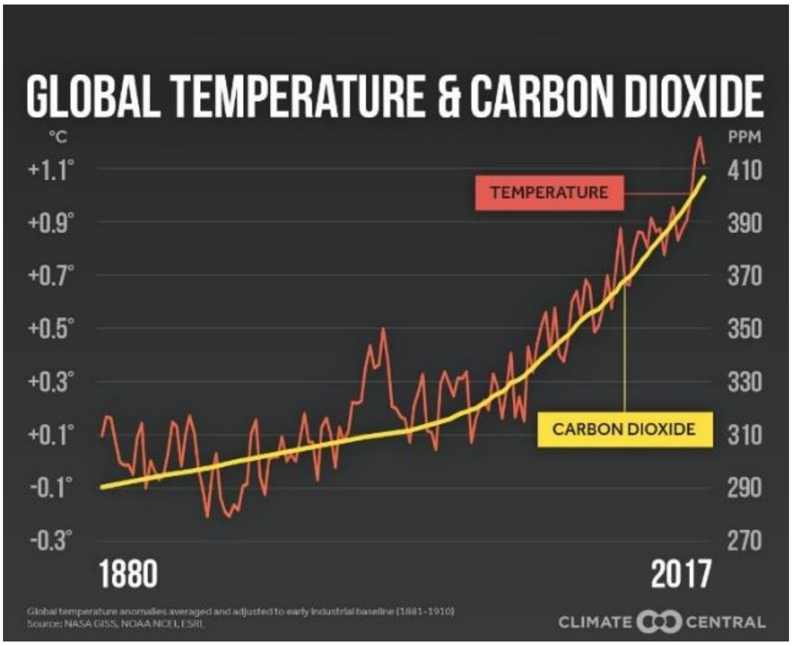


Figure 3.28 Global Temperature and Carbon dioxide

particulate matter (PM)

PM in motor vehicle exhaust mainly refers to soot an oil particle generated by incomplete fuel combustion. The particle size of soot is usually between 0.1μm and 0.5μm. Due to the porosity and adsorption activity of soot, it can carry harmful substances such as SO2, HC and NO2 or carcinogens such as benzopyrene into the human body, which is harmful to human health. Particles less than 2.5 micrometers in diameter can penetrate deeply into the human's lung, irritate, and corrode the alveolar wall, and consequently impair lung function. PM pollution caused by motor vehicle exhaust can account for 60% of urban air pollution, or even as high as 90%. The data provided by the World Health Organization show that: every increase of 50 μg/m3 of inhalable particles, human mortality will increase by 5%.

3.4.2 Emission due to Electric Vehicles

Electric vehicle (EV) refers to a vehicle that is powered by an onboard power supply and driven by electric motor to drive wheels. The power source of EV is electricity stored in batteries. Electric vehicles can be divided into three types which includes pure electric vehicle (BEV), hybrid electric vehicle (HEV), fuel cell electric vehicle (FCEV). Electric vehicles compose by the electric drive and control system, driving force transmission and other mechanical systems. The biggest difference from internal combustion engines (ICE) is caused by the electric drive and control system. The electric drive and control system consists of a drive motor a power supply, and a speed control device of electric vehicle are basically the same as ICE vehicles. the EV motor which converts the electric energy into the mechanical energy. At present most of the EV used the lead-acid batteries, but its charging time is so slow and short lifespan, nowadays the power source chooses to use nickel-cadmium batteries, fuel cells, lithium batteries and so on. In the future will mainly develop the batteries technology which use the renewable energy as EV power supply.

There are so many advantages of using EV. Firstly, **"No pollution", low noise.** In fact, EV do not produce the exhaust air pollution. Therefore, large using the EV will be a very friendly environmental plan. The pollutants from the ICE exhaust gas such as CO, HC, NOX, PM, internal combustion engine vehicles form acid rain, acid mist and photochemical smog. The pollution of electric vehicle is highly depending on the percentage of renewable source, as shown in **Figure 3.29**, if the electricity comes from the coal, nuclear, gas (not renewable energy), EV will create the emission, even this, it still less pollution than ICE vehicles. But if the charge source comes from renewable source such as waterpower, solar power, wind power, the pollution is almost zero. Electric vehicles have no noise generated by internal combustion engines, and the noise of electric motors is also smaller than that of internal combustion engines.

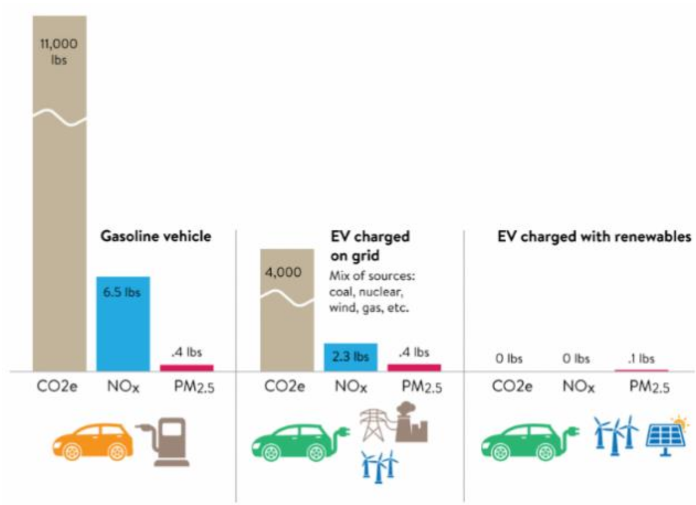


Figure 3.29 EV charge method emission comparison

High energy efficiency, research on electric vehicles has shown that EV's energy efficiency much higher than ICE vehicles. Especially when running in the cities, where vehicles always stop and go, the driving speed is low, so the electric vehicle is more suitable. When braking, the EV will automatically be converted into generator to realize the reuse of energy during braking and deceleration. So, it is significantly reducing the energy waste. The energy of the electricity used for the recharging of electric vehicle's battery can be generated from the chemical fuel source such as coal, natural gas, oil etc. and renewable energy source such as the hydro, wind, solar etc.

In the **Figure 3.30**, shows the total emissions of the simulated power and transportation sectors. To illustrate the impact of clean grid development and improved fuel economy of transport vehicles, we have included a basic greenhouse gas scenario without transport electrification. If the transport sector is electrified in the basic greenhouse gas scenario, by 2050 he will reduce emissions by 48% from 2015 levels. In the greenhouse gas reduction scenario, total emissions will be reduced by 70% from 2015 levels.

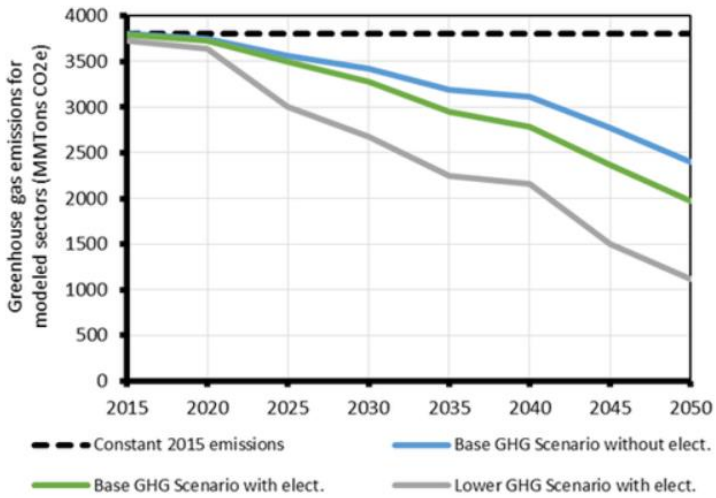
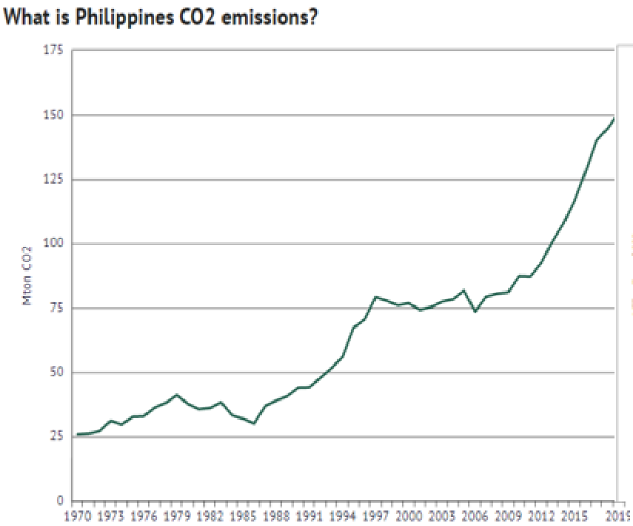


Figure 3.30 Emission reduce due to EV[42]

3.4.3 Emission condition in Metro Cebu

In the chapter 1 -- 1.3.2 Current state and Problems of traffic in Metro Cebu. We have already mentioned the air pollution in Cebu metro. As the population rapidly grow, the number of motor vehicles increase rapidly. Therefore, the air pollution becomes more and more serious. One of the most pollution source comes from Jeepneys. The main public transportation is Jeepney in Metro Cebu. Jeepneys contributes to greenhouse gas emission of about 12.49 – 17.48 tons of CO2 per year. As shown in **Figure 3.31**, the CO2 growth rapidly in Philippines. And the transport is the large source of air pollution in Philippines which occupied over 80%. And the PM and air quality in Cebu metro are in a very low level. Many vehicles on the road are inadequately maintained, particularly buses, jeepneys, and trucks. These vehicles contribute to the deterioration of air quality because of poorly controlled emissions.[13] in the **Figure 3.32**, it estimated the CO2 emissions from land transport sector in the Philippines.[43]



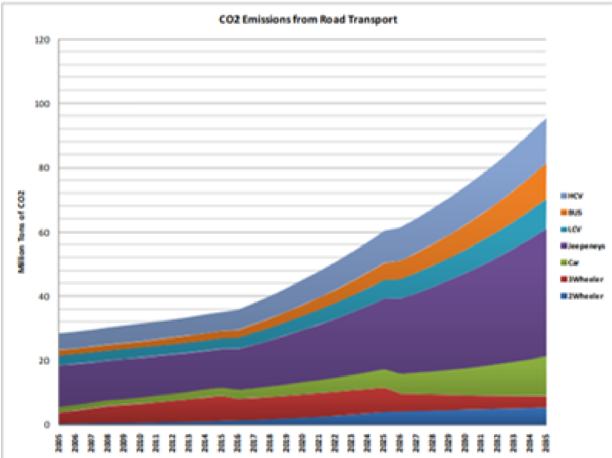


Figure 3.31 CO2 emission in Philippines **Figure 3.32 CO2 in Million Tons[43]**

3.4.4 Emission Analysis by MOVES

As the **Figure 3.30**, increase using electric vehicles will reduce the emission. in this chapter, we focus on our working area Lapu-Lapu city hall, conduct emission analysis by MOVES on the work area and observe the impact of electric vehicles on the environment by changing electric vehicles amount. When conducting urban emission analysis studies, model simulation methods are often used to estimate the emissions of motor vehicle exhaust pollutants. The motor vehicle emission model comprehensively considers the service life of the vehicle, mileage, emission standards, driving speed, temperature, I/M (detection and maintenance system) and the properties of the vehicle fuel etc. Using different calculation parameters and formulas for different vehicles to simulate vehicle emission levels. At present, some models have been developed, so we mainly rely on the mature models that have been developed to localize relevant parameters, and the calculate urban traffic emissions. According to different simulation scales, automobile exhaust emissions models can be divided into three types: macroscopic, mesoscopic, and microscopic. In addition, according to the different calculation principles of the model, it can be divided into an average speed model and a driving condition model. The average speed model includes MOBILE developed by U.S. Environmental Protection Agency, COPERT developed by the European Environmental Protection Agency, and EMFAC developed by the California Air Resources Agency. Driving mode models include CMEM, IVE and MOVES developed in the United States.[46][47][48][50][49] COPERT (Computer Program to Calculate Emissions from Road Transport) model was developed by the European Environment Agency in 1985. This model has many parameters but less input data. Therefore, it is widely used in European countries. 错误!未找到引用源。 CMEM (Comprehensive Modal Emissions Model) is an emission model which can predict the emission of various light vehicles under different conditions, this model has high requirements for vehicle operating stat data, and it is difficult to collect.[51][53][54][55] The IVE (International Vehicle Emission Model) is a vehicle emission inventory measurement model suitable for developing countries. IVE introduces VSP and ES to divide the instantaneous operating conditions of motor vehicles into 60 sections to reflect the pollutant emissions of vehicles under different operating conditions. However, the classification of vehicle types is too complicated to obtain data.[56][57] MOBILE (Mobile Source Emission Factor Model) and EMFAC models were developed by the U.S. Environmental Protection Agency (EPA) in 1978 and California Air Resources Agency. Their calculation principle is similar. MOBILE is currently the most widely used model. MOBILE model can simulate the average emission factors of HC, CO, and NOx for vehicles with different fuel types under actual road operating conditions. The development time of the MOBILE model is the earliest, and the data will be continuously expanded and updated in future applications, and the algorithm will also be continuously improved to supplement various correction factors that have an impact on the emission factor. But at the same time, the MOBILE model has some problems. Firstly, the operation is very inconvenient. The model input file has strict requirements on the format and order of the input process. If there is a error, it needs to be re-entered. Secondly, The MOBILE model predicts emissions based on fixed operating conditions. Since the model is based on a fixed driving cycle and basic emission rate, and cannot represent the actual road operating conditions, it cannot accurately quantify vehicle exhaust emissions.[59] In addition, the US Environmental Protection Agency has done a lot of testing and research, using the MOVES model and the MOBILE model for test comparisons. The results show that MOVES has an advantage in accuracy over MOBIIE. In addition, because the model uses an open database management system, the model also has strong adaptability to different regions.[58]

MOVES Overview

MOVES (Motor Vehicle Emission Simulator) was developed by the U.S. Environmental Protection Agency (EPA), the University of California at Riverside, and North Carolina State University based on the MOBILE model and the NONROAD model and depend on large number of vehicle test and bench test data. This model is a vehicle exhaust emission prediction model that integrates the macroscopic (national), mesoscopic (county) and microscopic (project), the model has become the most advanced tool recommended by the EPA for predicting road vehicle emissions. The model can be calculated on a single computer alone and can also be used to perform online calculations on multiple computers when the amount of data is large which greatly improves work efficiency. And it can be combined with the air quality model for air quality simulation analysis. MOVES is jointly developed by Java language and MySQL relational database [60]. Java is a modern and widely used object-oriented programming language, which provides a highly independent platform for the operation of MOVES; MySQL is a database management system based on a structured (SQL) query language. MOVES is used in data input, output, and calculation. The data storage in the process is stored in the MySQL database. MOVES model classifies motor vehicles according to many factors such as vehicle type, load, engine technical conditions and fuel type, and obtains a unique combination of various factors and correspond to different emission sources bin. At the same time, the operating condition distribution module (ODMG) divides the vehicle operating condition into different bins (start, running, idling, etc.) related to the vehicle specific power (VSP) and speed of the vehicle, and performs operating conditions through the defined operating condition interval calculation of distribution. Distribute the operating information of all vehicles to the emission source and operating condition interval, and weight all the emissions distributed in the emission source and operation condition interval to obtain pollutant emissions. The MOVES model establishes a direct relationship between emission rate and vehicle specific power (VSP). Many experimental studies have proved that vehicle specific power (VSP) can more accurately reflect the relationship between vehicle operating conditions and pollutant emissions than specific speed and acceleration. When use MOVES model, users can input local traffic parameters required at different levels according to research needs, so that the calculation results can reflect local emission characteristics. In our study of emission analysis, we used the latest versions of MOVES which is MOVES3 as shown in **Figure 3.33** [62].

When successfully started MOVES3 interface, there are 11 main tabs to input as shown in **Figure 3.33** right. Once all the file has entered completely, it can be saved as a “RunSpec” with will record the user’s setting.

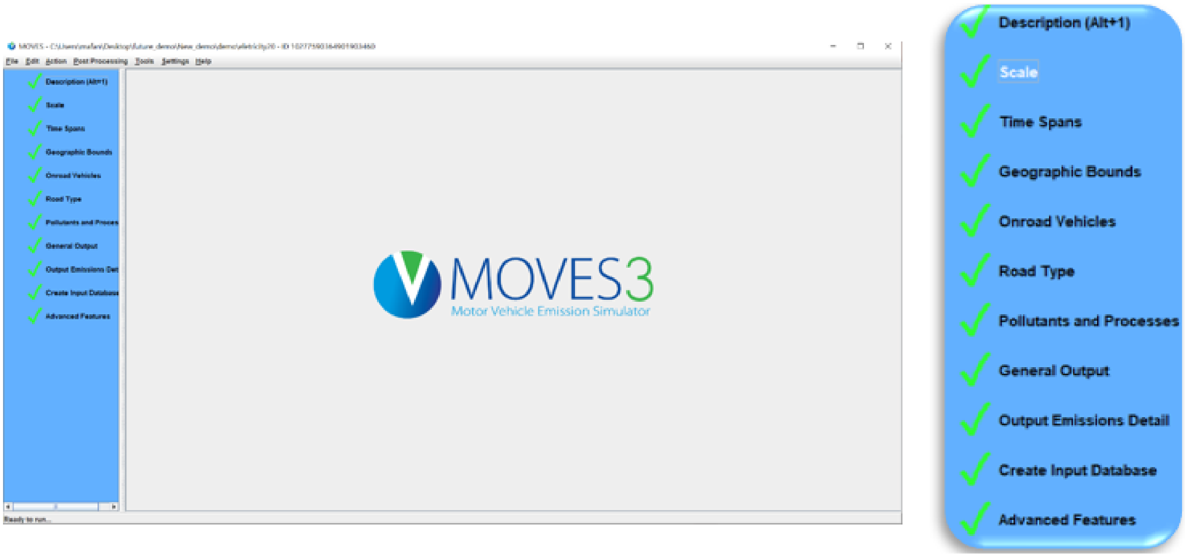


Figure 3.33 MOVES3

Vehicle Exhaust Emission Model Based on VSP Distribution

Vehicles in the road network will be affected by different factors during the driving process, including the weather environment, traffic conditions, and the vehicle's own conditions. These factors will cause changes in the power consumption of the vehicles which will lead to changes in the vehicle's power consumption which will induce the energy consumption and pollutant emissions are different. in the view of the relationship between the vehicle's work requirements and the energy consumption and pollutant emissions during the movement of the vehicle, if the detailed instantaneous power output of the vehicle is obtained, the energy consumption and emissions of the vehicle can be obtained. For the need to obtain detailed power output, the concept of Vehicle Specific Power (VSP) was introduced by Jimenez Palacios of the Massachusetts Institute of Technology in 1999 which proposed in his doctoral thesis. VSP is defined as the input power for each ton of mass (including its own weight) moved by the engine, its unit is KW/t (w/kg). from his thesis, he explained the application method of VSP variables in Remote Sensing Device (RSD)[63]. Because the remote sensing exhaust detection position has a large degree of limitations in many parameters of the vehicle cannot be recorded except for a single instantaneous detection data and the VSP variable is independent of the vehicle weight and other variables, which can link the vehicle's instantaneous working conditions of the vehicle and vehicle's pollutant emissions. Therefore, CSP variables can be used compare the pollutant emissions of different type of vehicles with different types of vehicles with different detection methods. In recently years, many researchers, such as Frey[64],Davis[66] have studied the application of modeling methods based on VSP. The widely used MOVES model and IVE model also use VSP as the main calculation model for emission analysis. Theoretically speaking, a motor vehicle will be powered by the engine during driving, and at the same time it must overcome friction resistance from ground and aerodynamic resistance. These factors comprehensively determine the change in the power of the motor vehicle. For this situation, the motor vehicle VSP comprehensively considers the change in the work of the engine by converting the heat energy generated by fuel combustion into kinetic energy during the driving process, the change in the potential energy consumed by the road height, and the change in the vehicle during the travel and sliding friction on the ground and aerodynamic.

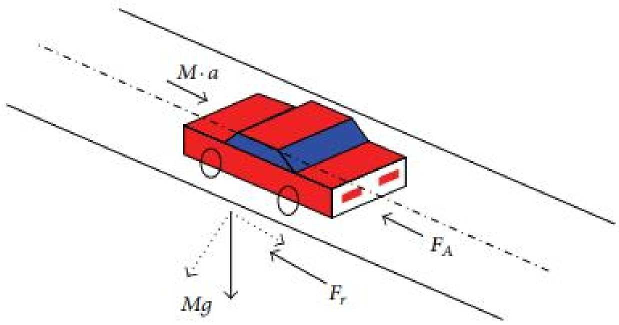


Figure 3.34 VSP of Vehicle[67]

As the **Figure 3.34** shown a VSP of light-duty vehicle, VSP includes two parts, one is the output power of the engine, which is used to overcome friction from wheel rotation resistance, aerodynamic resistance and increase the kinetic energy and potential energy of motor vehicles, the other is the transmission mechanical power loss caused by internal fingernail friction during transmission. [67] VSP considers the changes in the kinematic energy and potential energy of the vehicle, and overcomes the rolling resistance and air resistance of the vehicle, the VSP formula shown as:

$$VSP = \frac{\left\{\frac{d}{dt}(KE + PE) + F_{rolling}V + \frac{1}{2}\rho_a C_D A(v + v_w)^2 v\right\}}{m}$$

$$= \frac{\frac{d}{dt}\left(\frac{1}{2}m(1 + \varepsilon_i)v^2 + mgh\right) + C_r mgv + \frac{1}{2}\rho_a C_D A(v + v_w)^2 v}{m}$$

$$= v(a(1 + \varepsilon_i) + g \times grade + gC_r) + \frac{1}{2}\rho_a \frac{C_D A}{m}(v + v_w)^2 v \quad (3.1)$$

Where: **KE** is the kinematic energy, **PE** is the potential energy, $\frac{d}{dt}(KE + PE)$ is the output power required for the kinematic or potential energy of the motor vehicle, $F_{rolling}$ is rolling resistance force, $\frac{1}{2}\boldsymbol{\rho_a C_D A(v+\ v_w)^2}$ is the aerodynamic resistance force, $\boldsymbol{v}$ is the speed of motor vehicle (m/s), **m** is total mass of the motor vehicle (kg), **a** is acceleration, **h** is the altitude, $\boldsymbol{\varepsilon_i}$ is the effect of translational mass of powertrain rotating components, $\boldsymbol{\rho_a}$ is air density (1.2 kg/m3), v_W is the wind speed, $\boldsymbol{A}$ is frontal area of vehicle, $\boldsymbol{g}$ is the gravitational constant (9.81 m/s2), $\boldsymbol{C_r}$ is the rolling coefficient which related to the road material and tire type, and $\boldsymbol{C_D}$ is the aerodynamic coefficient, $\boldsymbol{grade}$ is the slope of the road.

