RESEARCH ARTICLE OPEN ACCESS

Design of Rumble Strips with Embedded Piezoelectric Harvesting Device as a Source of Renewable Energy for Traffic Counting Detectors

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Abstract:

This study focuses on designing a prototype of Rumble Strips with embedded Piezoelectric Harvesting Devices to collect energy from vehicle vibrations and power traffic counting detectors. The use of renewable energy provides sustainability because of the number of benefits it provides and alleviates the use of fossils that are commonly used to produce energy in households and public use. The rumble strips with piezoelectric harvesting devices are a combination of materials that provide two different benefits: alerting drivers to changing traffic conditions and contributing energy through vehicle vibration utilizing piezoelectric devices. Previous studies have demonstrated that materials such as piezo-tiles, and road cement-based piezoelectric have a substantial impact on energy generation and give an extensive amount of electricity. The designed thermoplastic rumble strips are as follows: base layer of primer, 2-mm thick of thermoplastic paint; after that, the Piezoelectric Harvesting Devices are installed; next, it is covered with 8-mm thick thermoplastic paint. The rumble strips are subjected to external factors, and the AASHTO T250-19, or Hardness Test, is performed. The study shows that in laboratory, the rumble strips are classified as Extra Hard, yet in dry and wet conditions, they are categorized as Hard material, which satisfies the rumble strip requirements. After that, the Vehicle Energy harvesting where the researchers utilized six records using motorcycle, sedan, L300Van, and Patrol2004 that pass through the rumble strips to obtain average volts. The rumble strips with piezoelectric produced a minimum average of 22.13-volts and maximum of 1036.57-volts, which are stored in the 3200-volt battery and it shows capability to power the 5-volt camera in the study. The 5-volt and watts camera have a computed operating time of 30.72-hours using the battery efficiency specifications. Overall, the design, classifications, and results in the voltage computations of the study were viable and effective.

Indexed Terms—Renewable Energy, Thermoplastic, Rumble Strips, Piezoelectric Harvesting Device, Vehicle vibration, Viable

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I. INTRODUCTION

In recent years, the world has witnessed a growing concern for sustainable energy sources to combat climate change and reduce the dependence on fossil fuels. Renewable energy, such as solar and wind power, has emerged as a promising solution. However, it is crucial to address the issue of energy losses that occur due to vehicle vibrations.As vehicles move along roads, they generate vibrations that can be detrimental to renewable energy infrastructure. While renewable energy holds immense potential for a sustainable future, it is essential to address the challenges posed by vehicle-induced vibrations. In line with Sustainable Development Goal 7 of the United Nations, which focuses on Affordable and Clean Energy, passing vehicles create vibrations on highways and this vibration is a waste product of energy or pressure on the roadways, which piezoelectric technology can collect and transform into electrical power.

Designing of Rumble Strips and providing power supply for Traffic Counting Detectors which will count the vehicles passing through a specific area using Piezoelectric Harvesting Devices is a significant advancement in transportation technology. Rumble strips are intended to warn drivers when they deviate off the road, thereby preventing accidents and enhancing road safety. Designing rumble strips with embedded piezoelectric harvesting devices is an innovative approach to improve road safety while also providing a sustainable power source for traffic counting detectors.

The public utilizes the road for transportation; designing road markings such as pedestrian lanes and rumble strips with the use of appropriate technology like embedded piezoelectric harvesting devices to convert waste energy from the vibration produced by the vehicle can improve the transportation system and promote sustainable development. In the study of Sun [1], the use of piezoelectric materials generates an electrical voltage when subjected to external force (pressure or stress). If irregular force is continuously applied to a piezoelectric material, the charges are simultaneously collected by the charge collector and stored in the energy source equipment. Piezoelectric power generation is without pollution, thermal radiation, electromagnetic interference (EMI), or noise. It is considered green power generation as it has no emissions, heat, electromagnetic conversion, or big mechanical vibration.

Transportation is the movement of goods and persons from place to place and the various means by which such movement is accomplished. The growth of the ability and the need to transport large quantities of goods or numbers of people over long distances at high speeds in comfort and safety has been an index of civilization and in particular of technological progress [2].Traffic congestion can cause a lot of negative impact not only to the people who travels, but also to the economy of the society. Numerous cities throughout developing countries, particularly in Asia, struggle the joint harms of rising population, high density and increasing use of private vehicles, motorbikes or cars, resulting to unpleasant levels of air pollution and severe traffic congestion. These changes are not new to the Philippines. Since the 1990’s, the Philippines are dealing with an explosive increase [3]. This issue is affecting numerous regions of the country, and its impact becoming an inconvenience for communities and the government.

Considering Sustainable Development Goal (SDG) 11, which states Sustainable Cities and Communities, Municipalities and cities may enhance city roadway safety and traffic flow by incorporating Smart Traffic Management Systems or STMS, which are technology solutions, into traffic cabinets and junctions. These systems alleviate congestion by using sensors, cameras, cellular routers, and automation to monitor and direct traffic. Mazur [4] stated that, Innovative cities known as "smart cities," are enhancing safety and traffic flow by combining hardware, software, and cloud solutions. The newest developments in Internet of Things (IoT) technology are used by these systems, which fall under the general category of "intelligent transportation systems" or "intelligent traffic management," to optimize traffic flow and improve safety. They employ cellular technology, cameras, routers, and sensors to dynamically modify control mechanisms like speed limits, bus rapid transit lanes, highway message boards, traffic lights, and freeway on-ramp meters.