As some research, we put $\boldsymbol{\varepsilon_i}$ is equal to 1, and the Put the $\boldsymbol{C_r}$ is equal to 0.0135, $\boldsymbol{\frac{C_D A}{m}}$ for classical light-duty vehicle is equal to 0.005, $\boldsymbol{grade}$ is equal to 0. The data measured directly into the formula, after simplifying the formula, we will get the following general formula of VSP as shown in (3.2)

$$VSP = v(1.1 \times a + 0.132) + 0.302 \times\ 10^{-3} \times v^3 \qquad (3.2)$$

In our Lapu-Lapu city, we have lots of kinds of vehicle, different kinds of vehicle have different VSP formulas. For heavy vehicles such as HGV, due to the vehicle's aerodynamic coefficient $\boldsymbol{C_D}$, frontal area of vehicle $\boldsymbol{A}$, total mass of the vehicle **m,** these values have large difference from light – duty vehicles. Formula 3.2 cannot be applied when calculating the VSP of the heavy vehicles. [71] In 2001, Andrei [68] considered the differences in the vehicle weight and size between heavy vehicles and light vehicle in the modelling process of heavy – duty vehicle emissions, finally got the corresponding VSP formula for heavy-duty vehicles, and this formula has also been recognized in other researches[69][70]. The VSP formula for the heavy – duty vehicle is shown in formula 3.3.

$$VSP = v(a + 0.09199) + 0.169 \times\ 10^{-3} \times v^3 \qquad (3.3)$$

One of the main transportations in Lapu-Lapu is Motorcycle, in this case the VSP of motorcycle is also different from the formula (3.3) and (3.2), in a literature[72], the motorcycle's aerodynamic coefficient $\boldsymbol{C_D}$ is equal to 0.75, and the frontal area of vehicle $\boldsymbol{A}$ is equal to 0.65 m^2, the mass **m** is equal to 140 kg for motorcycle and 70 kg for the rider. Therefore, we got the VSP formula for motorcycle, which the formula is shown in formula 3.4. $\boldsymbol{\theta}$ is the slope of the road.

$$MSP = v(1.01a + 9.81 \sin\theta + 0.137) + 0.169 \times\ 10^{-3} \times v^3 \qquad (3.4)$$

The same as mentioned before, the VSP for transit buses was different from other VSP formula, in the study [73], has defined the formula of VSP for transit, $\boldsymbol{C_r}$ rolling coefficient for transit is equal to 0.092, the transit bus's aerodynamic coefficient $\boldsymbol{C_D}$ is equal to 0.00021, the VSP formula is shown in formula 3.5.

$$VSP = v(a + 9.81 \sin\theta + 0.092) + 0.21 \times 10^{-3} \times v^3 \qquad (3.5)$$

In the MOVES, the vehicle emission rate is determined by the Operation Mode (OpModelID). MOVES calculate emission based on the operation mode, as we know the vehicle in the different state has different energy consumption, even if the same vehicle travelled in the same distance, if change the driver then emission will be changed, because the emission depend on the driving behavior as the operation mode. Different vehicle type has different VSP, through the value of VSP, speed and acceleration, we will get each vehicle's OpModelID as shown in **Figure 3.35**. The operation mode which is related to the VSP and vehicle speed. Each OpModelID relates to an emission rate for a specific type of emissions in MOVES. VSP is a connection between the driving behaviors and the vehicle emission. [74] The Operation Mode as input data of the emission analysis in MOVES. It will be described more detail in next chapter.

OpModeID	*Operation Mode Description*	*VSP (kw/t)*	*Speed (mph)*	*Acceleration (mph/s)*
0	Deceleration/Braking	-	-	Acceleration ≤ -2 or Acceleration < -1 for 3 consecutive seconds
1	Idling	-	-1 ≤ Speed < 1	-
11	Cruise/Acceleration	VSP < 0	0 ≤ Speed < 25	-
12	Cruise/Acceleration	0 ≤ VSP < 3	0 ≤ Speed < 25	-
13	Cruise/Acceleration	3 ≤ VSP < 6	0 ≤ Speed < 25	-
14	Cruise/Acceleration	6 ≤ VSP < 9	0 ≤ Speed < 25	-
15	Cruise/Acceleration	9 ≤ VSP < 12	0 ≤ Speed < 25	-
16	Cruise/Acceleration	12 ≤ VSP	0 ≤ Speed < 25	-
21	Cruise/Acceleration	VSP < 0	25 ≤ Speed < 50	-
22	Cruise/Acceleration	0 ≤ VSP < 3	25 ≤ Speed < 50	-
23	Cruise/Acceleration	3 ≤ VSP < 6	25 ≤ Speed < 50	-
24	Cruise/Acceleration	6 ≤ VSP < 9	25 ≤ Speed < 50	-
25	Cruise/Acceleration	9 ≤ VSP < 12	25 ≤ Speed < 50	-
26	Cruise/Acceleration	12 ≤ VSP	25 ≤ Speed < 50	-
33	Cruise/Acceleration	VSP < 6	50 ≤ Speed	-
35	Cruise/Acceleration	6 ≤ VSP < 12	50 ≤ Speed	-
36	Cruise/Acceleration	12 ≤ VSP	50 ≤ Speed	-

Figure 3.35 Definition of MOVES Operating Mode Attributes [74]

The connection between VISSIM and MOVES

In the **chapter 3 VISSM Simulation result evaluation,** we have gotten the vehicle information from microscopic simulation of Lapu-Lapu City Hall by VISSIM. Integrating the traffic simulation model VISSIM with the emission models MOVES can effectively study the operating mode of all vehicles on the road network in our working area and establish the relationship between the road network and traffic emissions, and we can evaluate the road network from multiple factors Emission levels. VISSIM can output the parameters as said in **chapter 3 VISSM Simulation result evaluation**, use this vehicle information can as an input of MOVES to calculate OpModelID for each vehicle and then calculate emissions as shown in **Figure 3.36**.

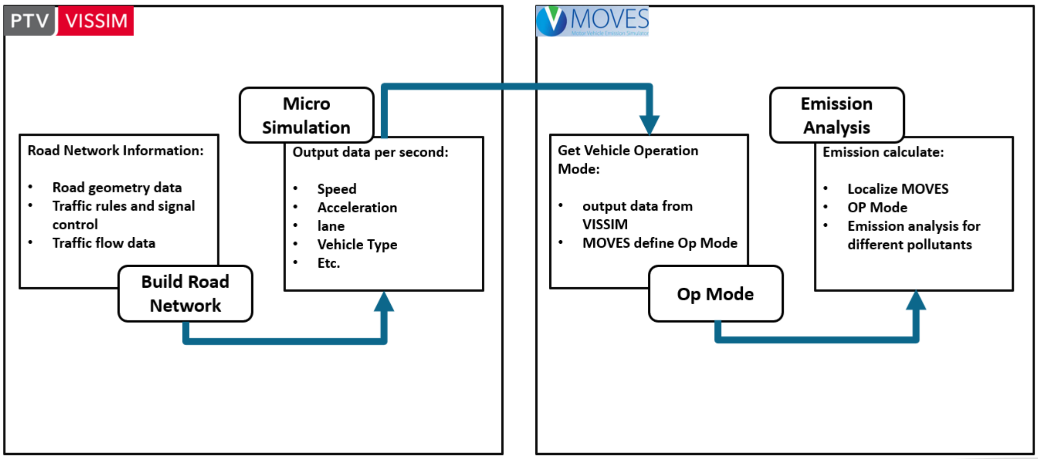


Figure 3.36 Relationship between VISSIM and MOVES

When using the emission model MOVES for emission calculation, the speed and acceleration parameters output by the simulation model VISSIM are required to calculate the VSP. But these two models have difference in vehicle classification, we should standardize the vehicles between these two models. In the VISSIM we divide all traffic transportation into 7 categories: Car, HGV, Bus, Jeepney, Pickup, Motorcycle, Light truck based on the length, width, mass, and engine power of the vehicles. In the MOVES we use Passenger car, Refuse Trunk, Transit Bus, passenger Truck, Light Commercial Truck and Motorcycle to fit the vehicle models in VISSIM. For different vehicle classification of the two models, just need specify a corresponding vehicle type in MOVES as shown in TABLE 3.1.

TABLE 3.1

VISSM	**Corresponding models in MOVES**
100 - CAR	21 - Passenger car
200 - HGV	51 - Refuse Trunk
300 - BUS	42 - Transit Bus

630 - JEEPNEY	31 – Passenger Truck
640 - PICKUP	32 - Light Commercial Truck
650 - MOTORCYCLE	11 - Motorcycle
660 – LIGHT TRUCK	32 - Light Commercial Truck

Parameters and data input of MOVES model

As the **Figure** shown in **3.33**, there are 11 main tabs need to input. **Description:** the user can use this window to give the RunSpec a specific text description. As our study goal, we want to see how electric vehicle effects the emission in Lapu-Lapu city hall. In the window, we can specify the number of electric vehicles. **Scale:** MOVES can analysis emission in three levels: macroscopic (National), mesoscopic (County) and microscopic (Project). User can select the model scale from the Scale windows based on the study area. In our case, the interested area is not so large, it contains one intersection and the area of government service offices. We have microscopic traffic simulation to generate trajectory vehicle to vehicle, so the project level is more propriate. **Time Spans:** user can select the year, month, day, hour, and minute of the simulation condition. **Geographic Bounds:** MOVES can simulate U.S. motor vehicle emissions from 1990 to 2050. it is the same as geographical area, the user can select the geographic location given in the model. User can choose the existing countries, states. In our simulation of Lapu-Lapu city hall, we can random choose a city as geographical area, and in the input file of database to do the localization. **Onroad Vehicle:** As said before, In the MOVES we use Passenger car, Refuse Trunk, Transit Bus, passenger Truck, Light Commercial Truck and Motorcycle to fit the vehicle models in VISSIM. As the same time, in this window, the fuel type and the emission source type must be selected for input. In our simulation for Lapu-Lapu city hall, the fuel type of all vehicles can be classified into 5 kinds, Gasoline, Diesel Fuel, Compressed Natural Gas, Liquefied Petroleum Gas, Electricity. The corresponding ID and fuel type of the motor vehicle fuel type that shown in Table 3.2.

TABLE 3.2

FUELTYPE ID	**FuelTypeDesc**
1	Gasoline
2	Diesel Fuel
3	Compressed Natural Gas
4	Liquefied Petroleum Gas
9	Electricity

The complete table of the selection of the onroad vehicle is shown in the **Figure 3.37**.

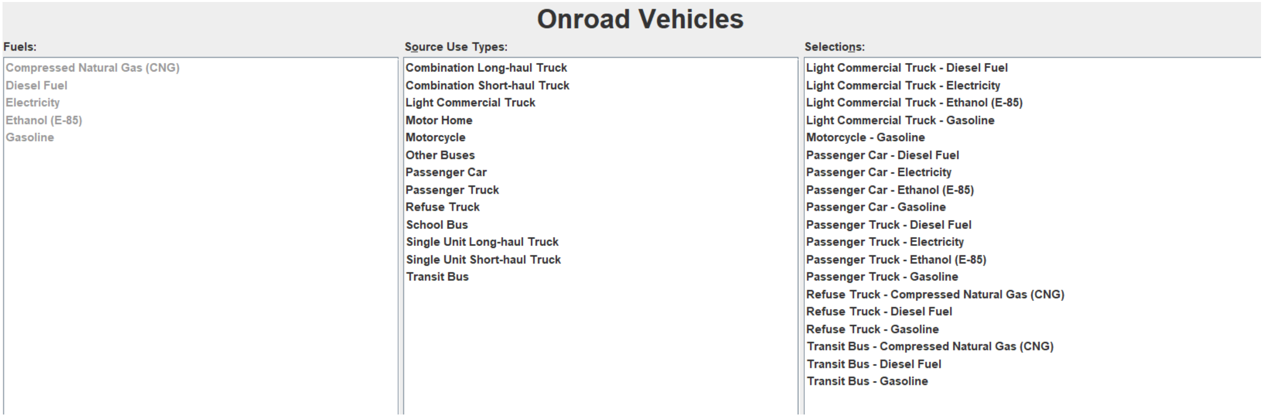
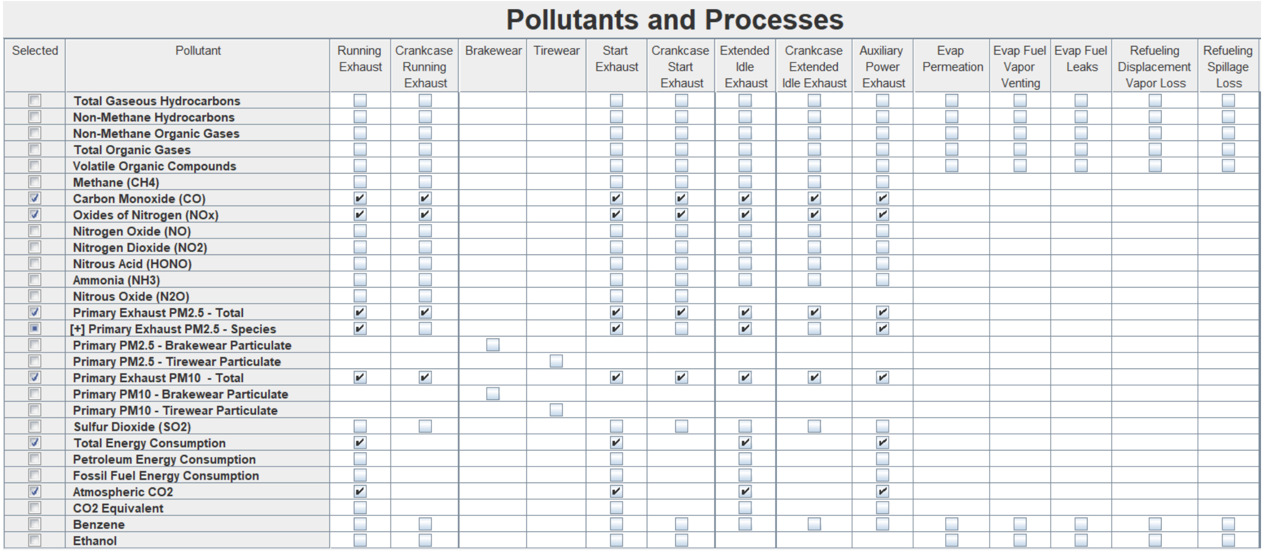


Figure 3.37 Onroad Vehicles selection

Road type: in the MOVES the Road type can be divided into Off-Network, rural restricted Access, rural Unrestricted Access, urban restricted Access, and urban Unrestricted Access. The Off-network emission source mainly simulates the emissions when the vehicle is not moving, such as startup and evaporative emissions, but the idling emissions under normal operation are calculated in the road emission sources. Road emission sources mainly simulate the emission of motor vehicles in operation, including rural roads and urban roads. Rural roads and urban roads are divided into restrictive and non-restrictive. Restrictive refers to roads that include ramps and other entrances, such as expressways Unrestrictive roads refer to roads that do not restrict entrances, which are ordinary roads. **Pollutants and Processes**: the types of pollutants include HC, NOx, NH3, CO, CO_2, SO_2, PM10, PM2.5, toxic gases and so on. The emission process includes operating emission, starting emission, braking emission and other 14 types of emission which includes tire wear emissions, fuel evaporation and leakage, and other emissions. In our emission analysis we considered the most serious pollutants: CO, NOx, PM2.5, Energy Consumption, CO_2, and the processes we chose running exhaust, Crankcase Running Exhaust, Start Exhaust, Extended Idle Exhaust, Crankcase Extended Idle and Auxiliary Power Exhaust as shown in **Figure 3.38**.



Pollutants and Processes

Selected	Pollutant	Running Exhaust	Crankcase Running Exhaust	Brakewear	Tirewear	Start Exhaust	Crankcase Start Exhaust	Extended Idle Exhaust	Crankcase Extended Idle Exhaust	Auxiliary Power Exhaust	Evap Permeation	Evap Fuel Vapor Venting	Evap Fuel Leaks	Refueling Displacement Vapor Loss	Refueling Spillage Loss
☐	Total Gaseous Hydrocarbons	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Non-Methane Hydrocarbons	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Non-Methane Organic Gases	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Total Organic Gases	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Volatile Organic Compounds	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Methane (CH4)	☐	☐			☐	☐	☐	☐	☐					
☑	Carbon Monoxide (CO)	☑	☑			☑	☑	☑	☑	☑					
☑	Oxides of Nitrogen (NOx)	☑	☑			☑	☑	☑	☑	☑					
☐	Nitrogen Oxide (NO)	☐	☐			☐	☐	☐	☐	☐					
☐	Nitrogen Dioxide (NO2)	☐	☐			☐	☐	☐	☐	☐					
☐	Nitrous Acid (HONO)	☐	☐			☐	☐	☐	☐	☐					
☐	Ammonia (NH3)	☐	☐			☐	☐	☐	☐	☐					
☐	Nitrous Oxide (N2O)	☐	☐			☐	☐								
☑	Primary Exhaust PM2.5 - Total	☑	☑			☑	☑	☑	☑	☑					
▣	[+] Primary Exhaust PM2.5 - Species	☑	☐			☑	☐	☑	☐	☑					
☐	Primary PM2.5 - Brakewear Particulate			☐											
☐	Primary PM2.5 - Tirewear Particulate				☐										
☑	Primary Exhaust PM10 - Total	☑	☑			☑	☑	☑	☑	☑					
☐	Primary PM10 - Brakewear Particulate			☐											
☐	Primary PM10 - Tirewear Particulate				☐										
☐	Sulfur Dioxide (SO2)	☐	☐			☐	☐	☐	☐	☐					
☑	Total Energy Consumption	☑				☑		☑		☑					
☐	Petroleum Energy Consumption	☐				☐		☐		☐					
☐	Fossil Fuel Energy Consumption	☐				☐		☐		☐					
☑	Atmospheric CO2	☑				☑		☑		☑					
☐	CO2 Equivalent	☐				☐		☐		☐					
☐	Benzene	☐	☐			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Ethanol	☐	☐			☐	☐				☐	☐	☐	☐	☐

Figure 3.38 Pollutants and Processes

General Output and **Output Emission Detail**: it is used to specify the output database, unit, and emission activity, and some output properties. The unit of mass is Kg, the unit of energy is Joules, and the Distance unit is miles. **Advanced Performance Features:** this interface is used for problem analysis after calculation, and the intermediate calculation process can be changed artificially without setting. **Create Input database:** in this window, user cannot directly use the default input database of MOVES, we should input user defined data information of our working area – Lapu-Lapu city hall. When we choose the project scale to simulate, this window is very important to enter for emission analysis. Before the user enters the localized data, the required database must be created in the database table. After the database is established, MOVES select useful input information during operation for simulation. In the **Figure 3.39**, there are the needed database to enter the localized data for simulation, mainly includes Meteorology Data, Operating Mode Distribution, Age Distribution, Fuel, Links, Link Source Types, I/M Programs, Link Drive Schedules and so on.

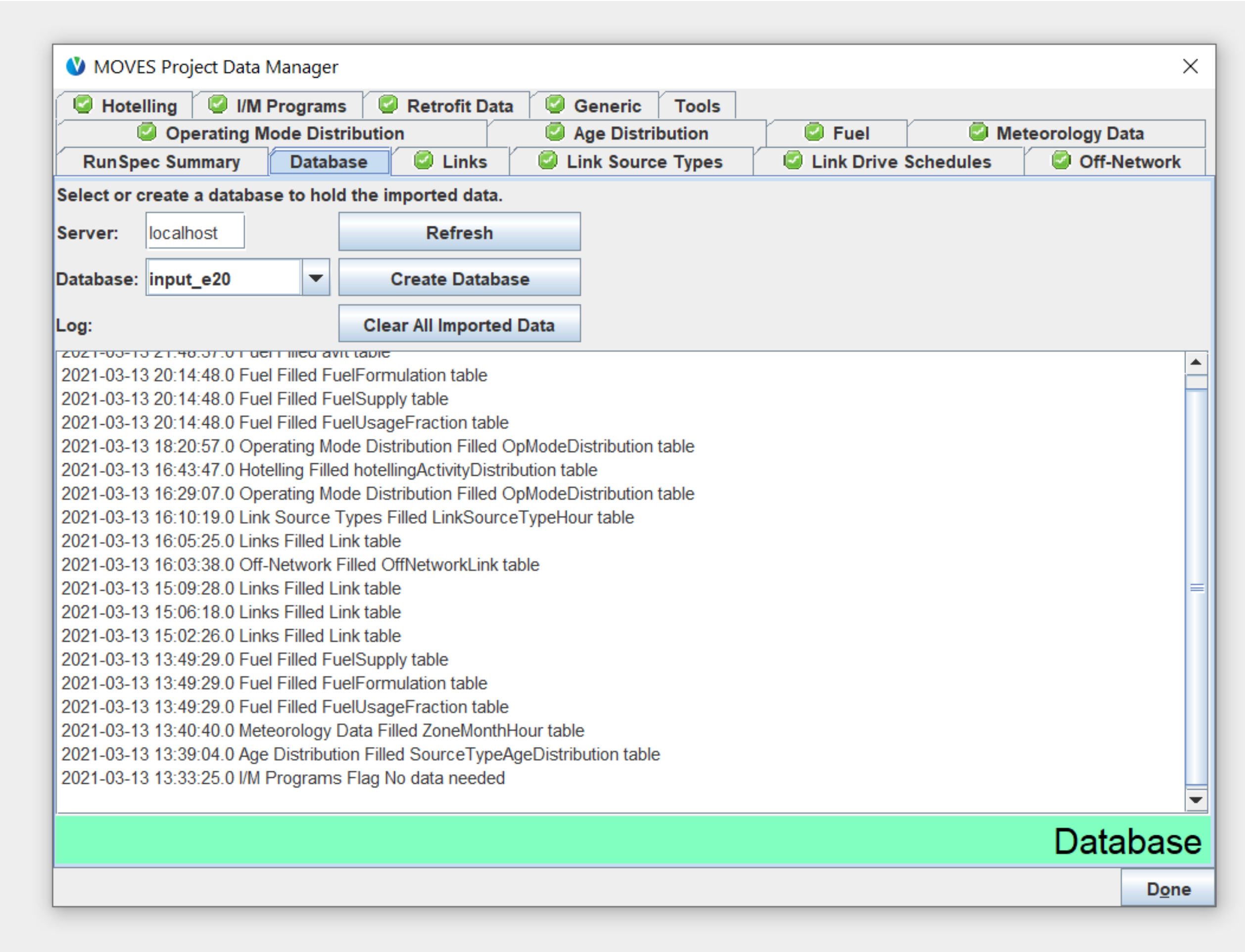


Figure 3.39 Project Data Manager

Input Database

Age Distribution: it is very important to make statistics on the age distribution of motor vehicles. If the proportion of old vehicles in the vehicle distribution is relatively high, it will greatly increase motor vehicle emission. First, the total distance of old vehicle is very large, and the motor vehicle emission control system is relatively backward and old, these will induce a large amount of emission pollutants, which seriously affects the atmospheric environment. And also, the production of old motor vehicles did not implement stricter emission standards. The increase in the ratio of old motor vehicles means that new energy sources and new vehicles which with strict emission standard will occupied decrease in the age distribution of vehicles. In MOVES, a typical fleet database includes a 30-year range of vehicle age distribution, obtained through a survey of the age of motor vehicles. We should enter all kinds of vehicle's age distribution in the Excel as an input of emission analysis. The Age distribution of Motorcycle in 2020 is shown in the **Figure 3.40**. In the right, the horizontal axis is the age of vehicles.

sourceTypeID	yearID	ageID	ageFraction
11	2020	0	0.060165771
11	2020	1	0.060286967
11	2020	2	0.059565007
11	2020	3	0.043879748
11	2020	4	0.04129909

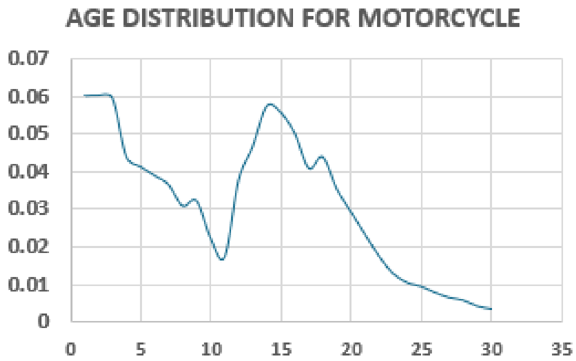


Figure 3.40 Age Distribution

Meteorology Data: when using MOVES for emission analysis, user should enter the local temperature and humidity data. Temperature is an important factor used to estimate the emission of vehicles on the road. The temperature and humidity will affect the engine state and also the battery efficiency, the humidity also will affect the measurement of NOx emission from the vehicles. we entered the relative humidity which is in percentage and this data we considered the average temperature 80 °F (27 °C) of Lapu-Lapu city as shown in **Figure 3.41**.

monthID	zoneID	hourID	temperature(F)	relHumidity
3	150010	13	80	72

Figure 3.41 Meteorology Data of Lapu-Lapu city

Fuel Type: from MOVES default excel, we can know there are some input database need users to enter: Fuel supply data source, Fuel formulation data source, avft database, fuel usage fraction and fuel type engine fraction. Fuel Type is shown in **Figure 3.42**, as we shown in table 3.2, we have 6 kinds of fuel for vehicles. Fuel formulation contains all adjustment factors for different fuel types. It is recommended that the user input the default data from MOVES database[40]. The AVFT table is very important because we can specify the type of the fuel and the type of the engine used by each type of vehicle. In this table, there is a column named **FuelEngFraciton,** this value specifies the percentage of each vehicle using each fuel and engine type combination. For FuelEngFraciton should sum to 1.[40] Also include the percentage of electric vehicle, we can define electric vehicle's percentage in this table as shown in **Figure 3.43**.

	A	B	C	D
1	fuelTypeID	fuelTypeDesc	humidityCorrectionCoeff	fuelDensity
2	1	Gasoline	0.0038	2839
3	2	Diesel Fuel	0.0026	3167
4	3	Compressed Natural Gas	0	0
5	5	Ethanol (E-85)	0.0038	2944
6	9	Electricity	0	0
7				
8				

Figure 3.42 Fuel Type

	index	sourceTypeID	modelYearID	fuelTypeID	engTechID	fuelEngFraction
0	30	11	1990	1	1	1.000000
1	31	11	1991	1	1	1.000000
2	32	11	1992	1	1	1.000000
3	33	11	1993	1	1	1.000000
4	34	11	1994	1	1	1.000000
...	...	...	...	...	...	...
584	1794	51	2019	2	1	0.769069
585	1795	51	2019	3	1	0.230931
586	1796	51	2020	1	1	0.000000
587	1797	51	2020	2	1	0.769069
588	1798	51	2020	3	1	0.230931

Figure 3.43 AVFT Table

I/M Programs: this data import tab allows the user to specify inspection and maintenance management procedures for studying vehicle conditions. Since most project level analyses do not require I/M programs, so we can specify "No I/M programs" in the MOVES interface.

Links, Link Source Types, Operating Mode Distribution

These three tables need the VISSIM output file. We run the microscopic traffic simulation with VISSM and output the data second by second. From VISSIM we have the data about each vehicles type, acceleration (m/s^2), Speed (km/h), vehicle's number, Simulation Second (s), Distance traveled (total) (DISTTRSVTOT)(m), Delay time (Difference between optimal (ideal, theoretical) driving time) (s) as shown in **Figure 3.27**. the output file is in format "*.fzp", as we can see there are more than hundred thousand rows of data in the **Figure 3.44**. We convert the data from VISSIM into data needed by MOVES.

	$VEHICLE:SIMSEC	ACCELERATION	SPEED	VEHTYPE	NO	DISTTRAVTOT	DELAYTM
0	600.1	0.00	0.00	630	280	444.24	78.25
1	600.1	0.00	40.53	630	290	377.42	84.85
2	600.1	0.00	0.00	630	307	451.64	21.02
3	600.1	0.00	0.00	630	309	429.58	46.52
4	600.1	-0.27	62.28	650	317	370.14	87.60
...	...	...	...	...	...	...	...
152349	4199.1	2.57	40.26	100	2634	104.82	0.37
152350	4199.1	0.20	42.96	640	2635	71.59	0.21
152351	4199.1	1.30	49.43	650	2636	16.72	0.41
152352	4199.1	0.88	36.99	100	2637	4.05	0.14
152353	4199.1	0.62	37.03	650	2638	2.05	0.09

152354 rows × 7 columns

Figure 3.44 VISSM Simulation output results

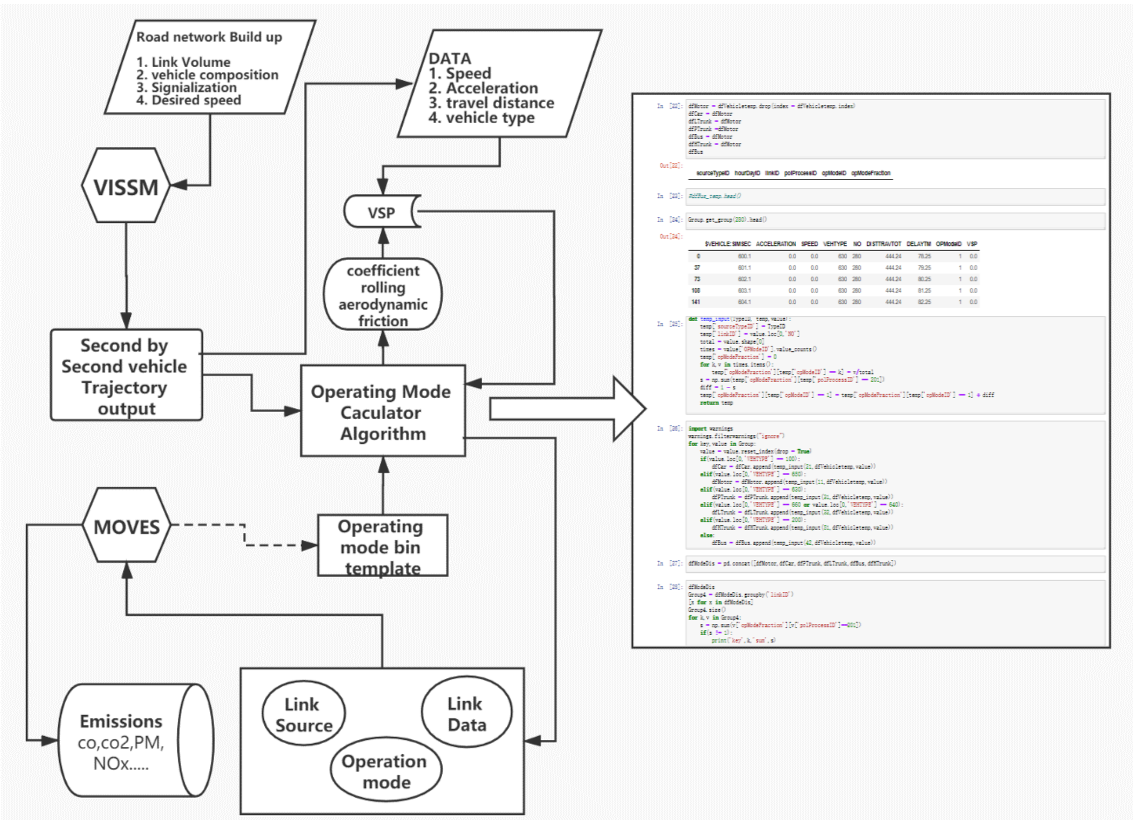


Figure 3.45 Workflow of algorithm

The overall process of the algorithm is demonstrated through the flowchart in **Figure 3.45**. the key input of the emission model of MOVES is Links, Link Source Type and Operation mode Distribution. The Conversion is shown in **Figure 3.46**. The data needed to enter these input files are come from VISSIM output file. Though VISSIM simulation, we can get the vehicle trajectory output (Speed, Acceleration, distance, etc.) second by second. And we can calculate each vehicle's VSP value through each vehicle speed and acceleration. Then through the VSP bins to determine each vehicle OpModelID. The OpModelID is an input data of OP Mode Distribution file. Links and Link Source Type will be established by VISSIM simulation output data. Because the amount of data from VISSIM second by second trajectory which composed of millions of lines as shown in **Figure** 3.42. the main purpose of develop this algorithm is to convert these million data into the file which input the MOVES. The algorithm is developed by an open-source programming language, Python 3 which wrote on the open-source web Jupyter Notebook. The step of the Algorithm is below.

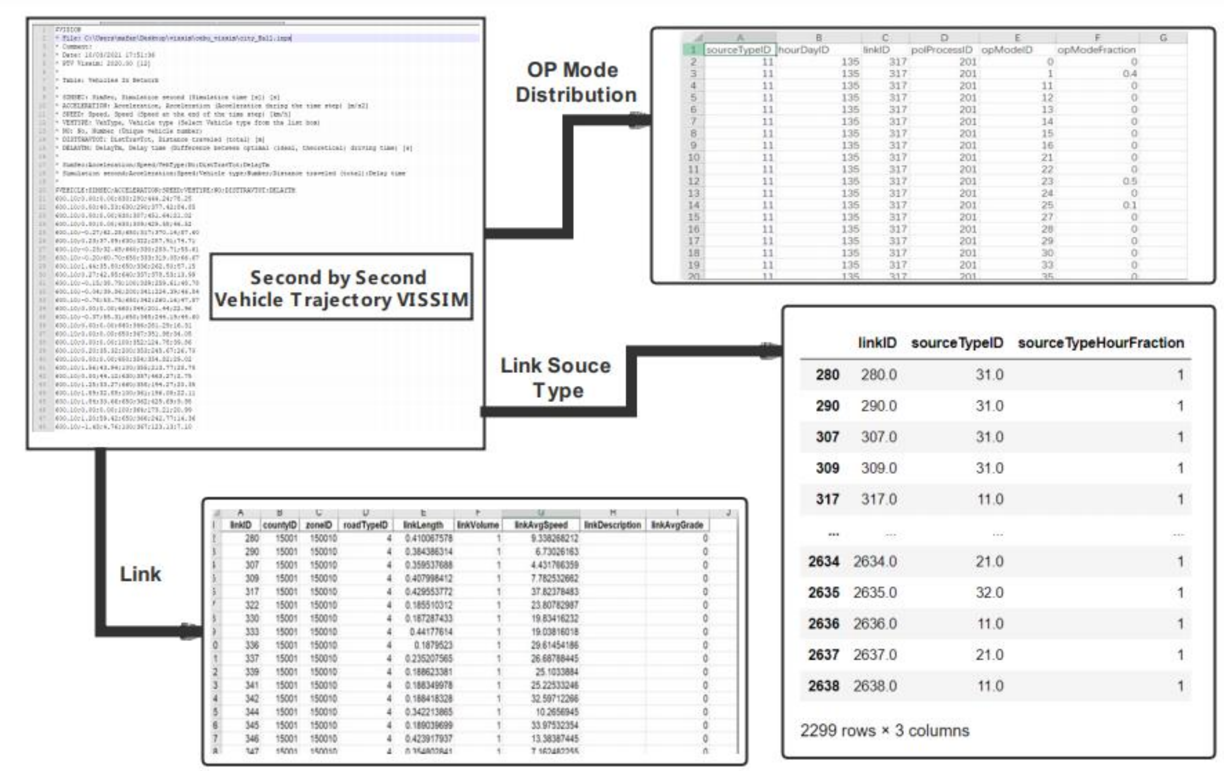


Figure 3.46 Data conversion between VISSIM and Excel

Step 1

Import raw data into Jupyter Notebook and convert it to a data frame through pandas. Import pandas as pd. And change the unit to fit the format of MOVES.

df = pd. read_excel('city_hall.xlsx')

Step 2

Define a function get_vsp to calculate VSP, each kind of vehicle has it own VSP Function.

If vehicle = car, truck, bus, motorcycle, etc.

Calculate VSP for each of them by formula 3.2, 3.3, 3.4, 3.5.

Step 3

Group the df by NO. vehicle (as a link in MOVES) save into a dictionary named Group, iterate over the dictionary, and extract the attributes from df of step 1, create LINK DATABASE.

Group = df. groupby("NO") [x for x in Group]

for vehicleNo(key), value in Group:

'linkID' = vehicleNo

'linkLength' = np.max

'linkAvgSpeed' = np. mean

'linkVolume' = 1

Step 4

Iterate over the dictionary Group and extract the attributes from df of step 1, create LINK_SOURCE DATABASE.

for vehicleNo(key), value in Group:

'linkID' = vehicleNo

'sourceTypeHourFraction' = 1

Step 5

Define a function get_opModelID to determine each vehicle operation mode ID, through the VSP value, acceleration, and speed to determine the OpModelID.

```
if(array['ACCELERATION'] <= -2):
      return OpModelID = 0
   elif(array['SPEED'] < 1):
      return OpModelID = 1
   elif(array['SPEED'] < 25):
      if(array['VSP'] <0):
      return OpModelID = 11
```

Step 6

Import the OpMode distribution default database template, and group it by sourceTypeID. Each group as a template 'dfVehicletemp' **to enter the function of the function temp_input.**

GroupOP = OPmode. groupby("sourceTypeID") [x for x in GroupOP] *dfVehicletemp = GroupOP.get_group (motorcycle, car, bus, etc.)*

Step 7

Define the temp_input function to calculate each kind vehicle type's OpModelFraction and create the 'dfVehicletemp' **for each kind of vehicle.**

def temp_input (Vehicle type, dfVehicletemp, value):

'sourceTypeID' = Vehicle type

'linkID' = value.loc[0,'NO']

All column of value: value. shape [0]

Define the number of occurrences of each kind of OpModelID (times), value_counts output is a dictionary, which key is the OpModelID, value is the number of occurrences of this ID.

times = value['OpModelID'].value_counts ()

for key, value in times. Items ():

'opModeFraction' = value / All column of value

Step 8

Create each kind of vehicle 'dfVehicletemp **'database.**

if(value.loc[0,'VEHTYPE'] == passenger car):

dfCar = dfCar.append(temp_input (vehicleNo of car, dfVehicletemp, value))

elif(value.loc[0,'VEHTYPE'] == motorcycle):

dfMotorcycle==dfMotorcycle. append (temp_input (vehicleNo of motorcycle, dfVehicletemp, value))

the same for trunk, bus, etc.

Step 9

Combine all the vehicle's operation mode distribution and create the OPERATION MODE DISTRIBUTION DATABASE as input file of MOVES.

OpMode Distribution = pd. concat ([dfMotorcycle, dfCar, dfPTrunk, dfLTrunk, dfBus, dfHTrunk])

Link: in the tables of Link, the user can indicate different parameters related to the project scale related to each road in the research network. In the project scale, we should specify a row of data in this tab for each link being analyzed in the network. In our case we consider each vehicle's trajectory as a link and so each link contains only one vehicle. This method we can calculate the emission of every single vehicle and sum them up the whole emission. So, the linkVolume is equal 1for each row. This method is accuracy to each road, we can get a much more accuracy result, but it is computationally expensive. LinkID is the identifier integer specified by the user. This value does not directly change the calculation of MOVES but help users to identify the output result. Link Length is the length of the link in miles. We get the values of LinkLength from VISSM's

DISTTRAVTOT and change the data's unit. linkAvgSpeed is the average speed (or speed limit) of all vehicles on each specific link. We record each road speed in the VISSIM, the value of linkAvgSpeed is equal to the VISSM's SPEED as shown in **Figure 3.47**.

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
280	15001	150010	4	0.410067578	1	9.338268212		0
290	15001	150010	4	0.384386314	1	6.73026163		0
307	15001	150010	4	0.359537688	1	4.431766359		0
309	15001	150010	4	0.407998412	1	7.782532662		0
317	15001	150010	4	0.429553772	1	37.82378483		0
322	15001	150010	4	0.185510312	1	23.80782987		0
330	15001	150010	4	0.187287433	1	19.83416232		0
333	15001	150010	4	0.44177614	1	19.03816018		0
336	15001	150010	4	0.1879523	1	29.61454186		0
337	15001	150010	4	0.235207565	1	26.68788445		0
339	15001	150010	4	0.188623381	1	25.1033884		0
341	15001	150010	4	0.188349978	1	25.22533246		0
342	15001	150010	4	0.188418328	1	32.59712266		0
344	15001	150010	4	0.342213865	1	10.2656945		0
345	15001	150010	4	0.189039699	1	33.97532354		0
346	15001	150010	4	0.423917937	1	13.38387445		0
347	15001	150010	4	0.354802841	1	7.162482255		0

Figure 3.47 Link database

Link Source Type: Link Source type specify the percentage of vehicle type's occupying each link in this table. LinkID does not affect calculations directly. sourceTypeID is an integer represent the vehicle type which has shown in Table 3.1. for every link and source type combination, sourceTypeHourFraction must sum to 1. In this file we specified each links vehicle type, since we considered each vehicle as a link, the source type of each link is only one, through this file and the previous file, the simulator MOVES can understand how many vehicles and the type of the vehicles in one hour. The final excel of Link Source is shown in **Figure 3.48**.

	linkID	sourceTypeID	sourceTypeHourFraction
280	280.0	31.0	1
290	290.0	31.0	1
307	307.0	31.0	1
309	309.0	31.0	1
317	317.0	11.0	1
...	...	...	...
2634	2634.0	21.0	1
2635	2635.0	32.0	1
2636	2636.0	11.0	1
2637	2637.0	21.0	1
2638	2638.0	11.0	1

2299 rows × 3 columns

Figure 3.48 Link Source Type

Operation mode: MOVES calculate emission based on the operation mode distribution file. The user should specify vehicle behavior and the activity every second followed by a function of VSP which has said in the **Chapter -- Vehicle Exhaust Emission Model Based on VSP Distribution.** Due to the fact that our vehicles have different types and sizes, we use the simple formula 3.2 as the VSP function of Car, light truck and Jeepney, the formula 3.3 as the VSP function of HGV, the formula 3.4 as the VSP function of motorcycle and the formula 3.5 as the VSP function of transit bus. Through the output file from VISSIM, we can get the Speed, Acceleration these two parameters of each vehicle, and put these two parameters into the VSP function to calculate each vehicle VSP value. Through the VSP value, speed, and acceleration we can determine each vehicle's OpModelID and input this value into Operation mode distribution table. polProcessID is the pollutant process ID, which defines the emission source or energy use type and that generates those emissions, follow the table 3.3, we can determine the polProcessID. Table 3.3 show all the emission pollutants and process which we will analysis in the MOVES.

Table 3.3

polProcessID	processID	processName	pollutantID	pollutantName
201	1	Running Exhaust	2	Carbon Monoxide (CO)
202	2	Start Exhaust	2	Carbon Monoxide (CO)
290	90	Extended Idle Exhaust	2	Carbon Monoxide (CO)
291	91	Auxiliary Power Exhaust	2	Carbon Monoxide (CO)
301	1	Running Exhaust	3	Oxides of Nitrogen (NOx)
302	2	Start Exhaust	3	Oxides of Nitrogen (NOx)
390	90	Extended Idle Exhaust	3	Oxides of Nitrogen (NOx)
391	91	Auxiliary Power Exhaust	3	Oxides of Nitrogen (NOx)
9090	90	Extended Idle Exhaust	90	Atmospheric CO2
9091	91	Auxiliary Power Exhaust	90	Atmospheric CO2
9101	1	Running Exhaust	91	Total Energy Consumption
9102	2	Start Exhaust	91	Total Energy Consumption
9190	90	Extended Idle Exhaust	91	Total Energy Consumption
9191	91	Auxiliary Power Exhaust	91	Total Energy Consumption
11201	1	Running Exhaust	112	Elemental Carbon
11202	2	Start Exhaust	112	Elemental Carbon
11290	90	Extended Idle Exhaust	112	Elemental Carbon
11291	91	Auxiliary Power Exhaust	112	Elemental Carbon
11590	90	Extended Idle Exhaust	115	Sulfate Particulate

11801	1	Running Exhaust	118	Composite - NonECPM
11802	2	Start Exhaust	118	Composite - NonECPM
11890	90	Extended Idle Exhaust	118	Composite - NonECPM
11891	91	Auxiliary Power Exhaust	118	Composite - NonECPM

OpModeFraction is the fraction of vehicle activity taking place in each operating mode[40]. This integer must sum to 1 for each link's "sourceTypeID – polProcessID" combination. The final operation mode is shown in **Figure 3.49**.

	A	B	C	D	E	F	G
1	sourceTypeID	hourDayID	linkID	polProcessID	opModeID	opModeFraction	
2	11	135	317	201	0	0	
3	11	135	317	201	1	0.4	
4	11	135	317	201	11	0	
5	11	135	317	201	12	0	
6	11	135	317	201	13	0	
7	11	135	317	201	14	0	
8	11	135	317	201	15	0	
9	11	135	317	201	16	0	
10	11	135	317	201	21	0	
11	11	135	317	201	22	0	
12	11	135	317	201	23	0.5	
13	11	135	317	201	24	0	
14	11	135	317	201	25	0.1	
15	11	135	317	201	27	0	
16	11	135	317	201	28	0	
17	11	135	317	201	29	0	
18	11	135	317	201	30	0	
19	11	135	317	201	33	0	
20	11	135	317	201	35	0	

Figure 3.49 Operation Mode Distribution

Emission Analysis Result Analysis

As said before, a VISSIM-MOVES integrated framework is developed to calculate the accurate emission of each vehicle passing through the area of Lapu-Lapu city for one hour time in simulation. we have already got all the database for the emission analysis by MOVES. We change the electric vehicle percentage to observe how the electric vehicle effect the emission. The major pollutants have been studied is CO, CO_2, NOx and PM and total energy. We have considered 6 situations for emission analysis which are the actual situation, 20% electric vehicle, 40% electric vehicle, 60% electric vehicle, 80% electric vehicle and 100% electric vehicle of Lapu-Lapu city hall. With the VISSIM output file and the MOVES result we can get the vehicle distribution in Lapu-Lapu city hall which is shown in table 3.4. there are more than 2000 vehicles involved during this simulation. From the table, we can know the greatest number of vehicles in Lapu-Lapu city hall area is Motorcycle. It can be found that the local people prefer to choose the micro transportation such as motorcycles to travel. Because there is no clear boundary between electric motorcycle and electric bicycle, the MOVES did not provide electric model of motorcycle therefore, we only increase the percentage of electric car, electric pick-up, electric Jeepney, electric HGV and electric bus. But in the table 3.4, Motorcycle occupied a large partial. If instead all the traditional motorcycle into electric micro mobilities will significantly reduce pollution in Lapu-Lapu.

Table3.4

Type	Number	Percentage
Motorcycle	937	41%
Car	669	29%
Pick-up	385	17%
Jeepney	248	11%
HGV	38	2%
BUS	22	1%

The Table 3.5 shows the energy and emission analysis of currently situation in Lapu-Lapu city hall. In the table shows each kind of vehicle's total travel distance in the simulation, the total energy consumption, the emission production of CO_2 and the percentage of CO_2 produced by each type of vehicle to the total CO_2 amount. Because there are no experiment pollution data for Jeepney, we classified it as the passenger truck. (In the actual situation, jeepney's emission data should be larger than the passenger truck because its average age is elder and due to no certain stations, drivers of Jeepney always stop and go in the middle of streets). From the **Figure 3.50**, we can realize that if the travel distance of motorcycle is higher than passenger car, the total energy is lower due to the motorcycle has a lower weight compared with passenger car. Overall, as we can see, motorcycles and passenger's cars consume the most energy and they cause a significant increase in CO_2 emissions.

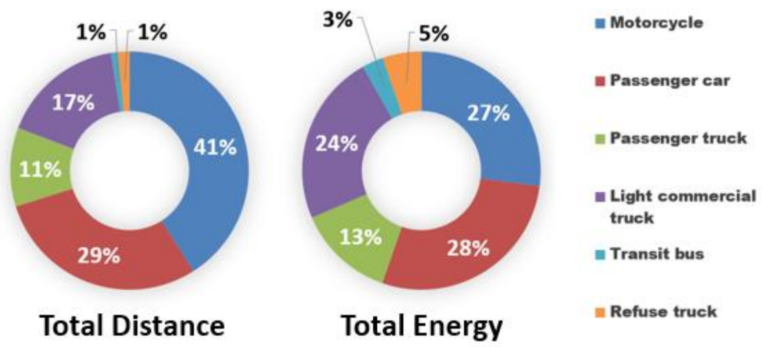


Figure 3.50 Total Distance VS Total Energy

Table3.5

Type	Distance [Km]	Total Energy [KJ]	CO_2[g]	CO_2 Percentage
Motorcycle	344.4	1239272.32	89062	0.27
Passenger car	244.6	1291159.482	90940	0.28
Passenger truck	90.1	603272.37	42634	0.13
Light commercial truck	140	1066856.112	75541	0.23
Transit bus	8	131944.138	9507	0.03
Refuse truck	12.9	240759.359	17428	0.05

In the **Figure 3.51**, it represents that under different percentage of electric vehicles (Actual, 20%, 40%, 60%, 80%, 100%), the emissions of CO_2, CO, NOx, and total energy. From the comparison of the different percentage of electric vehicles, all the emission is decreased significantly as the electric vehicle increased. The vertical axis of diagram (CO_2, NOx, CO) is the amount of the emission production which unit is g. From the result we can know, as the electric vehicles increase, lead to a significant reduction in the emission of CO_2 compared to other pollutants. And a little bit reduces for the total energy consumption. Therefore, extensive use of electric vehicles can significantly improve air pollution and reduce CO_2 emission thereby reducing the greenhouse effect in Lapu-Lapu.

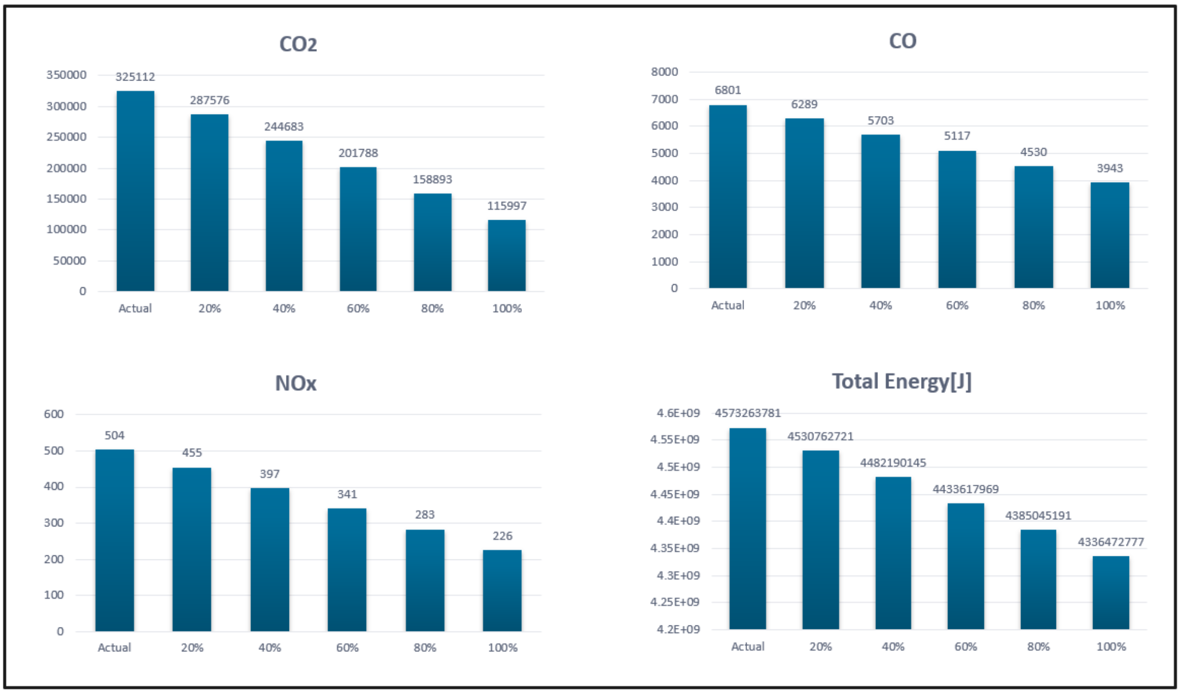


Figure 3.51 Emission Comparison

Table3.6

Source	Fuel	CO2	CO	Nox	TotalEnergy[J]	Distance[KM]
Motorcycle	Gasoline	89062	3836	98	1239272320	344.4
Passenger car	Electric	0	0	0	1286224384	244.6
Passenger truck	Electric	0	0	0	554149184	90.1
Light commercial truck	Electric	0	0	0	884123392	141.6
Transit bus	Gasoline	1090	5	0	15164326	1.6
Transit bus	Diesel	7671	20	32	104138624	6.4
Transit bus	Compressed Natural Gas	746	13	2	12641188	0.0
Refuse truck	Gasoline	159	7	1	2208637	0.0
Refuse truck	Diesel	16047	42	92	217853600	11.3
Refuse truck	Compressed Natural Gas	1222	20	1	20697122	1.6

In the Table 3.6 is the 100% percentage electric vehicle's emission simulation. we can observe that the main pollution comes from the motorcycles. If instead the motorcycle into the shared micro-mobility will significantly reduce the energy consumption and emission. From this table, we observed MOVES treated all the emission of electric vehicle equal to zero. It is true for the driving phase, electric vehicles do not emit exhaust gas and they will not pollute the air, the emission is zero around the road. Also, electric vehicle's motor is completely stationary when parking, avoiding unnecessary energy consumption, carbon emission, and recover kinetic energy to recharge the battery when braking and downhill. But in the reality condition, the emissions of electric vehicle cannot equal to zero as shown in **Figure 3.52**. Also consider the real situation in Lapu-Lapu, the benefit from electric vehicle is overestimated, since the percentage of usage of renewable energy is still lower than the usage of fossil energy.

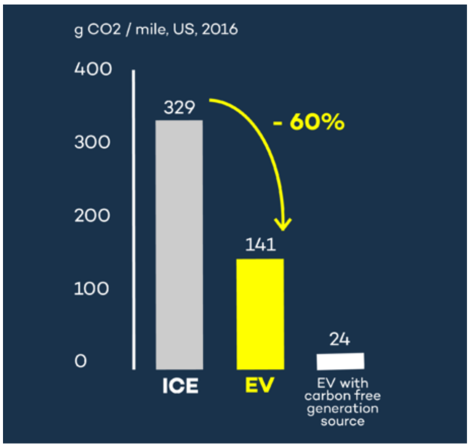


Figure 3.52 Emission between ICE and EV[75]

Because we should consider the emission about the energy source of the electric vehicle and electric vehicle production. During the battery production and power generation phases will produce emission and pollutants. The production process of an average electric vehicle results 15% more emission than a production of a gasoline car. [76]The emission from electric vehicle production depends on battery production and recycling technology. The batteries of electric vehicles are larger and heavier than ordinary fossil fuel vehicles and consist of hundreds of individual lithium - ion batteries, all of which need to be disassembled for recycling. They contain dangerous substances: lead, arsenic, cadmium, mercury, chromium, etc. and if they are disassembled improperly, they tend to explode Also, in the metal material processing in the battery production process will be released into dust and water and cause pollution. On the other hand, the emission also depends on the energy generate source. The pollution of electric vehicle is highly depending on the use percentage of renewable source, as **Figure 3.27** shows that if charge energy comes from renewable energy source, it will be zero pollution.

3.4.5 Energy Analysis for electric transportation

Electric transportation in Lapu-Lapu city

From the emission analysis by MOVES, the locals prefer choose motorcycle (more flexible micro transportation) as travel transportation and increase the use of electric vehicle will significantly reduce the emissions. When passenger exit from the come to airport or handle affairs in city hall, the choice of transportation can be electric transportation to reduce the emission and decongestion. The type of electric transportation can be selected ae electric public transportation (E-Jeepney), electric passenger car, shared-electric micro-mobility (Scooter and Electric bike). In the **3.4.2 Emission due to Electric Vehicles,** we have introduced that change all the ICE passenger car into electric passenger car will rapidly decrease the emission and save the energy. **E-Jeepney (electric Jeepney): Figure 3.53** shows the E-Jeepney. there are currently about 3 million jeepneys in the Philippines which a main public transportation in Lapu-Lapu. The promotion of E-Jeepney will undoubtedly greatly reduce the pollution of public transportation. The QEV Philippines is the Electromobility ecosystems company will be converting jeepneys with ICE into electric vehicles. The conversion to be done in partnership with local manufacturers, can be done in just two hours[77]. The PUVMP (PUV Modernization Program) aims to employ around 200,000 e-jeepney or EURO-4 jeepney (or better) in the next six years.[78] QEV will set up the first charging station network in the country for electric vehicles. The charging station will have fast chargers that can charge lithium-ion batteries for 15 minutes. This will enable the E-Jeepney to run for 100 to 140 kilometers.[77] **Electric micro-mobility:** micro-mobility refers to a range of small, lightweight vehicles operating at speeds typically below 25 km/h which contains e-bike, e-scooter and so on. obviously, there are many benefits of electric micro -mobility, Both in terms of the positive impact on congestion level and air pollution. Even if the e-scooters' batteries are powered by a grid that relies on fossil fuels, the emission from the electricity generation is negligible. Also, e-bike and e-scooter size are small, and light weight which can be easily drive around the narrow street which it very fit for the narrow streets of Lapu-Lapu. Due to the large size of passenger car, there are some places which passenger car cannot arrive, but micro-mobility can arrive. Micro-mobility can be easily placed in the designated location of the community, without occupying parking spaces and excessive public space.

Figure 3.53 Jeep to E-Jeep

Table 3.7

attributes	***E-Vehicle***	***E-Bike***	***E-Scooter***	***E-Jeepney***
Autonomy	320 km	30 km	30 km	120 km
Battery Capacity	42 kwh	0.576 kwh	0.335 kwh	7.5 kwh
Area Occupation	6.09 m^2	1.04 m^2	0.46 m^2	10.4 m^2
Carrying capacity	3	1	1	14-20
Energy Consumption (kwh/km/person)	0.043	0.019	0.011	0.0045

We collected each kind of electric transportation technology data and fill in the table3.7. We compare these kinds of electric transportation in three aspects: autonomy, carrying capacity and energy consumption as shown in **Figure 3.54**. through the comparison, we realize that electric passenger vehicle has a high autonomy, good carrying capacity and flexible characteristics but the energy consumption is higher. For the electric micro-mobility (electric bike and electric scooter), the energy consumption is less, flexible but low carrying capacity and less autonomy. For the E-public transportation (E-Jeepney), the energy consumption is less, the carry capacity is good, and autonomy is high, but which is very inflexible, because the e-jeepney does not has a certain station and some places cannot reach. Through the comparison, each kind of transportation has its own advantage and disadvantage. If the travel distance is shorter, passenger can choose micro-mobility as travel transportation, if passengers are near the public transportation station, the prefer travel method is electric public transportation, if the travel distance is long and cannot find stations the best travel method is electric vehicle. Through effective use of different electric transportation to provide Lapu-Lapu with a convenient, energy saving and environmentally transportation plan.

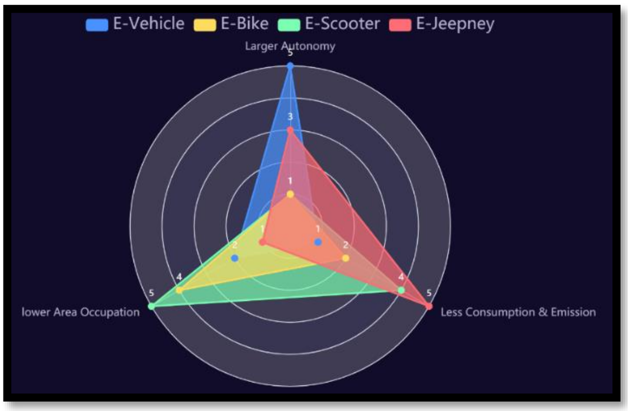


Figure 3.54 E-Transportation Comparison

Energy Analysis of Mobility Hub

Our Mobility hub is located at the city hall of Lapu-Lapu city. Around this area, there are so many service offices and places such as the Police office, Hall of Justice, Gaisano Mall and so on. Many people come to this area to handle affairs. Also, we established the walkway between MICA airport and City Hall, the entry and exit port Walkway towards Airport makes this area become a transit point (between walk and other transportation methods).

The mobility hub is composed by smart parking hubs, shared-electric micro-mobility hub, and walkway exits and entry ports.

We concluded that using electric vehicle and using the renewable energy source will significantly optimize the environment and reduce emission in Lapu-Lapu city. The Philippine's government also established a RE (renewable energy) installed capacity target. They amended solar energy installation target from 50MW to 500MW. Philippines government strongly supports the use of solar energy. Therefore, for the Lapu-Lapu city we choose the solar energy as the energy source of electric vehicles. we installed the solar panel in the top of the moving walkway, the roof of smart parking hub and the top of the micro-mobility hub. From civil building field, Daniele has provided the energy analysis and spatial analysis of Solar Panels: there is enough space to install 2650 solar panels as the energy source of parking area, micro-mobility area and walkway. The total energy that can be provided is 850000W as shown in table 3.8. From the table 3.6 when there are 100% of electric vehicle the total energy for one hour is $2.72*10^9$ (1286224384 + 554149184 + 884123392) which the solar panel can provide enough energy to 100% electric vehicles in one hour.

Table3.8

Solar Panel Model	Number	Power [W]	Total Power [W]	Total Energy/h [J]
A-320P GSE	2650	320w	850000w	$3.06*10^9$

Before we have compared the mobility and consumption of the transportation method, in the table 3.9 show each electric transportation energy request.

Table 3.9

Type	Time to Charge	Charge Power
Electric Vehicle	3h45m	7400w
Electric Scooter	4h43m	71w
Electric Bike	3h45m	150w
Electric Jeepney	15min	30000w

The micro-mobility hub will include 40 electric bikes and 30 electric bicycles, and the parking area will include 34 electric vehicle slots and 4 electric Jeepneys. All these electric transportation's energy source comes from the 2650 solar panels. In the Table 3.10, through the charge power of each kind of electric transportation for Table 3.9, the total needed power for each kinds of transportation are shown. And after calculating all electric vehicles need power, the total needed power is 424130w, the total solar panel can provide 850000w which is sufficiently enough provide electric energy to all electric transportation in mobility hub. In Philippine, the full sunshine duration is 4-5 hours, during the day, the power generated by the solar panels exceeds the power required by the mobile hub, but at night, the energy from the solar is not enough. Therefore, the solar panel should connect with the grid, the grid will distribute the energy which generated by solar panel. The gird distributes the residual energy to some useful field such as the surrounding area of walkway and residential usage and so on.

Table 3.10

	E-Vehicle	E-Bike	E-scooter	E-Jeepney	Total	Residual
Needed Power	251600w	6000w	2130w	120000w	424130w	423870w

Since if we charge full of micro-mobility battery will spend hours which takes a long time. due to the usage of electric micro mobility much more higher during the day, therefore the charging time for electric micro mobility is in the evening, but in the evening also the peak hours of electricity consumption for residential usage. So, we can use the battery swapping technology for the micro-mobility hub which will reduce the pressure on the urban power grid. The swapping battery station charge the battery whole day. when the battery of your micro-mobility is low or empty, just take the battery from the micro-mobility and take the full charge battery from battery swapping station. The switch battery process only takes one minute which is very flexible and efficiency as shown in **Figure 3.55**.

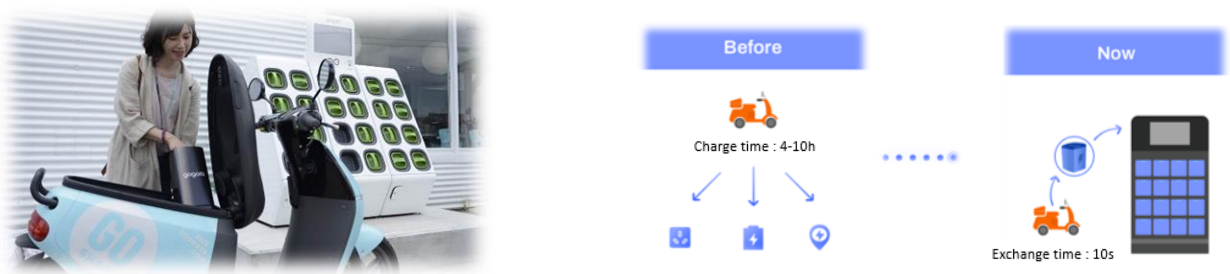


Figure 3.55 Battery Swapping Station

3.5 Digital twin Management system

As said before, the mobility hub which contains smart parking area, micro-mobility hub and the exit and entry port of walkway towards airport is built in the Lapu-Lapu city hall. Firstly, there are many public services which induce many people stay here to handle affairs. Secondly, the walkway is directly connecting the MCIA airport, make the area become a transit point between walk and other transportation. Thirdly, the smart parking area and public transportation services make people come for service here. All these factors make this position important; it will induce larger flow of people and traffic flow. And in this area contains many kinds of transportation services which we established before, thus, make this area traffic complex and easier induce safety problem. In this chapter, we developed a data visualization management system based on the digital twin technology to improve the mobility of this area, prevent people gathering, real-time monitoring and controlling the mobility hub. The digital city provides a 3D visualized mirror model of the physical city which through the combination of data and 3D model, realize to visualize the data of the energy state, traffic flow, building information and passenger flow in the virtual 3D city model to control and monitor the physical city. The 3D visualization makes the simulation more realistic, and users can obtain an immersive interactive experience in the city through this system. In the **Figure 3.56** shows the relationship between digital and real city and the data visualization system.

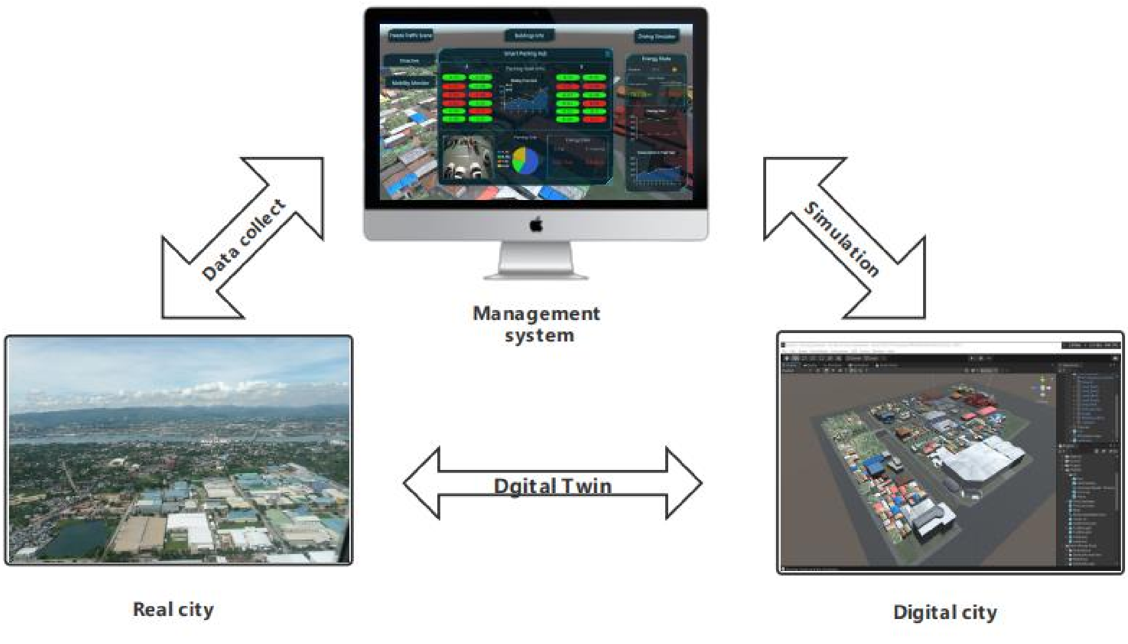


Figure 3.56 relationship between real-digital city and management system

3D city model which developed by the 3dsMAX and CityEngine, the combination data and 3D model base on the platform Unity3D. At the same time, combined with UGUI design of Unity3D, the visualization of the data (energy state, traffic, building information, mobility hub information) is realized which is convenient for manager to obtain accurate information of the data while using this system. The interactive design realize operational interaction between the manager and the virtual 3D city model, enhances the user experience and provides the basis of the development of VR. The language used by the digital twin management system established is C#. The relationship between 3dMAX, Unity3D and C# is shown in the **Figure 3.57**.

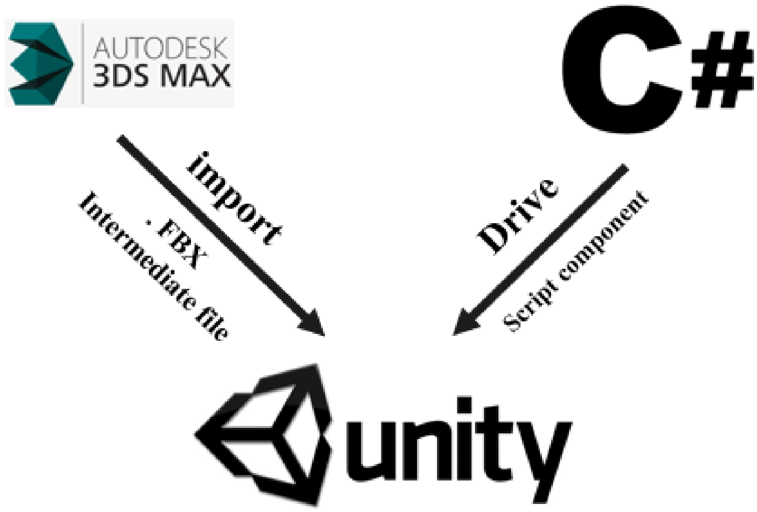


Figure 3.57 The relationship between develop platforms

3.5.1 Software Platform introduction

Unity 3D

Unity3D is a game engine developed by Unity Technologies.[79] It is a convenient and easy-to-use interactive graphical comprehensive game development tool. We can use it to create our own three-dimensional computer games, visualized architecture roaming, and real-time interactive three-dimensional animation production. The game engine supports a variety of system platforms. The works it develops can not only run-on computer platforms such as PC and MAC, but also run-on mobile device platforms such as Android and IOS and can also be directly published to the web to run. The game engine also has very good compatibility with commonly used 3D modeling software such as 3ds Max, Maya, etc. Unity has a powerful physics engine, which gives objects collision volume, and can trigger corresponding events through collisions. At the same time, Unity 3D has a good editing interface and can realize dynamic game previews; the actions of these models are controlled through scripting. Unity3D supports C# and JavaScript scripts, and comes with its own script editor MonoDevelop. During the operation of the system, the user can observe the entire system in all directions by moving the pre-arranged lens to achieve the effect of virtual roaming. In summary, this thesis uses Unity3D physics engine as the visualization development platform. Unity3D can support almost all file formats and can work with many related applications. The vast and complex scenes can also run smoothly on low-end hardware. Its built-in NVIDIA and PhysX physics engines can also run smoothly and give user interactive feeling. The Unity3D engine has the advantages of high technology, advanced rendering capabilities and support for user customization in the development process, which is far higher than other engines, and it is very suitable for the needs of interactive access and realistic performance of virtual roaming display.[80] Unity3D are undoubtedly help for virtual reality technology at present. And a great role promoting its development.

Unity3D Development Interface

In the **Figure 3.58** shows the interface of Unity 3D, **Project** mainly stores all resource files in the game. You can operate files in the project folder or in the Project panel. If you operate in the project folder, the project panel will automatically update the displayed content. **Scene** mainly to construct the game scene, such as adjusting the position and angle of the camera, the position and angle of each game object (GameObject), etc. **Hierarchy** mainly stores the game objects which stored in the game scene and displays their parent-child relationship. In UGUI the order of the objects will also affect the image rendering order. **Game** displays the things in the main camera's field of vision. After the game is running, the player will see the same as the game panel, which can be considered as the place where the game effect is finally displayed. **Inspector** mainly displays resource information. When you click on a game object in the hierarchy panel or a file in the project panel. The Inspector will display the component information which it contains, and you can check and modify information during the development.

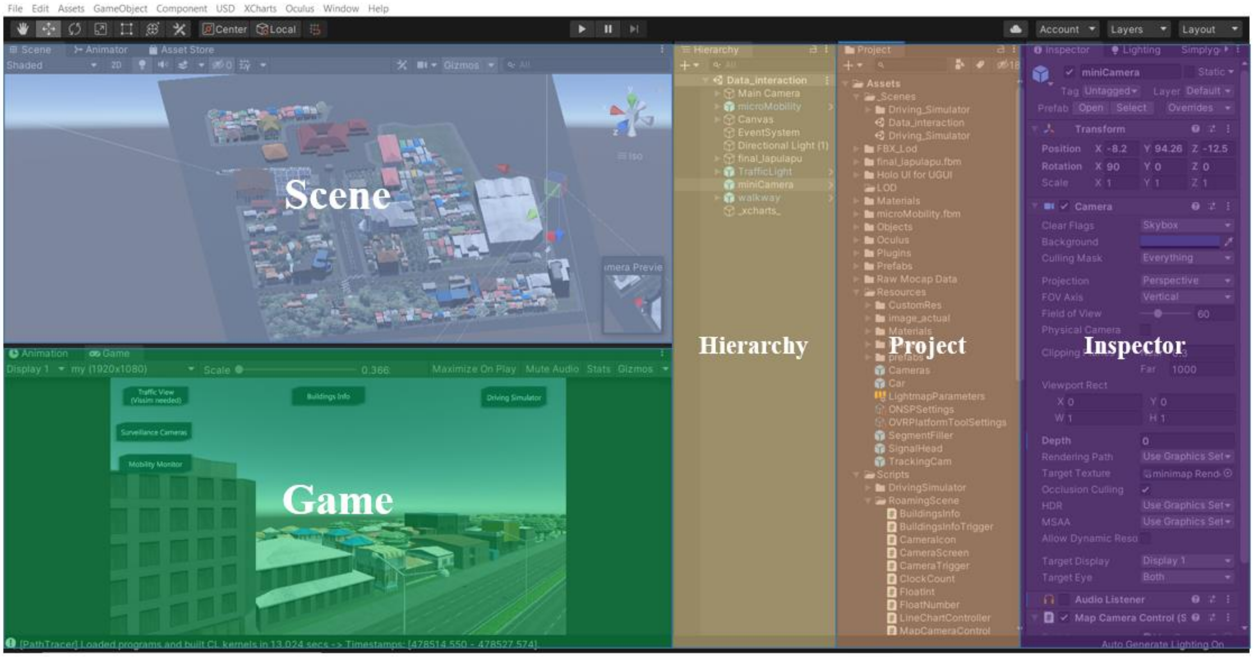


Figure 3.58 Unity3D Interface

Unity3D framework

Unity3D contains many subsystems and framework elements, such as sound system, light system, and terrain system. The framework can be roughly divided into 4 layers: **Application** contains some encapsulated function, such as collider, Rigidbody, Skybox, etc. these components can be used directly without development. User can adject the parameters of these components, such as shape and size of the collision body, the quality of the rigid body, the picture of the skybox, etc. to achieve the desired effect. **GameObject** includes all things in the game, it can be an actual object such as a character model, a building model, also can be an empty object used to trigger or respond to certain events. User can add various attributes (components, texture, loading models) to GameObject which will achieve the purpose of user. **Components** is some common functions that come with unity. The components can be some application such as collider, Rigidbody and script. A script is a code file written by the user to control and define the certain specific needs of GameObject. It is the key to the game has its own characteristics. Because Unity3D's built-in components can only complete some basic operations, more complex and characteristic functions need to be implemented by developers themselves. The user makes the object work by adding the Component to the target GameObject. **Scene** is the game world built by the user. The scene is composed of each GameObject and the Component which added to each GameObject. It can be considered that the game is switched and generated between different scenes. When editing the scene in Unity, you should carefully consider the number, size, and style of the objects in the scene according to requirements to make corresponding adjustments. Too much content will slow down the efficiency of the game when it is loaded.

3dsMAX

The full name of 3ds Max is 3D Studio Max, which is a PC system-based 3D animation rendering and production software developed by Discreet (later merged by Autodesk). A wide range of applications, good scalability, professional software that works well with other related software, especially in terms of simplification of operations, 3ds Max continues to simplify operations, allowing users to achieve some complex rendering effects through simple steps. 3ds Max is widely used in industrial product design, advertising, film and television animation, environmental art design, multimedia, Sports production, games, virtual reality, cultural heritage protection, engineering visualization and many other fields. [82] 3ds Max has different application characteristics in different industries, and its corresponding application modules are also different. For example, the relatively mature environmental art design developed is inseparable from the application of 3ds Max. To show the effect of interior decoration design, you can make an interior model through 3ds Max software, assign materials, and add rendering effects and environmental effects. The 3d model file format supported by 3ds Max. FBX is a universal intermediate format, which can realize the direct import of the model from the 3d Max software to the Unity software for development. The .FBX file format includes the description of the model data and the description of the material file, And various data collections.

C#

C# language is a programming language made by Microsoft for .NET. C# is developed from C and C++, and C# has four characteristics: easy to use, modern, object-oriented, and type safe. The original intention of designing this language was to combine the ability of Visual Basic to develop applications at a high speed and the powerful functions of C++. For this reason, the appearance and operation of C# code are highly like high-level languages such as C++ and java. The type of C# is the type of .NET. C# itself does not have a class library, and it uses the class library provided by the .NET framework. In addition, the type of safety check and structured exception handling are also handed over to the CLR for processing. C# is the most suitable for the development of .NET application. Data types in C# can be divided into value types and reference types as shown in **Figure 3.59**. Value types include enumeration types and structure types; reference types include class types, object types, string types, array types, interface types, and proxy types. In the .NET framework environment, when the code is executed, there are two places in the memory to store these codes which is steak and heap. They reside in the machine’s memory and contain all the information needed for code execution. The stack is responsible for saving the code execution path, and the heap is responsible for the object. Stack space is small but has a fast-reading speed, heap space is large but slow reading speed. Reference types are always in the heap, Value types and pointer are always placed where they are declared.

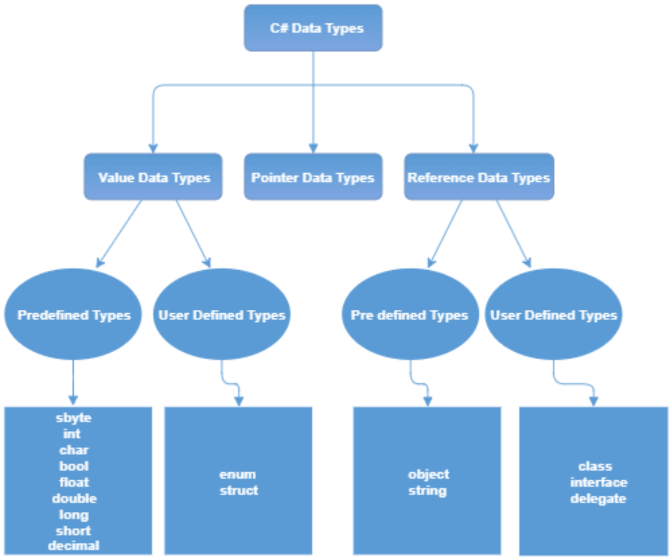


Figure 3.59 Data type of C#

3.5.2 Digital City modelling

The digital city model can be divided into two parts: static models and dynamic models. Our working area which are located around the Lapu-Lapu city hall. Therefore, the static models are composed by the function buildings and residential area, the road network, Mobility Hub, and infrastructures. The dynamic models are the vehicles models which can move in the roads of our city models. For the function buildings such as the Justice of City Hall, Gaisano Mall, City Hall we model them in the 3dsMAX. For the Mobility Hub which is modelled by civil student Daniele by using Revit. And due to our working area is extremely huge which the unity cannot load large number of files (which will make the load speed very slowly), we cannot model each building in detail, therefore we choose the CityEngine as a tool to model the residential building. CityEngine is a software to rapid build 3D models. The current application area includes geographic information urban planning, rail transit, cultural heritage, simulation, game development, etc. The biggest advantage of CityEngine is rapid modelling. At beginning of modelling, it takes a certain amount of time to write the rule file. The established rules can be directly dragged into the scene, then the large-scale mass models of urban 3d Scene can be built up immediately which will save a lot of time and cost. And once the model rules are established, they can be reused. The road establishes needed the collaboration between VISSIM and Unity3D. the road network has established in the VISSIM. And we can open the VISSIM file (*. inpx) into XML configuration file which contains all element data of the road network such as link, link segment, connector) and so on. Through the code C# which read the data of each links and connectors build up the whole road network into Unity 3D. In the unity are the same shape, size, position, orientation as in VISSIM. Then we export the road network as .FBX file and import into 3dsMAX as a basis benchmark for building other models. The dynamic model which is built in the Sketchup and then import into Unity3D to adjust the size and shape. The automotive student Zheyuan mainly modeled the whole city models. In his thesis will introduce the detail workflow of building 3d models.

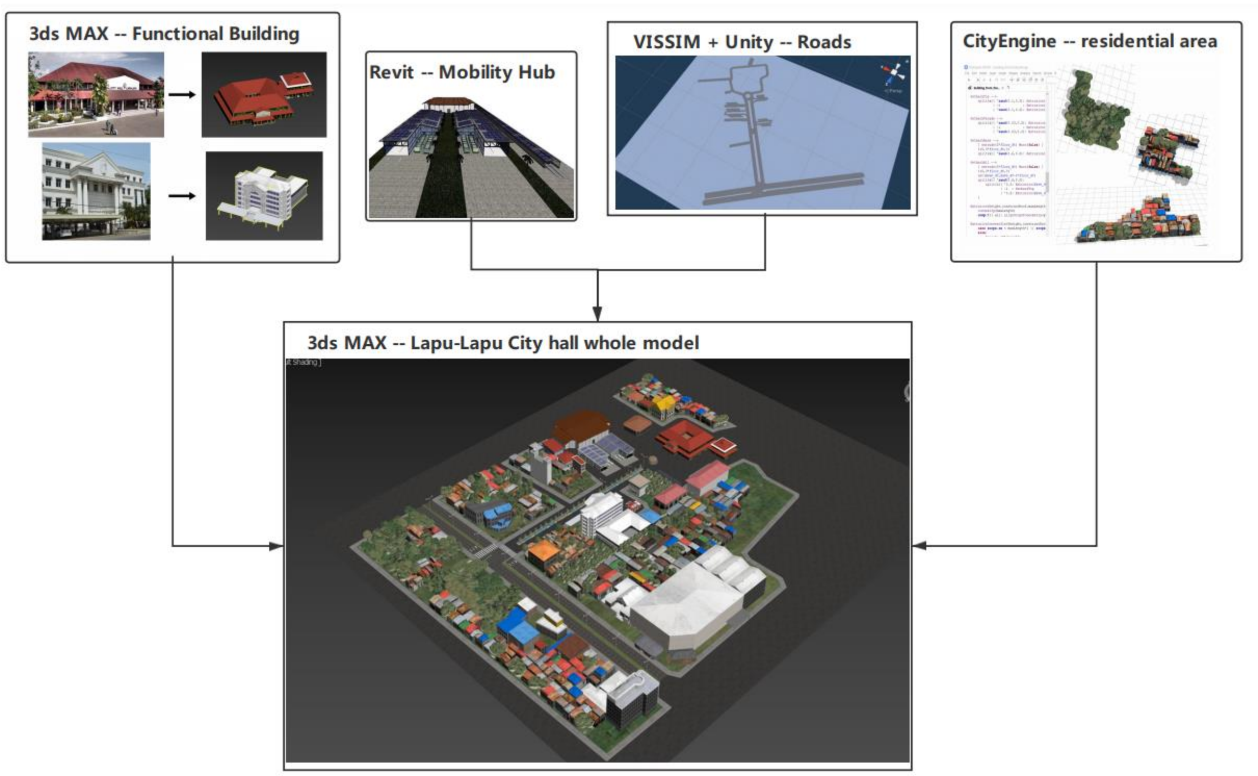


Figure 3.60 Static City models

In the **Figure 3.60** is shown the whole static 3D model of our working area of Lapu-Lapu city. And the construction of the virtual model scene needs to be realized through the Unity3D engine software. In the 3dsMAX exported the created 3D model as Game Exporter (*. FBX) file and import into Unity3D as shown in the **Figure 3.61**. The static 3D model contains the road network, functional buildings, residential area, mobility hub and other important infrastructures. In the Unity, we add the physical attributes to the models in the Unity3D, for example adding collider and Rigidbody to the buildings to allow GameObject has its physic boundary and to be controlled by the physics engine which can prevent the camera and the vehicles goes through the wall. And then convert all the models into Prefab which can be regarded as a description file of the game object in the scene, which can be stored in the Asset folder to facilitate reuse in other scenes. To have an interaction with the city, it is necessary to write the control scripts for each management system functions which will introduce more detail in the next section. The dynamic model – the vehicle models which model in the Sketchup and import to the Unity3D and convert all the vehicle models as prefabs.

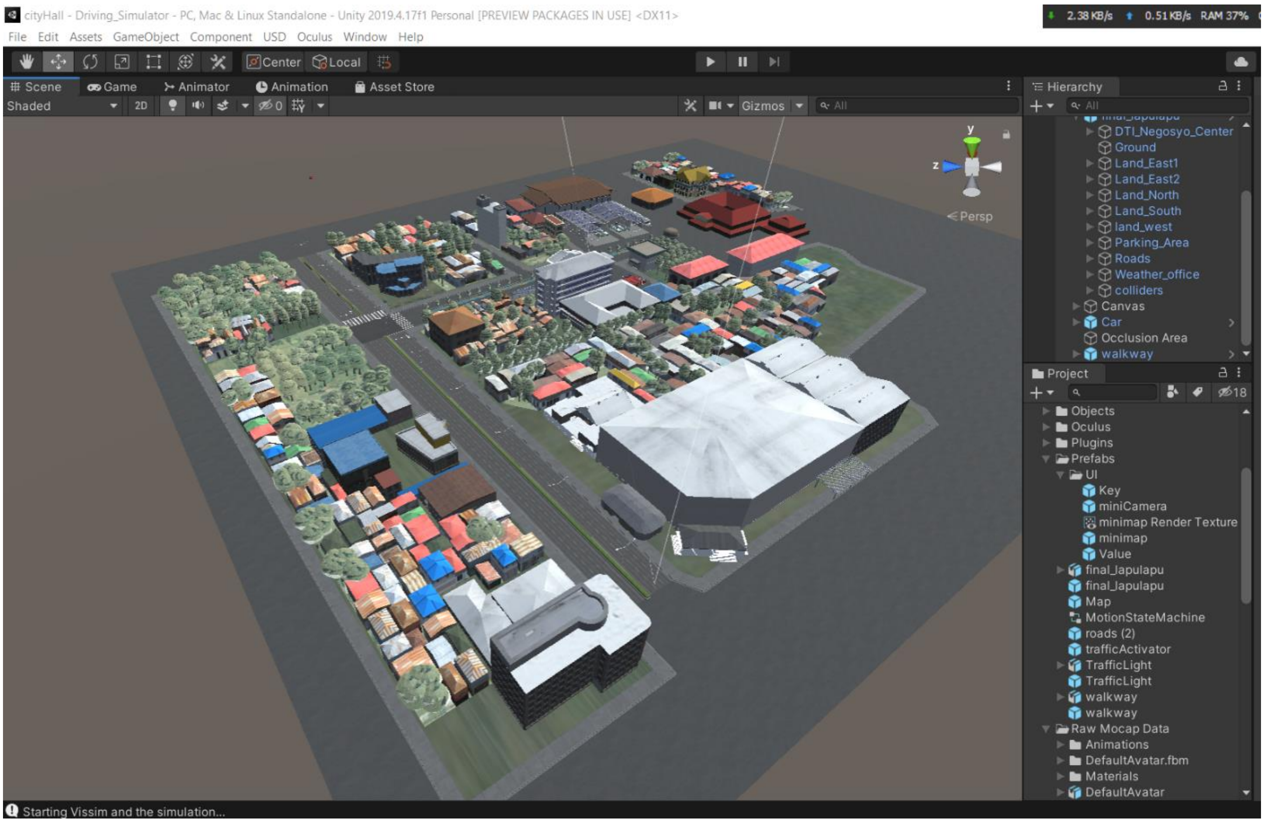


Figure 3.61 3D models in Unity

3.5.3 Develop various functions of management system

As said before, since there are many public services, the entry and exit port of Walkway and many people come to the smart parking area and the mobility hub is in the Lapu-Lapu area. Therefore, it will have a larger flow of people and traffic in this area. If it does not have an effective management to control the passenger density and the traffic condition, it will induce traffic congestion and safety problem. Therefore, we develop a management system to control and monitoring the traffic, building, the energy state, and mobility hub with the help of digital twin dashboard to improve the mobility of this area and prevent traffic congestion and people gathering in an effective and environmentally friendly way. The structure of the management system is shown in the **Figure**

3.62.

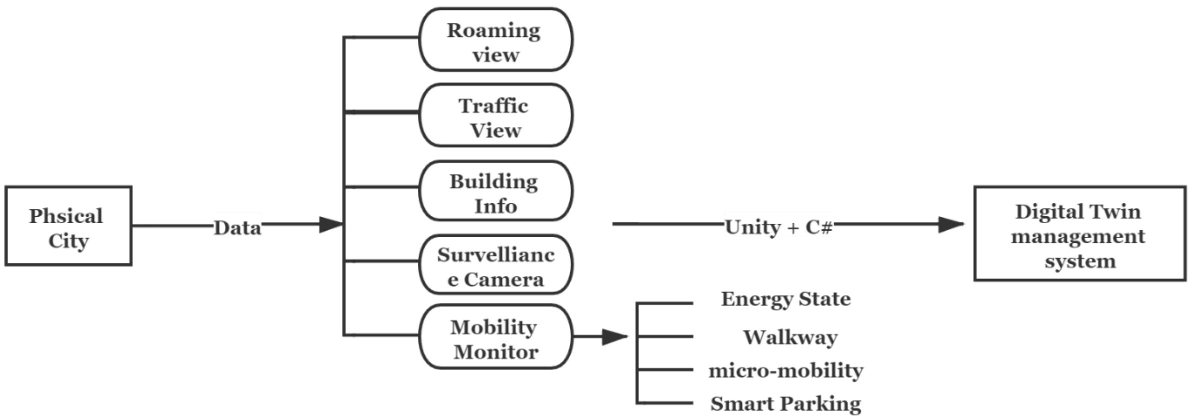


Figure 3.62 Structure of Digital twin management system

The functions of the digital twin management system mainly include roaming view of the working area, through traffic view to monitor and control the traffic, inquire existing building accessibility information, Surveillance camera of road intersection and smart parking area, and mobility monitor. In the function of mobility monitor, it can be divided into four directions. Energy state shows the real and historical solar energy production and actual consumption from solar panels. Micro-mobility panel show the micro-mobilities ready to run and battery state of charge. Walkway panel includes the real and historical passenger number, flight information and college schedule to forecast the potential flow and can real-time check the state of walkway and repair intervention for passenger safety. Parking area information panel including the vehicle arrangement, energy state and can check each parking slot vehicle information. This management system has the functions of real time information which needs the real time data to show the real time condition. But now we do not have the raw data of real time information of Lapu-Lapu. Also, we cannot install the sensors in the real city now, we do not have the connection between the surveillance camera in Lapu-Lapu. Therefore, we suppose the data is transmitted from the sensor such as camera or inductive loop, and this system can convert the raw data from sensors into an easy-to-use panel data, which will improve management efficiency and save social public resources. These functions can be established in the Unity3D platform by using the language C#. This thesis uses the Unity platform to build the interaction management interface for visualizing data in the virtual city and to realize part of functions of the digital twin management system.

Roaming View

The roaming view of the virtual city is the basic function of the system. Through this function, user can move freely in the scene. By writing the control script in Unity3D, the user can simulate themselves roaming in the city through the keyboard and mouse, so that they can observe the detail of the whole working area. In our roaming view system to realize the interaction from two aspects: First control users to move in the virtual scene through the W/A/S/D key in the keyboard and move fast through pressing "shift". The function ***Input.GetAxis()*** and ***Input.GetKey()*** in this script is used to monitor the key value entered by the user's keyboard. This function is a member of the Input class, and the ***transform.Translate()*** is used to translate objects. And ***Time.deltaTime()*** is expressed as a unity local variable, which is updated in each frame as the data in Time class. In each frame, the variable shows the elapsed time value (in seconds) from previous frame. And if we want to calculate the move distance, we should multiply the move speed. Second control users to freely adjust the viewing angle in the virtual scene by pressing the left "shift" and moving the mouse in vertical direction and in horizontal direction. ***Input.GetMouseButton()*** is the function monitor the mouse (2 presents mouse scroll wheel). And the function ***transform.Rotate()*** is used to rotate the object. When rotate in the vertical direction which rotate relate to the local coordinate system (space.self). When rotate in the horizontal direction which rotate relate to the world's coordinate system (space.world). 3D interactive roaming in the Unity3D is realized through the combination of Camera and script. Camera can adjust the field of view and distance of observation. Script is mounted in Camera to realize the operation and control of mouse and keyboard on viewing angle transformation. The code to realize these two aspects are shown as follows:

Aspect1: control users to move

Move in vertical direction: *dz = Input.GetAxis("Vertical") * movingSpeed * Time.deltaTime*

Move in horizontal direction: *dx = Input.GetAxis("Horizontal") * movingSpeed * Time.deltaTime*

Move in fast speed if press "shift":

```
if (Input.GetKey(KeyCode.LeftShift)){
  dz = Input.GetAxis("Vertical") * movingSpeed * Time.deltaTime * 5
  dx = Input.GetAxis("Horizontal") * movingSpeed * Time.deltaTime * 5}
```

Objects translate move: *transform. Translate (dx, 0, dz)*

Aspect2: users to freely adjust the viewing angle by press mouse scroll wheel

Rotation view in vertical direction (yaw) and Rotation view in horizontal direction (pitch) :

```
if (Input.GetMouseButton(2)){
dyaw = Input.GetAxis("Mouse X") * Time.deltaTime * angularSpeed
```

*dpitch = Input.GetAxis("Mouse Y") * Time.deltaTime * angularSpeed}*

View Rotate:

transform.Rotate(Vector3.right,-dpitch,Space.Self)

transform.Rotate(Vector3.up, dyaw, Space.World)

Surveillance Camera

We established three surveillance cameras in the virtual city. Two of them are from two directions (west /east and north/south) in the road intersection of the M.L. Quezon National Highway which can observe the real-time traffic condition. another is located inside the smart parking area for detecting each vehicle information. This function which is designed for the future because at this moment we do not have the surveillance camera in the physical Lapu-Lapu city, we assume that the phone's camera is the camera of the intersection on parking area or smart parking area to show the real time communication between sensor and digital world. We used the API from **VLC unity** which through http or rtsp protocol to build the connection and through VLC player to play the real-time video streaming. Video streaming refers to the transmission of video data, for example it can be processed as a stable and continuous stream through the network. Because of the streaming, the client browser or plug in can display multimedia data before the entre file is transferred. The real-time video stream of the camera generally uses the RTSP protocol (Real-Time Stream protocol) , it is an application layer protocol in the TCP/IP protocol system. RTSP protocol defines how one to many applications can effectively transmit multimedia data through an IP network. RTSP is above RTP (real rime transport protocol) and RTCP (real time transport control protocol) in architecture, and it uses TCP, UDP (User Datagram Protocol) or RTP to complete data transmission. RTP is responsible for the carrying, packaging and transmission of video data; RTCP provides services such as flow control, congestion control and network status feedback for RTSP transmission. RTSP is a two-way real-time data transmission protocol, RTSP responsible for the control of the establishment, interaction, and disconnection of the session between the server and the client, the user can control the downloaded real-time data, such as pause, continue, back, forward, etc. which is equivalent to a network video "remote control". RTSP protocol through the streaming technology to divide the continuous data into different size data packs, therefore client can watch the video while downloading, do not need download the entire video file. The real time effect of RTSP is very good, suitable for video chat, surveillance camera. It is a network application protocol like the HTTP protocol which at the same layer as HTTP. HTTP protocol (Hypertext Transfer protocol) is not a streaming media protocol, HTTP transfer data is based on TCP/IP protocol. Traditional video transmission is that the application layer uses the HTTP protocol and is carried on the transport layer TCP protocol, which is a connection-oriented transmission method for downloading video files. User can play the video files after they are completely download and stored, and it is not belonging to video streaming, which no longer used for the video transmission. In recent years, with the development of network infrastructure and technology, the transmission protocol TCP has been greatly improved, based on the HTTP adaptive video streaming transmission method has been research, developed and standardized, and TCP video transmission is completely possible. To overcome the shortcomings of traditional streaming media methods such as the need for a dedicated media server and error-free control, in recently years, a class of video progressive download playback technology based on http has emerged. The client of progressive download only needs to wait for a short period of time to download and buffer the first small amount of data of the media file before starting to play, and then it can download and play at the same time. although this progressive download method based on HTTP/TCP protocol is a great improvement but still has some shortcomings. For example, to maximize the data transmission rate under the premise of ensuring the stability of the network, TCP adopts a slow start method. It starts to transmit data at a lower rate, and then gradually increases the transmission rate until packet loss or congestion occurs, then reduce the transmission rate to a certain level, and then gradually accelerates, and so on to keep the transmission rate near the highest bandwidth. But TCP cannot guarantee that all retransmitted data packets arrive at the client on time which will lead to the phenomenon of "jamming" in playing video. Therefore, in recent years, in addition to universities and research institutions, many well-known companies and organizations have also launched their own dynamic and adaptive video streaming system based on HTTP, such as Microsoft-SS, Apple-HLS, Adobe-HDS, and 3GPP-AHS and so on. If the data source's URL (Uniform Resource Locator) starts with "RTSP://" which is use the RTSP protocol and TCP transmit data, if the data source's URL starts with "HTTP://" which will use the HTTP protocol and TCP transmit data. The Video streaming transport protocol roadmap is illustrated in **Figure 3.63**.

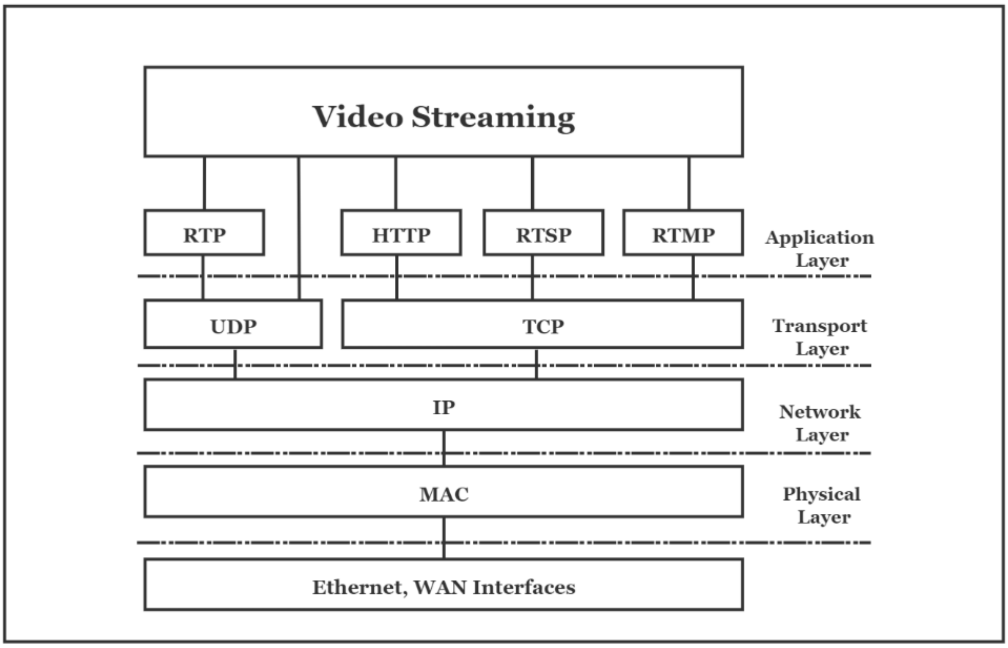


Figure 3.63 Video Transport Protocol Stack

IP camera is a digital camera that can receive control data and send image data through an IP network, and does not require local recording equipment. Most IP cameras are based on RTSP protocol, that means user can use media player to watch the real-time video. The video stream can be obtained wirelessly through the IP address. In our project, we use mobile phone's camera as IP monitor camera. First, we should build a LAN (Local Area Network) through WIFI hotspot. And make sure the cell phone and the laptop are on the same LAN. In the mobile phone, install an IP camera application IP-webcam to build a LAN camera. Through the IP-webcam from the mobile phone, we can get the IP address which the URL starts with "HTTP" or "RTSP" as shown in the **Figure 3.64**.

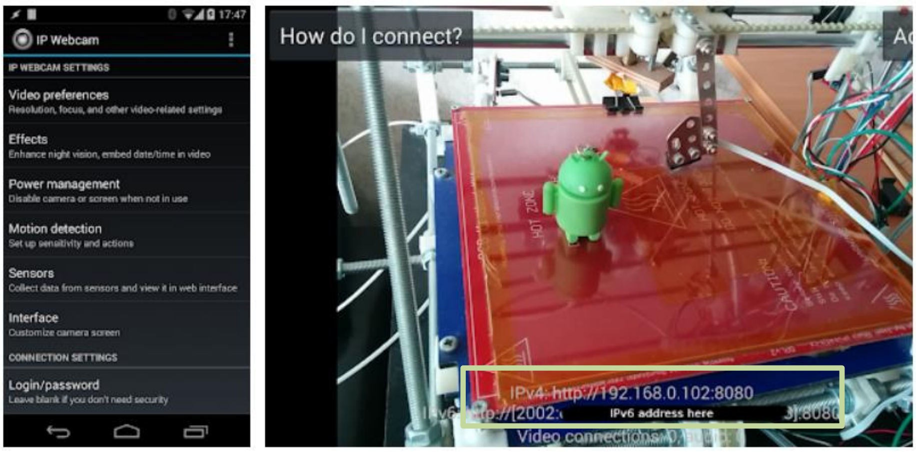


Figure 3.64 IP webcam on mobile phone

Then in the Unity3D from laptop, we use the VLC unity plugin to play the RTSP or HTTP video streaming in real time from the mobile camera (IP camera). It also supports common local videos. In the Unity, through the script to call the ***LibVLC*** (VLC library) to decode the video and display it in the 3D screen. This control script also contains the function of playing and stopping the video. We can through this script to adjust the size of the screen. This script was written by following the documentation of VLC Unity.[83] In our management system we have established three surveillance cameras, two of them are located at the interaction but for different direction (WE and NS) and other is located at the parking area. We use three mobile phones as three real world surveillance cameras. And make sure the mobile phones and laptop in the same LAN, by obtaining the IP address of the three mobile phones and inputting them into Unity as shown in **Figure 3.65**, through the RTSP/TCP and HTTP/TCP connection protocol, the real/time video stream transmission was realized. In the unity, the video is shown as a Texture in the Scene. And part of scripts of control and display realization is shown as followed:

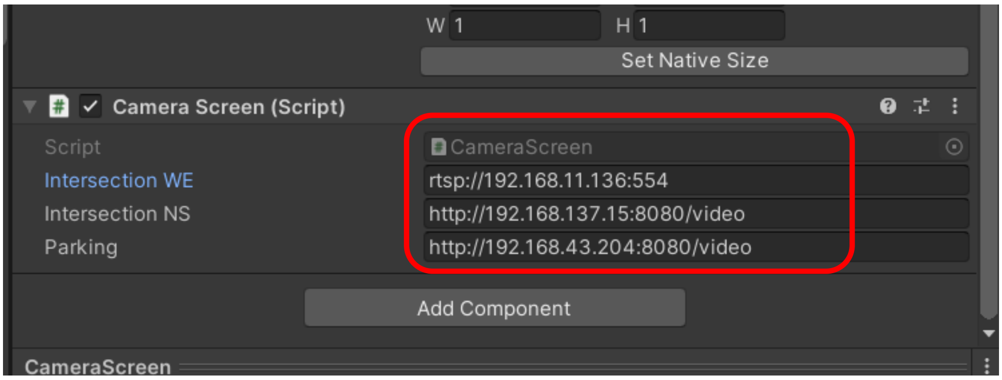


Figure 3.65 Display real time video stream in Unity

Load the native libraries (LibVLC):

Core. Initialize (UnityEngine.Application.dataPath)

Create LibVLCSharp:

LibVLC = new LibVLC(); MediaPlayer = new MediaPlayer(LibVLC)

Each frame updating:

InPtr texptr = Mediaplayer.GetFrame(out bool updated)

Play and stop the MediaPlayer:

MediaPlayer. Play() *MediaPlayer. Stop()*

Adjust the MediaPlayer size and Screen texture size in Unity:

MediaPlayer. Size (0, width, height); texture = Texture2D.CreateExternalTexture(width, height, TextureFormat.RGBA32, false, true, texptr) until now the surveillance camera function has finished. In the **Figure 3.66** left is shown the three surveillance cameras position in the digital city. And the final real-time video displays are shown in the **Figure 3.66** right.

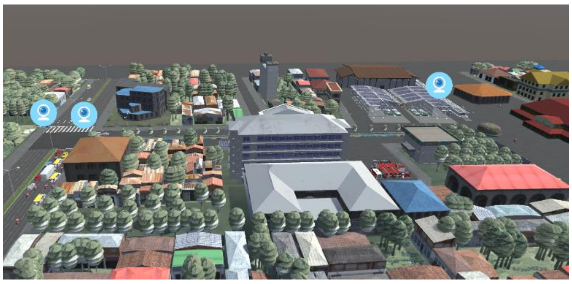


Figure 3.66 Surveillance Camera in Unity

Building Information

This function allows us to visualize the accessibility information of different buildings or area. We divided the entire virtual city into four types: green area, functional buildings, residential area, and mobility hub. In the function, we focus on the green area, functional buildings, and residential area. For the green area will show the information about the land area, the amount of CO_2 reduction by plant photosynthesis to absorb carbon dioxide. For the residential area will show the number of residents, land area and average height. For the functional buildings which include the city hall, Hotel, Gaisano Mall, shop center, social security system, bank, city hall of Justice, school, ABEJO law office, Restaurant, swat office, police office, land transportation office, fire station, City health office, DTI Negosyo Center, weather office, Post office and D.S.W.D. In the management system we will show different information for different functional buildings. For example, the Hotel will show the star level, the price, height, and the contact telephone number. The Gaisano Mail will show the functions, open hours, and contact number. Also, the land transportation office will show the contact telephone number, the purpose, Open hours, and the website. Manager can click on each area or building model to read its information. Through read the information of the residential, manager can estimate the local population in a more effective way. And the land area and height will provide a comprehensive and intuitive analysis and decision-making basis for the functional layout of urban land use, spatial analysis, and project approval management. In this working area, there are many service offices will provide various kind of services. Due to the serious problem "information islands" of departments, the data and information of various departments and platforms could not be integrated and shared information, through this function we can classify and deal with urban events, manage relevant departments one to one to facilitate the intelligent distribution and processing of different events. When an incident occurs, the relevant department are selected and intelligent distributed and assigned according to different incident. Provide efficient data for the prevention, preparation, response, and recovery stages of urban emergency management, and assist manager make rapid decisions and reasonable deployments in the handling of man-made accidents or natural disasters. Such as if a fire occurs the manager will contact the fire station and police office through the management system as soon as possible which will greatly protect personal safety and improves efficiency. In our project, we do not have detail information for each building and area. We collected the useful historical information of all the buildings and areas from internet and Google map and established the building information system. In this section will introduce the methodology of establishing this system. the real time and accuracy information can be added or updated in the future.

The information function allows us to visualize the information in the panel as shown in **Figure** 3.**67**. Since the realization of the building information query system requires many various types of sensors. This leads to the data extracted from the bottom layer has many multi-source heterogeneous characteristics, making the bottom layer data unable to be directly used by the upper layer program. Therefore, we adopt XML configuration file to realize the information storage and expression, the collected data information of each building and area converted into event information in XML uniform document format to provide data support for the subsequent application of complex event processing technology and with the script in C# to read the information in the XML file and show each building's information in the Scene.

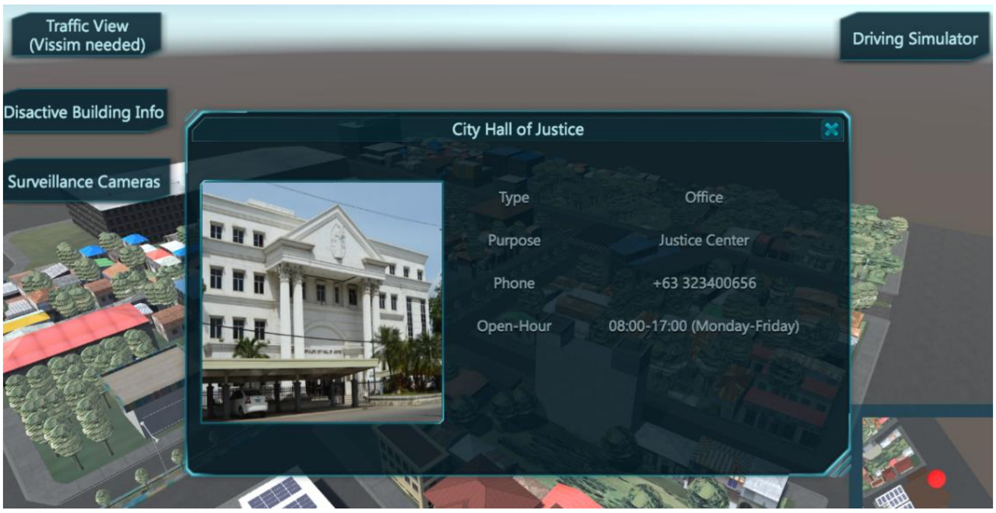


Figure 3.67 Building Information system

Extensible Markup Language (XML) is a text markup language much like HTML which use UTF-

8 encoding. It is a data representation format that can describe very complex data structures. It is often used to transmit and store data. The World Wide Web Consortium (W3C) was designed based on the Standard Generalized Markup Language (SGML) and the first edition was released in 1998. XML data is self-descriptive, and users can define and tag the data according to their needs. As log as a kind of data can be converted into XML document format data, it can be used by other platforms by coveting the data into other formats. XML needs to follow strict grammatical requirements, while XML complies with tag pairing and nesting, it must also strictly comply with the Document Type Definition (DTD) regulations. The advantage of doing this is to increase the readability and maintainability of the document. Also, XML has a good scalability, XML allows users to customize their own unique tags according to their own needs. Separation of information content and information presentation form. In XML, the display method of the information has been extracted from the information itself. The advantage of this is that it is easy to search and modify, and it can clearly describe the meaning of the information itself and the relationship between them.

In our building information system, the main function is **Click query function**. When user runs the system, click on the building of interest, and the model of building will be highlighted in the middle of the screen. And find the relevant attribute information of the corresponding building in the XML files, and the obtained attribute information will be displayed in the form of text and actual picture in the real city on the screen. If the building's information contains the website, if user click on the website will enter the webpage.

Step 1: User's mouse passes the building of interest highlighted it and click on it show information panel:

To realize the function of passing the building and highlighted, we need the collision detection technology. There are many collision methods in the physics engine of Unity3D., such as the collision between rigid body and rigid body, and the collision between a rigid body and a collider. These collisions all have some common feature is the actual contact between the colliding objects. In the Unity3D uses the collider in the rigid body to ensure that the collision between the rigid bodies can occur normally. There are five types of Colliders in Unity: BoxCollider, SphereCollider, CapsuleCollider, CylinderCollider, MeshCollider. These five colliders are used on different objects. If you add a collider to the object, the rigid body will not pass through the collision body. Different shapes need add different types of collision bodies. Our buildings' shape is irregular, but they are composed by many cubes; therefore, we add collider for buildings by composing some Box Colliders as shown in **Figure 3.68**.

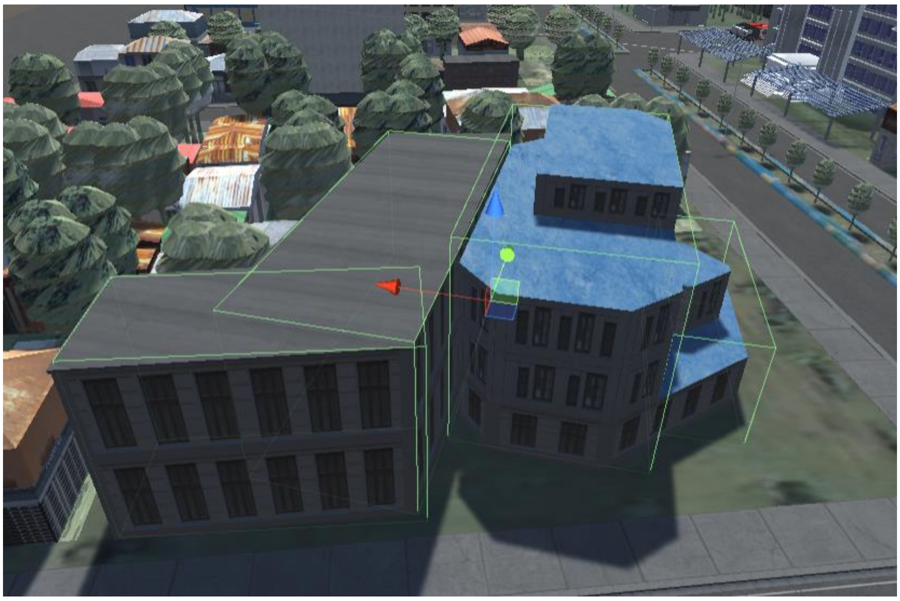


Figure 3.68 Collider for Buildings

After adding all the buildings' collider, Unity3D provides a way of ray detection. In this way, users can use an invisible ray with a certain length to detect whether there is contact with other colliders. The realization of this function is mainly achieved by the ***Raycast*** function in the Physic class. With this function, user can emit a ray to detect whether the ray collides with other colliders. In this function, we can set the starting point of the ray. As saying in the **Roaming View** function, user first person view is the camera, the ray will be emitted from the camera, also we can set the direction and length of the ray. In our system, the direction of the ray is from the center of the screen to the position of the mouse. The distance of the ray is the value of distance, and the objects that the ray can collide with are objects in the layerMask layer. Raycast function is generally written in the Update function. This function will call Raycast function every frame when program is running. After the ray hit on the building, the building will be highlighted, we use a script contains the highlighted function which developed by other developers to realize high light function. And use the ***Input.GetMouseButtonDown(0)*** (0 means left key of mouse) to realize the function of click on the building shows the information panel. The main code is shown as follow:

Create Ray which from Camera to mouse click position (the interest building) :

ray = Camera.main.ScreenPointToRay(Input.mousePostion)

Call the Raycast function and calculate the start point and end point of ray:

Private RaycastHit hit; *Physic. Raycast(ray, out hit, Distance, LayerMask)*

Determine whether the ray hits the building, and the building will highlight and click on the building shows the information panel:

If (hit.transform != null) {

Interested building = hit.transform.parent.GetComponentInParent <Hightlightableobject>()

Interested building.FlashingOn()

Panel.SetActive()

}

Step 2: Write and process the data from XML files

All the information we collected for real city is saved in the XML files. XML file includes node relationships, element, attribute content, etc. Element is the most basic unit that composes XML. It consists of start tag, attribute, and end tag. Each element must have an element name, and an element can have several attributes and attribute values. In the **Figure 3.69** shows our XML file structure. <BuildingInfo> is the root element of the XML document. There is one and only one root element in each XML file. Root element is an element that completely includes all other elements in the document. The start tag of the root element should be placed before the start tags of all other elements. The end tag of the root element should be placed after the end tags of all other elements. <Building> and <Info> are elements in our XML file. And <Info> is a subset of <Building>. Elements are the main part of an XML document. An element can have multiple attributes, the attribute of <Building> is the name of each building and <Info> contain multiple attributes which include the type, purpose, mobile phone number, Website and so on. The element has multiple attributes, its basic format is *<Info Type="Office" Purpose="Local government office use" Phone="+63 323410659" WebSite="http://lapulapucity.gov.ph/" />*

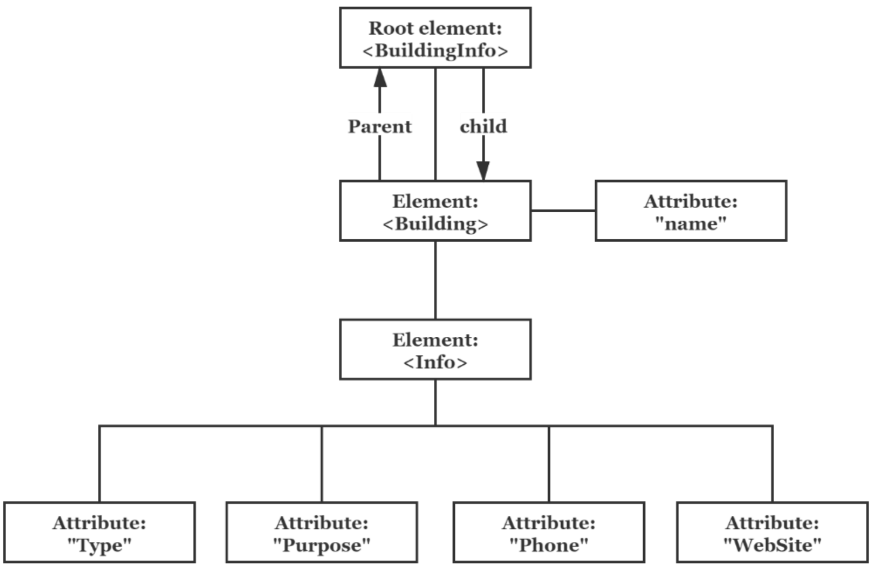


Figure 3.69 XML file Tree

In this building information system, when the program start running, the XML file of the building information is automated created by the function ***CreateXml(),*** user can click each building and through the function ***LoadXml()*** to load the building information XML file and through the building's name to find the corresponding building information in the XML file. Load the XML need ***XmlDocument*** class, this class is the DOC parser of the .NET framework. XmlDocument regards XML as a tree structure. It loads the XML document and builds the tree structure of document and builds the tree structure of the document in memory which has many functions to parse the XML file. After loading the XML file to obtains the information to the corresponding building, then using the script to display all the information in the Unity3D Scene. If the user clicks one building which its information is not contained in the XML file, through the function ***AddXml()*** will automate write this new building's XML structure in the XML file. Then the information of this new building can be updated by manually way or through the script to enter. In the real world, if the building information will change or some new buildings are built, the information can be updated by managers by using this system. The final entire XML file is shown in the **Figure 3.70**. The control script of process XML file should use two namespaces are ***System.Xml*** and ***System.IO***, the first it contains many API related to XML, and another is for reading and writing files, which is the reading and saving operation. The main part script as follows:

First step: Obtain building_info XML file save path (Application.streamingAssetsPath provide the path to folder)

Xml_path = Path.combine(Application.streamingAssetsPath, "Building_Info.xml")

Function 1 Create Xml file:

xmlDoc = new XmlDocument(); root = xmlDoc.CreateElement("BuildingInfo");
xmlDoc.Appendchild(root); xmlDoc.Save(xml_path)

Function 2 Add tree structure in XML file:

Add Root element: root = *xmlDoc.DocumentElement; //documentElement returns the root node*
Add Element: *element = xmlDoc.CreateElement ("building")*
Add sub-Element: *sub element = xmlDoc.CreateElement ("Info")*
Add attribute of Element: *element.SetAttribute("name", name);*
Add sub-Element into Element: *element.AppendChild(subElement);*
Add Element into Root element: *root.AppendChild(element);*
Create dictionary for building which didn't recorded before: *this.buildingInfo.Add(name, new Dictionary<string, string>());*

Function 3 obtain XML file's building information (output is an information dictionary):

Create a dictionary to store all load information (key: the name of building, value: one dictionary contains this building's information) :

information = new Dictionary<building's name, Dictionary<attribute's name, attribute's value>>();

Loads exist xml file:

xmlDoc.Load(this.xml_path)

Iterate the xml file obtain and add element <name>**'s attribute as the key to the dictionary (information); obtain and add sub element** <info>**'s attribute and attribute value as the value to the dictionary (information)**

```
foreach (XmlElement item in xmlDoc.SelectSingleNode("BuildingInfo").ChildNodes)
    {
        name = item.GetAttribute("name");
        infomation.Add(name, new Dictionary<string, string>());
        foreach (XmlAttribute subItem in item.FirstChild.Attributes)
        {
            infomation[name].Add(subItem.Name, subItem.Value);
        }
    }
```


```xml
<BuildingInfo>
  <Building name="CityHall">
    <Info Type="Office" Purpose="Local government office use" Phone="+63 323410659" WebSite="http://lapulapucity.gov.ph/" />
  </Building>
  <Building name="Hotel ACE Penzionne">
    <Info Type="Service" Level="* * *" price="19-40 euro" Phone="+63 323411140" Height="20.4 m" />
  </Building>
  <Building name="Shop Center">
    <Info Type="Service" Products="Cosmetic, Clothes, Accessories" Open-Hour="10:00 - 19:00" Phone="+63 9238586890" ATM="Available" />
  </Building>
  <Building name="Residential North">
    <Info Type="Residential Area" Population="511" Area="6816 m2" Aver-Height="6 m" />
  </Building>
  <Building name="Shop Electronic">
    <Info Type="Service" Products="Electric Devices, Elettronic Components" Open-Hour="10:00 - 19:00" Phone="+63 323412499" />
  </Building>
  <Building name="Shop Center N">
    <Info Type="Service" Products="Water Spa, Mactan Warehouse and Logistics Services, Video Game" Open-Hour="10:00 - 19:00" ATM="Available" />
  </Building>
  <Building name="Hotel Dulcinea">
    <Info Type="Service" Level="* * *" price="36-60 euro" Phone="+63 9064722628" Height="8 m" />
  </Building>
  <Building name="Green Area North">
    <Info Type="Green Area" Area="8528 m2" CO2-reduction="767.5 kg/day" />
  </Building>
  <Building name="Gaisano Mall">
    <Info Type="Service" Function="Supermarket, restaurants, Shops, Delivery Service, Financial Service, Play Area" Open-Hour="16:00 - 24:00" Phone="+63 9153783680" 
  </Building>
  <Building name="Social Security System">
    <Info Type="Office" Purpose="Social Security Services" Phone="+63 323401886" WebSite="https://www.sss.gov.ph/" />
  </Building>
  <Building name="Residential West">
    <Info Type="Residential Area" Population="1511" Area="10224 m2" Aver-Height="6 m" />
  </Building>
  <Building name="Green Area West">
    <Info Type="Green Area" Area="1216 m2" CO2-reduction="109.4 kg/day" />
  </Building>
  <Building name="Residential Middle">
```


Figure 3.70 Building information XML file

Step 3 Building information display on Screen based on UGUI interface

For the display of building information required by the system, a two-dimensional UI (user interface) is usually used to display the information in the development of a three-dimensional game engine. In addition to Unity3D's own UGUI to develop UI, it also supports UI development plug-ins such as NGUI and FairyGUI for users to develop two-dimensional interfaces in Unity3D. The UGUI system allow the developer to create graphical user interface quickly and intuitively, with high development efficiency, and can satisfy any GUI production requirements. In our system, we select UGUI to build a UI interface for displaying the building information which will increase the user experience of human computer interaction and enhance the visualization of information from our UGUI system includes Text, Image, Raw Image, Button controls that respond to user click events. A button is used to initiate an action when the users click and releases it. If you move the mouse away from the button control before releasing the click, no action will be performed. The button has an event called ***on click*** that will response when the user finished clicking. Typical use cases include Confirm a decision, cancel an operation and so on.

In our system' UI panel, As shown in **Figure 3.71**, the header "Gaisano Mall" is a Text control, the image on the left is a Raw image control, the close image on the top which contain a button control component if user wants to close this panel by clicking this button. And the building's information on the left, which is different for different building, therefore through the function ***GamerObject.Instantiate()*** instantiating Text control to display all information by the script. The building information system does not display all building information at the same time. if the users want to know the information of a certain building or area, just click the model corresponding to the building, and call the UGUI display script. Each of the building's information storage in the XML file, through script to find the corresponding building's name (element) in the XML file and display this building's information (sub element) on the panel. The building's name will write into the Header's Title (Text control) and the building information will write into a text control which instantiate by the script. The main part of script shows as follow:

Figure 3.71 UGUI information panel

Aspect 1: show the actual picture of interested building

Image. Sprite = Resources. Load<Sprite>("image_actual/" + interested building.name)

Aspect 2: write the interested building's name in the Header – Title

Title .text = interested building.name

Aspect 3: write the interested building's information

Step 1: iterate the dictionary of building information find the building information of interested building :

foreach (Building_info<attribute, attribute_value> sub-element in buildingInfo[interested building.name])

Step 2: instantiate text for writing attribute, instantiate text for writing attribute's value and adjust their position

Text for attribute = GameObject.Instantiate(text for attribute, panel.transform);

Text for attribute's value = GameObject.Instantiate(text for attribute's value, panel.transform);

Determine and adjust the text position of the pivot of this RectTransform relate to the anchor reference point:

Text for Attribute.rectTransform.anchoredPosition = new Vector2(x, y)

Text for Attribute's value .rectTransform.anchoredPosition = new Vector2(x, y)

Step 3: Write the attribute and attribute's value

Text for attribute. Text = Building_info. Key; Text for attribute's value. Text = Building_info.Value

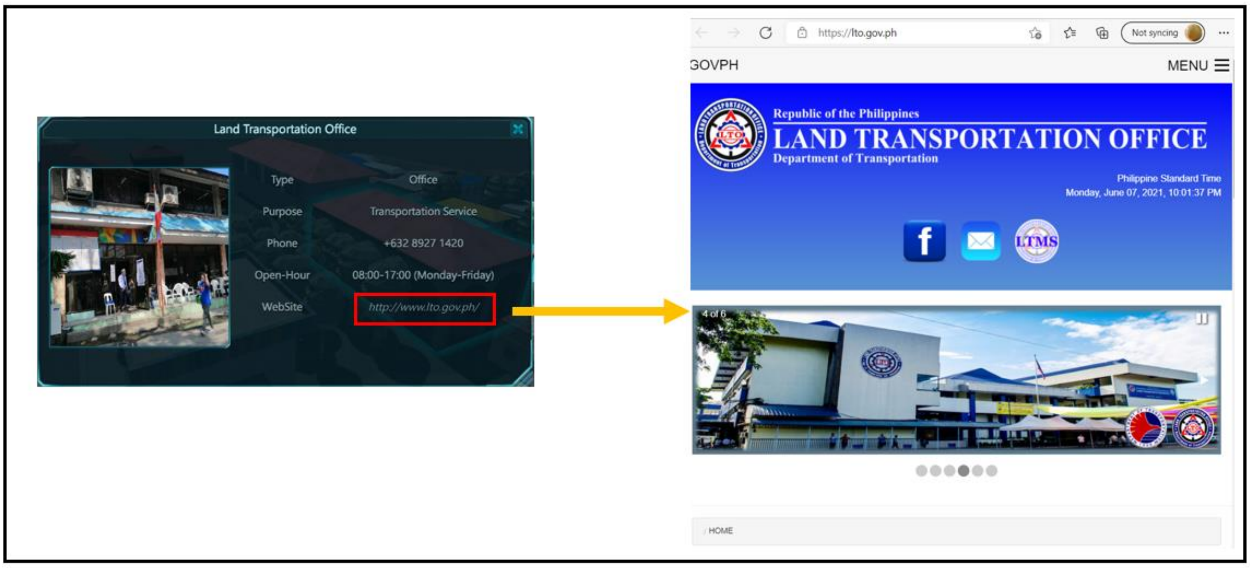


Figure 3.72 click website enter webpage

Step 4 Click the website and enter the webpage

In our building information system, there are some buildings have the information of its own website as shown in **Figure 3.72**. The manager can through the website of each building will obtain the function and more detail information of this building. To realize the function of clicking the website in the panel to enter the webpage will use the ***UGUI – EventSystem.*** Add any UI component to the scene, and the EventSystem object is automatically created. This object is responsible for monitoring the user's input behaviors such as clicking, dragging, and touching, and passing events to the object. **Event System *Manager*** is a component of Event System object, responsible for managing all events. It is a bridge between input behavior and selected objects. In each frame of Update, EventSystem will updates the state of the ***BaseInputModule*** component mounted on the same GameObject every frame and determines whether the Module should be activated, and if the module activated, it would call each module process. ***Raycasters*** is like a collector. When an event occurs, the Module will request a ray tap, return all the objects that can be tapped, and return it to the dispatcher for filtering. It has an internal management class ***RaycasterManager***, which is used as a one-way bridge linking collectors and event system's monitor. ***IEventSystemHandler*** and its subclasses such as the most used ***IPointerClickHandler*** is a responder that handles click event. through the ***ExecuteEvents*** class, all the responders on the object where the event occurred can be obtained and called its response logic. Take click as an example, the event will eventually be dispatched to the ***OnClick*** agent. Complete the execution of the logic.[84] The triggering process of Event System is shown in **Figure 3.73**. To realize the function of click the website in the UI panel as shown in **Figure 3.72**, we will use the ***IPointerClickHandler*** and the execute method is ***OnPointerClick()*** which will call when a pointer is pressed and released on the same object[84]. In our system, the object is the website text. After clicking the website text, we use ***Appication.OpenURL()*** which follows he permissions and restriction of the application's current platform and environment and open the specified URL. For example, it is used to open an HTTP (webpage) URL, and the webpage will be opened. The part of script is shown as follows:

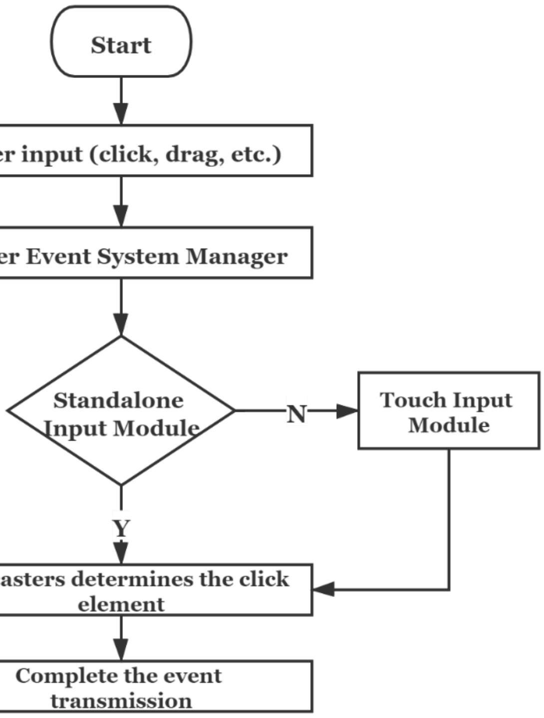


Figure 3.73 trigger process of Event System

Step 1: use the *IPointerClickHandler* and the execute method *OnPointerClick()*

public class webURL : MonoBehaviour, IPointerClickHandler

public void OnPointerClick(PointerEventData eventData)

Step 2: obtain the text (website) which the pointer clicks on

text = eventData.pointerCurrentRaycast.gameObject.GetComponent<Text>();

Step 3: open the website

Application.OpenURL(text.text);

Mobility Monitor

As said before, our Mobility hub is composed by three parts which are smart parking hubs, shared-electric micro-mobility hub, and walkway exits and entry ports. And the electric energy source comes from solar panel. The three parts' positions are shown in the **Figure 3.74**. in the Mobility monitor system, because in the real world, the mobility hub has not been established, we do not have the real-time data or historical data for analysis and visualization. Therefore, in the Mobility Monitor system, we assume the data is transmitted from various sensor which will be installed in the mobility hub in the future. This system will be able to convert the raw data from sensors into simple and understandable data to visualize in the screen. In the future, managers can obtain the real-time data and make urban management decision. In this section, it describes the design and ideas of each part of mobility hub's information panel. The data processing is the same as the building information system which uses the XML file to storage and present the data information. In the Mobility monitor system, there are four information panels : Energy State panel; Smart parking area panel, micro-mobility panel and the metro for pedestrians panel (Walkway). Through click each information icon will show each information panel.

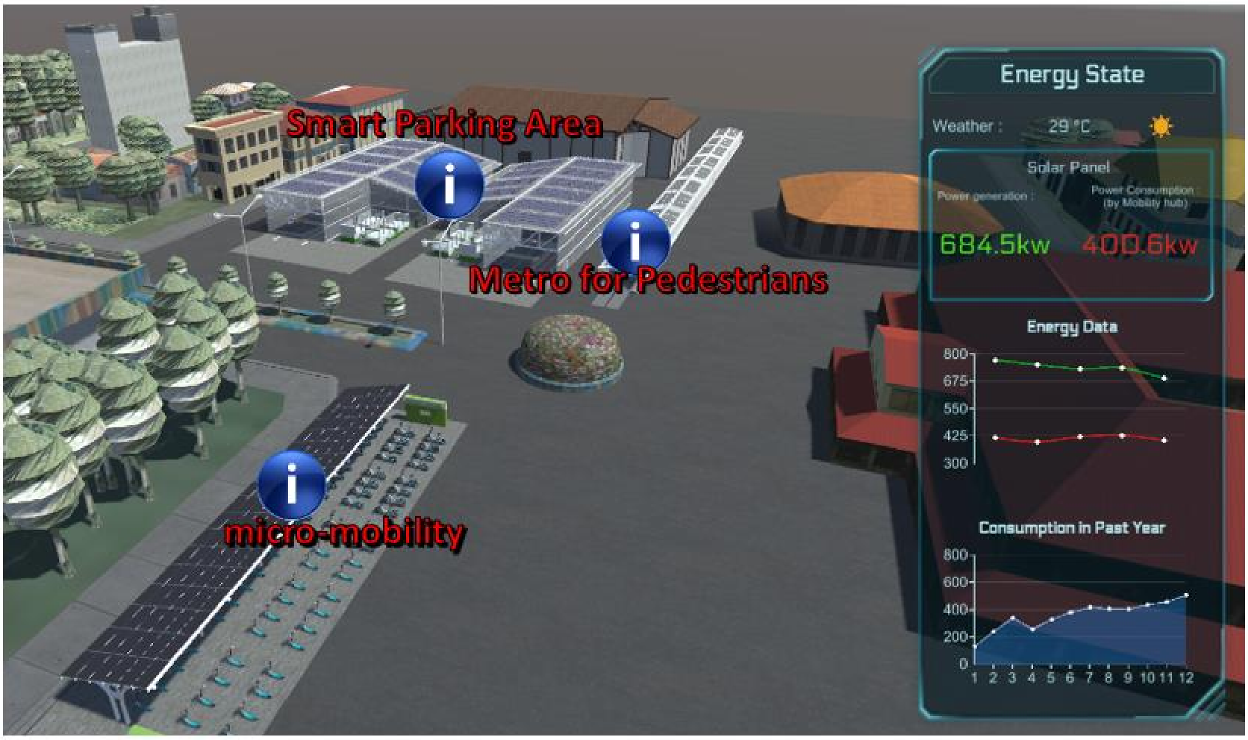


Figure 3.74 Mobility hub position

Energy State Monitor

As shown in the **Figure 3.74**, the right part is the energy state panel. In this panel will show the information of the weather and degree of Lapu-Lapu city, real time solar panel energy production and consumption by the entire mobility hub, and the whole year's solar energy consumption statistic data. Photovoltaic power generation is greatly affected by environmental factors. Through the restoration simulation of environment, combined with the power generation data, the energy efficiency of power generation can be better analyzed, providing a basis for the operation and maintenance and decision-making of photovoltaic in the mobility hub. Through Energy State panel, photovoltaic information, power generation and the power consumption by mobility hub are statistically displayed and monitored. It can be updated in real time by receiving and transmitting the real-time data in the background. The measurement, monitoring and management of energy consumption are the basis for achieving high efficiency, energy saving and emission reduction. The energy state monitor system can effectively collect energy consumption and generation data, manager can through the energy data to guide energy conservation and emission reduction work more efficiency. It will avoid the problem of incomplete energy consumption data, high energy consumption management costs, lack of energy consumption assessment mechanisms, and ineffective implementation of energy saving schemes are difficult to solve. Also, energy data visualization can realize the interaction between users and data, facilitate manager to control data. And display large-scale data in a visual form. Through observes and statistics the real-time energy data can analysis solar power consumption characteristic, power abnormal identification, and security defense and so on. The energy state system based on the IoT, which implements fine measurement, real-time monitoring, intelligent processing and dynamic management through various energy consumption transparency, analysis, and adjustments to achieve the goal of refined management. The advantages of energy state monitor system show as followed:

- Reduce resource waste and optimize solar energy resource allocation
- Effectively detect photovoltaic power plants in real time, improve and orderly information for maintenance personnel, remote operation and maintenance diagnosis, and equipment health management
- Maximize the operating efficiency of photovoltaic power
- Convenient management, remote monitoring operation is possible
- Optimize the large-scale data and display it more intuitively, which is helpful for analysis and decision making

Figure 3.75 Walkway

Walkway Monitor

As said before, the metro for pedestrian (walkway) is directly connect the MCIA airport and Lapu-Lapu city hall, which is zero emission, cheap, speeding up medium-distance travels, good travel panoramic etc. From Daniele's facility analysis and design as shown in **Figure 3.75**, This walkway travel for nearly 2 kms, and an intermediate stop is located at the half of the total development. It passes many important locations such as the city hall, Philippine state College of Aeronautics, EMD Carmelite School and MCIA airport. Therefore, there will be a large flow of people which contain the tourists come from airport to city hall, the students from college, the passengers from city hall to airport and others. One of the most important goals is to improve the fluidity of people to avoid serious accidents. In the **Figure 3.76** shows the Walkway Monitor panel. it is divided into five parts: Real-time surveillance video, real-time number of passengers, recent departure and arrival flight information, Conveyor equipment inspection, the college schedule. Using **video surveillance camera** as the front-end human flow data collection, the data statistics analysis through the passenger flow statistics system produces reports which provides manager with real-time dynamic information of the monitor area (inside walkway) and obtains accurate data on the number of passengers and crowed flow then fill the data in the **passenger information** panel. The system can accurately count the flow of people in the walkway, and when reach the upper limit passenger flow, Managers can effectively guide the flow of people and ensure safety. Through the **flight information** and **college schedule** to forecast potential flow. Flight information show the left time for next departure flight and arrive flight, and the college schedule shows the peak hour of the day. Through these two times, the system can predict the next peak time of human flow in the walkway.

Figure 3.76 Walkway Monitor

Then managers can divert passenger flow and dispatch in time to avoid causing a large backlog of passenger flow and causing traffic paralysis. This panel also shows **each conveyor's status**. As shown in the **Figure 3.76**, we assumed the entire walkway conveyor is composed by six parts. Through various sensors can obtain the operating status of each part of conveyor. If the button is green means this part of conveyor is operating normally. If the button changes to red means that there is an equipment problem with this conveyor. The manager will accurately obtain which part of conveyor appears problems through the walkway monitor panel. And effectively guide the flow of people to travel in other ways to avoid entering the problematic conveyor part. If the manager wants to check the problem, manager can click on the red button and pop-up a warning panel as shown in **Figure 3.77**. through clicking on the button "Contact Technical Support" can contact the technicians and other related personnel in time for maintenance processing. The technology problem can be solved in time and so that the walkway can be continuous to work as fast as possible. All in all, this panel will effectively optimize and control the passenger flow to ensure safety and decongestion. The main advantage shows as follow:

- Using the intelligent video surveillance camera to statistic the number of passengers and the direction of the crowed flow, provides this information to the manager to facilitate more efficient organization of decision work
- Through the flight information and college schedule to predict the peak passenger flow period and prepare in advance for the flow of people.
- Real time monitor the status of the entire walkway equipment, when part of the walkway conveyor appears problem, manager can arrange effective dredging to ensure safety and as soon as possible to dealt with and resolved the problem.

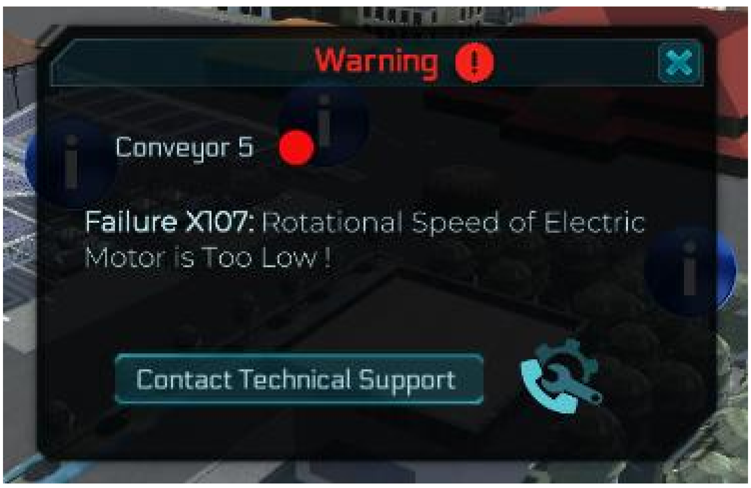


Figure 3.77 equipment problem warming panel

Smart Parking Area monitor

Smart parking hub is located in front of the DTI Negosyo Center Lapu-Lapu city. It provides parking slots for charging electric vehicles. And each parking slot equipped with the charging pile to support the energy supply requirement of the private electric vehicles. it also provides parking slots for electric public transportation (e-Jeepney) outdoor. In the **Figure 3.78** shows the smart parking area monitor. There are four functions include visualization of real-time parking slot status and statistic historical data of free slots information weekly, calculate vehicles average parking time, real-time monitoring of the parking lot by surveillance camera, and real-time energy usage of electric private vehicle and electric bus (E-jeepney). When manager wants to check each charging vehicle information which can click on the No. of the parking slot and a vehicle information panel is pop-up as shown in **Figure** 3.74. the vehicle information panel shows this parking lot's state, the license plate number of the occupied vehicle, and the occupied time. A sensor such as the ultrasonic sensor, camera or inductive loop is added to each parking slot to detect whether a vehicle is parked or driven out, and the real-time data is transmitted to the host of the parking lot statistics system and fed back to the management screen. Through the front-end acquisition system to acquire basic vehicle information, use the network to send the vehicle information data to the management center , and use the license plate recognition technology to obtain the detail information of vehicles and compare the license plate data to ensure the parking vehicle is documented and whether it can be controlled. Through the real-time monitoring of the parking lot, dynamically display the total number of parking vehicles , to ensure the reasonable utilization of parking slots. Also, visualization of abnormal vehicles or accident appears, providing data support for parking lot safety. Through showing the average parking time and the trend of parking space occupancy which can provide a data decision basis for the parking lot to improve parking difficulties at the macro level and assist managers in commanding and dispatching from the perspective of the parking lot to improve the utilization and turnover efficiency of parking lot resources. To monitor the real time energy state of the charge piles in the park to observe the energy usage of electric vehicles and electric bus and estimated the number of charging vehicles, use the historical data to predict peak electricity consumption period and take corresponding actions. Energy state information provides to facilitate the real-time usage and operation monitoring and maintenance of the charging pile. The smart parking monitor panel uses technologies realize real-time display of parking slots and equipment status and data graphical presentation, which saves manual management costs and provides a reference of decision-making manager to obtain the best operation plan, increase the efficiency and ensure safety. The main advantages are shown as follows:

- Visualization of parking lot status: carry out real-time monitoring of the parking lot, dynamic display the total number of parking vehicles and the number of free slots to assist managers command and dispatch. Through the statistic of average parking charge time and the trend of weekly free slots number to provide data decision-making basis for improving the utilization and turnover efficiency of parking lot resources and reducing parking difficulties. Real time monitor the parking lot to discover emergencies and accidents in time and solve to improve safety.

- Vehicle dynamic visualization: automatic identification the parking vehicle license obtain the parking vehicle detail information: parking time, vehicle plate number etc. to ensure the parking vehicle is documented and discover abnormal vehicles in time.
- Visualization of energy state: real-time monitoring the energy state to obtain the smart parking energy usage status, provides to facilitate the real-time usage and operation monitoring and maintenance of the charging pile.

Figure 3.78 Smart Parking hub panel

Micro-Mobility hub monitor

The micro-mobility hub contains 40 electric bikes and 30 electric scooters. We use two swap stations for charging the batteries of micro-mobility. One swapping station for electric bikes' batteries and another station for scooters' batteries. The two swap stations and the micro-mobility hub shows in **Figure 3.79**. The Micro-Mobility monitor panel in the **Figure 3.79** right which shows the number of electric bikes and electric scooters ready for using, and the energy state for charging station electric bikes and electric scooters. Through this panel, manager can obtain the real-time micro-mobility usage, if there is a shortage of micro-mobilities during peak usage periods, the manager can notify relevant personnel to supplement in time. From the energy state of recharging station , manager can obtain the two-swap charging station's energy consumption and to analysis and compare each part of mobility hub energy usage to distribute energy reasonably. The micro-mobility hub also provides the low batteries devices which through sensor to detect the voltage and current to obtain the real-time micro-mobility state of charge, statistic and select the low batteries which managers can connect with the relevant nearby personnel exchange electricity for low battery mobilities. The main advantage of this panel shows as follow:

- Real time monitoring the usage of micro-mobility, if there is a shortage of mobilities during peak hours, manager can connect the relevant nearby personnel to supplement in time.
- Discover the low battery mobilities, managers can connect with the relevant nearby personnel exchange electricity for low battery mobilities to satisfy passenger usage
- Through analysis and comparison each part of mobility hub energy usage to distribute energy reasonably .

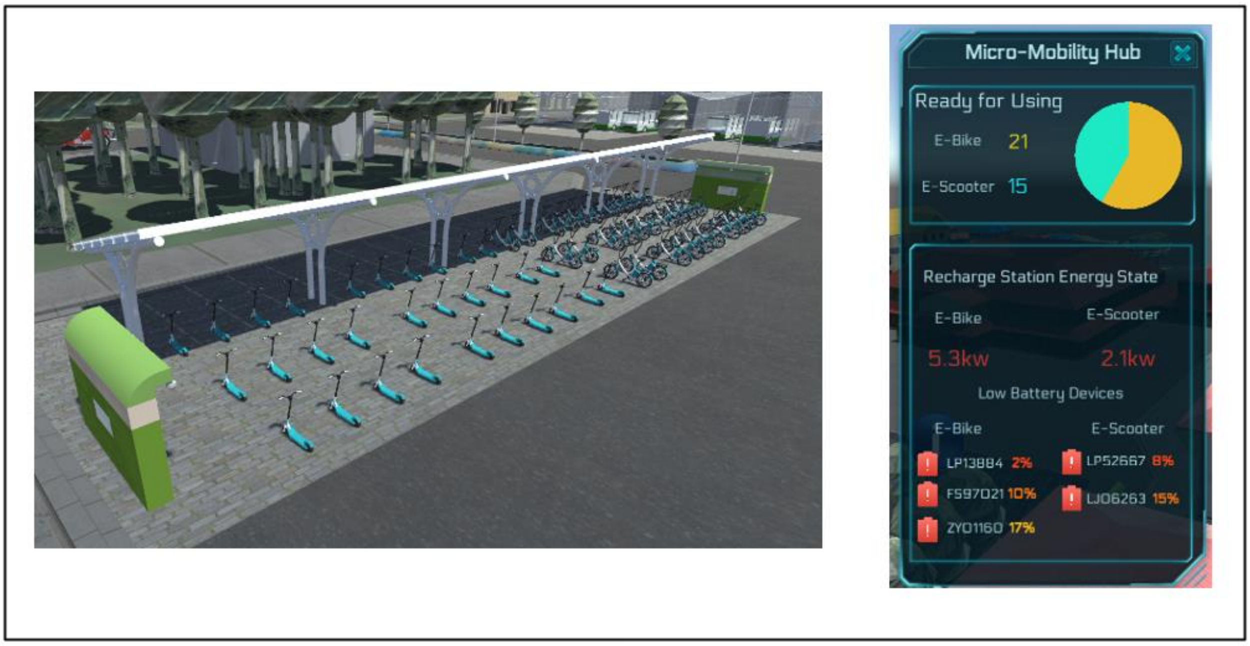


Figure 3.79 Micro-Mobility hub

Traffic View

Figure 3.80 shows the traffic view system. This function is to visualize the traffic in roaming view which used the data connection and transmission technology between VISSM and Unity3D. This technology is developed from Zheyuan. The vehicles in the scene will interact with each other and also interact with the traffic signal. In the traffic view management system, we do not have the real time traffic information in the Lapu-Lapu city, therefore we used the real-time simulation of

VISSIM traffic microscopic and synchronize the vehicle information and traffic light etc. in the Unity3D to simulate the real traffic conditions. In the real world, traffic data mainly refers to data generated and collected by location sensors of mobile devices and monitors installed on roads. For example, taxi GPS trajectory data records the real time precise latitude and longitude position of the vehicles, and the monitoring equipment on the road records, photographs and counts passing vehicle information in real time. Then through digital twin and IoT technology to realize the traffic data visualize in the screen. The Traffic view system collects traffic information in real time, and can comprehensively monitor traffic conditions, traffic incidents and police connection conditions, and combine various road monitoring facilities to early warning traffic congestion, help managers obtains the overall traffic situation in real time and effectively maintain traffic and realize traffic smart traffic visualized management. And in the traffic safety aspect, managers can real time monitoring of the traffic accidents and improve the emergency response capabilities of traffic accidents. This traffic view system can display the accuracy accident location which support the manager to judge and analyze the surrounding situation of the accident, provide decision support for the accident handling, and minimize the impact of the accident on the traffic operation and handling emergencies efficiency. In the traffic view system, we developed a function to freeze the traffic flow. When there are some vehicles did not obey the traffic rule such as ran the red light and some jeepney drivers stopped randomly in the middle of road to pick up passengers, through the freeze function can effectively monitor and identify the offending vehicle and driver's information which will reduce the accident and optimize the traffic condition.

Figure 3.80 Traffic view in Unity3D

Chapter 4: CONCLUSIONS & FUTURE DEVELOPMENT

4.1 Conclusions

This case study focus area is the region near to the MCIA airport which located in Lapu-Lapu city. Firstly, analyzes the global environment effects by urban traffic which reflects that improving transportation plays an important role in urban development and personal safety. Through reading a large number of literatures and relative articles to understand this case study's background and significance, discover the current traffic problem in Philippines and Metro Cebu to determine the case study's goal and practical solutions. As the same time, study the application of digital twins to smart cities and smart transportation, and think about how to use digital twin technologies to realize our case study's goal. In this thesis, through traffic analysis, emission analysis and energy analysis to establish a proposal to achieve our case study goal and through digital twin technologies to realize the practical solutions. The specifics results are as follows:

1. Nowadays all over the world, the number of vehicles is growing rapidly, and with the vehicles amount continuous increasing, the traffic congestion cannot be avoided. As the same time the emission of vehicle exhaust pollutants has become the main reasons cause of urban environmental degradation and induce serious health impacts.
2. In the Philippine and metro Cebu, the population grows fast induces the traffic volume increase but limit road capacity. Since the lack of quality infrastructure, insufficient public transport services and inadequate traffic management causes the seriously traffic congestion and air pollution.
3. Our case study defines the goal is to reduce traffic congestion and reduce the CO_2 and other pollutants emission.
4. Our group established a proposal to realize the case study goal: design of a mobility hub which includes smart parking area, micro-mobility hub and a walkway directly connect between MCIA airport and Lapu-Lapu city center. The energy source for charging comes from solar panels installed on the roof of smart parking area and the top of the walkway.
5. Through the Lapu-Lapu city traffic volume distribution results from Macroscopic traffic analysis by TransCAD as a basis for the choice of working area location (the area includes the intersection of the M.L. Quezon National highway and Lapu-Lapu city hall) which is one of the highest traffic density roads and has a high transportation demand.
6. Using VISSIM to simulate microscopic traffic analysis of the working area to obtain the

numbers of vehicles, average speed, acceleration, travel time, distance, etc. in one hour for the emission analysis.

7. Based on the MOVES emission estimation software and obtains meteorological data of the working area and the traffic data output from VISSIM using Python to sort and organize data, combined with the principle of VSP Operating mode distribution to analysis the emission of working area. Through setting different percentage of the electric vehicles to conclude that extensive use of electric vehicles and use solar energy as resource will significantly improve air pollution and reduce CO_2 thereby reducing the greenhouse effect in Lapu-Lapu. Through the energy analysis to prove our proposal's feasibility.
8. From our proposal can know, after establishing the mobility hub in the Lapu-Lapu will induce a large amount of people flow and traffic flow. Based on the digital twin technologies, research and realize the design and development of working area (Lapu-Lapu city hall) data visualization management by Unity3D can effectively monitor the traffic and improve the fluidity of people. Use 3D modeling tool 3dsMAX to construct the working area virtual models. Merge the 3D virtual models and data information in the Unity3D platform. Develop the functional modules: traffic view monitor, mobility hub monitor, energy state monitor, building information query system, surveillance cameras system to assist managers to control and monitor the traffic to reduce traffic congestion and provides decision-making basis for city management.

4.2 Future Development

Although I have achieved certain results in the research and implementation of the case study, due to my limited learning ability and technical level, as well as limited time and reference resources, some results and functions in this thesis have some deficiencies and have not achieved the expected results, I hope that these deficiencies can be improved in the future research work:

1. Lack of the accuracy real-time Philippines and Lapu-Lapu city traffic data and information which will induce the analysis results not accuracy which needs to go to the local area and collect information.
2. For macroscopic traffic analysis, because the number of statistics and analysis OD data is very large, and the regional road network is generally complicated. These all bring difficulties to the statistical analysis of OD data; the accuracy is not high, and the efficiency is low. The input road network data of Mactan island from OSM has breakpoints will create the inaccuracy.

3. The MOVES emission estimated software is based on the United State traffic emission model. Due to the drive habits and conditions in Philippines are different from United State. The emission model should optimize to fit for Philippine.
4. MOVES treats the vehicle emission is equal to zero. Next step is to research more detail about the energy source choice and the pollution caused by battery recycling and electric vehicle manufacturing.
5. For the digital twin data visualization management system need further development. First to install the various sensors in the physic city to collect real-time traffic data to realize the real time monitor and control. Second, this thesis only introduces the management system's monitor UI design ideas and data processing for the historical data in Lapu-Lapu city hall, which cannot be called a true digital twin. In the future, to realize the digital twin need to research deeply in the data collection technology, IoT technology, machine learning, data transmission and raw data from sensors processing.
6. The interactive system for management system is mainly though mouse click or pass over. In the future can develop the touch, voice, facial expressions, and other ways to interact which make the interaction more natural.
7. This thesis only thinks about the traffic management side, in the future can develop an APP as shown in **Figure** 4.1 in the passenger view. Passenger can choose the parking service to book parking slot or choose share mobility Service to choose the best travel method.

Figure 4.1 MaaS APP

APPEDIX

Electric vehicle 2.5%

Source	Fuel	CO2	CO	NOx	Total_PM10	Total_PM2.5	TotalEnergy[J]	Distance[Mile]
11	1	89062	3836	98	17	15	1239272320	214
21	1	72101	1330	46	1	1	1003255104	118
21	2	18839	320	14	0	0	255748752	30
21	9	0	0	0	0	0	32155626	4
31	1	31360	392	24	0	0	436366272	44
31	2	11274	72	63	3	3	153052368	11
31	9	0	0	0	0	0	13853730	1
32	1	56754	657	37	0	0	789711552	68
32	2	18787	87	94	3	3	255041472	17
32	9	0	0	0	0	0	22103088	2
42	1	1090	5	0	0	0	15164326	1
42	2	7671	20	32	1	1	104138624	4
42	3	746	13	2	0	0	12641188	0
51	1	159	7	1	0	0	2208637	0
51	2	16047	42	92	6	5	217853600	7
51	3	1222	20	1	0	0	20697122	1

Electric vehicle 20%

Source	Fuel	CO2	CO	NOx	Total_PM10	Total_PM2.5	TotalEnergy[J]	Distance[Mile]
11	1	89062	3836	98	17	15	1239272320	214
21	1	59159	1091	38	1	1	823183616	97
21	2	15457	263	11	0	0	209845120	24
21	9	0	0	0	0	0	257244848	30
31	1	25731	322	20	0	0	358044064	36
31	2	9250	59	52	2	2	125581448	9
31	9	0	0	0	0	0	110829856	11
32	1	46567	539	31	0	0	647968448	56
32	2	15415	72	77	3	3	209264800	14
32	9	0	0	0	0	0	176824704	18
42	1	1090	5	0	0	0	15164326	1
42	2	7671	20	32	1	1	104138624	4
42	3	746	13	2	0	0	12641188	0
51	1	159	7	1	0	0	2208637	0
51	2	16047	42	92	6	5	217853600	7
51	3	1222	20	1	0	0	20697122	1

Electric vehicle 40%

Source	Fuel	CO2	CO	NOx	Total_PM10	Total_PM2.5	TotalEnergy[J]	Distance[Mile]
11	1	89062	3836	98	17	15	1239272320	214
21	1	44370	818	28	1	1	617387648	73
21	2	11593	197	8	0	0	157383856	18
21	9	0	0	0	0	0	514489664	61
31	1	19299	241	15	0	0	268533088	27
31	2	6938	45	39	2	2	94186104	7
31	9	0	0	0	0	0	221659664	22
32	1	34925	405	23	0	0	485976320	42
32	2	11561	54	58	2	2	156948608	11
32	9	0	0	0	0	0	353649376	35
42	1	1090	5	0	0	0	15164326	1
42	2	7671	20	32	1	1	104138624	4
42	3	746	13	2	0	0	12641188	0
51	1	159	7	1	0	0	2208637	0
51	2	16047	42	92	6	5	217853600	7
51	3	1222	20	1	0	0	20697122	1

Electric vehicle 60%

Source	Fuel	CO2	CO	NOx	Total_PM10	Total_PM2.5	TotalEnergy[J]	Distance[Mile]
11	1	89062	3836	98	17	15	1239272320	214
21	1	29580	546	19	0	0	411591808	48
21	2	7729	131	6	0	0	104922584	12
21	9	0	0	0	0	0	771734720	91
31	1	12866	161	10	0	0	179022032	18
31	2	4625	30	26	1	1	62790736	4
31	9	0	0	0	0	0	332489504	34
32	1	23284	270	15	0	0	323984224	28
32	2	7707	36	39	1	1	104632432	7
32	9	0	0	0	0	0	530474112	53
42	1	1090	5	0	0	0	15164326	1
42	2	7671	20	32	1	1	104138624	4
42	3	746	13	2	0	0	12641188	0
51	1	159	7	1	0	0	2208637	0
51	2	16047	42	92	6	5	217853600	7
51	3	1222	20	1	0	0	20697122	1

Electric vehicle 80%

Source	Fuel	CO2	CO	NOx	Total_PM10	Total_PM2.5	TotalEnergy[J]	Distance[Mile]
11	1	89062	3836	98	17	15	1239272320	214
21	1	14790	273	9	0	0	205795904	24
21	2	3864	66	3	0	0	52461284	6
21	9	0	0	0	0	0	1028979392	121
31	1	6433	80	5	0	0	89511040	9
31	2	2313	15	13	1	1	31395370	2
31	9	0	0	0	0	0	443319328	45
32	1	11642	135	8	0	0	161992096	14
32	2	3854	18	19	1	1	52316208	4
32	9	0	0	0	0	0	707298752	70
42	1	1090	5	0	0	0	15164326	1
42	2	7671	20	32	1	1	104138624	4
42	3	746	13	2	0	0	12641188	0
51	1	159	7	1	0	0	2208637	0
51	2	16047	42	92	6	5	217853600	7
51	3	1222	20	1	0	0	20697122	1

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