Traffic detectors play a crucial role within modern transportation networks by collecting valuable data on current traffic conditions. This information is then used to enhance the oversight and operation of mobility systems. These detectors are responsible for monitoring various aspects, such as the number of vehicles, including trucks, passengers, and drivers.An example of a traffic detector in action is a radar detector installed on a roadway, which counts and measures the speeds of cars, trucks, and buses. The data collected by this radar detector can then be utilized by transportation agencies to implement variable speed systems, ramp metering systems, and calculate accurate journey durations for display on electronic message signs [5].

Traffic count is the number of vehicular or pedestrian traffic that is conducted on a particular road, path, or intersection. Traffic counts are usually obtained through an automatic (temporary or permanent) traffic recording device or manually through observation, a visual count, and recording traffic on an electronic device or tally sheet.It is related to the Traffic Volume definition of Musa[6], which is defined as the number of vehicles passing at a point on a road segment or in a lane during a specific time interval. In addition, Zhan [7] also added that, traffic volume estimation at the city scale is an important problem useful to many transportation operations and urban applications.

The application of renewable sources to road infrastructure are also not in sight or not that focus because of lacking of advancements to renewable and clean energy. In Pampanga, the City of San Fernando, where the City Public Order and Safety Coordinating Office or CPOSCO, is currently operating a traffic monitoring system that provides live streamed real-time traffic updates to the public in congested areas of the city. This is one of the city's concepts for informing the public about the traffic situation on their way towards their destination and also leads the construction of road infrastructures in the city.

In this study, the focus is to utilize the road markings, specifically the thermoplastic rumble strips which will incorporate or embed the Piezoelectric Harvesting Device (PEH) to generate the Traffic Counting Detector or simply camera.

REVIEW OF RELATED LITERATURE

A. Rumble Strips

Rumble Strips, also known as reflectorized thermoplastic rumble strips, serve as an essential safety feature on roadways. Reflectorized thermoplastic rumble strips serve several important purposes in traffic control. Warning Drivers: These strips are used to warn or alert drivers about upcoming roadway conditions. For example, they can indicate intersections, sharp curves, narrow bridge approaches, toll plazas, and tunnels. Complementary to Signs: They can complement advance warning signs, such as the “Stop Ahead” or various curve signs, providing an additional visual cue to drivers. Combat Drowsiness: Rumble strips are also effective in preventing or lessening the effects of drowsiness during long drives, inattention, and highway hypnosis. Thermoplastic rumble strips are made from a highly durable material called thermoplastic. Unlike other types of road paint, thermoplastic lasts for several years, making it a reliable choice for long-lasting road markings [8].

Rumble strips have several benefits. They are commonly used to reduce lane departure crashes and improve safety on roadways[9]. Temporary rumble strips are also effective in reducing vehicle speeds in work zones and alerting drivers to approaching work zones[10]. In pedestrian areas, rumble strips can help limit speed and reduce the number of traffic accidents [11]. Additionally, rubber sinusoidal rumble strips have been found to reduce noise outside the vehicle and maintain sound and vibration performance inside the vehicle[12]. Rumble strips are an effective countermeasure for reducing crashes, improving driver behavior, and enhancing safety on the roads. Rumble strips can be positioned to reduce unintentional crossing and run-off-road accidents, with the lateral distance needed depending on factors such as speed, angle of exit, and road surface conditions [13].

Rumble strips are safety measures used on highways to alert drivers when they deviate from their travel lane. Rumble strips in the centre of two-lane rural roads and on the shoulder of motorways are a countermeasure to help drivers who are unintentionally about to leave the lane, for example, due to sleepiness or inattention [14]. There are different types of rumble strips include centerline rumble strips, shoulder rumble strips, and transverse rumble strips. In the study, the Transverse Rumble Strips is utilized where it is stated that transverse rumble strips are designed to engage drivers' auditory and tactile senses and are often used in conjunction with traffic signals [15]. The ability of rumble strips to produce vibration varies depending on factors such as strip depth and design. Studies have shown that rumble strip depth has the greatest impact on alerting drivers, with deeper strips producing more vibration. Furthermore, in the study of Wang et.al [16] they can be formed either by cutting grooves into the pavement or creating raised ridges by adding material on surface of the pavement. Several types of portable rumble trips have been installed and tested in advance of work zones. Based on the material function and installation process, the portable rumble trips can be briefly categorized into two types, single use removable temporary rumble strips and reusable temporary rumble strips. As a proactive traffic measure, rumble strip is a useful way of controlling speeds where it is unnecessarily excessive and inappropriate for the place and use in the surroundings [17].

Fig. 1 Types of Rumble Strip – (Up Left) Centerline, (Up Right) Shoulder, and (Bottom) Transverse

B. Piezoelectric Technologies

Piezoelectric technology has various applications in different fields. It is used in aircraft and industrial contexts for efficient and economical energy conversion, such as in the Avionic Piezoelectric Deicing System. Piezoelectric materials are also used in energy harvesting systems, where they can generate electrical energy from a wide range of input frequencies and forces [18]. Additionally, piezoelectric materials play a crucial role in the development of sustainable energy systems and have applications in sensors, actuators, power sources, motors, and environmental and biomedical domains [19]. The performance of piezoelectric energy harvesting is influenced by various parameters, including the type of piezoelectric material, structure design, source of excitation, frequency and speed, electrical load, and energy accumulation methods [20].

Fig. 2 Piezoelectric Harvesting Devices – Disc (PEH)

Power is necessary for human health and survival, and waste energy can be converted into usable foot energy. Piezoelectric technology can be used to engineer floors.This technology uses ground sensors to detect electric power generated by stress and a piezo-powered transducer to transform that electric power into electrical energy. This energy can be utilized in homes, in congested places like train stations, for streetlights, in schools, and in colleges. A sophisticated footstep energy generator is suggested that harnesses the renewable energy of footsteps by using piezoelectric sensors.This renewable energy source is inexpensive, simple to use, and has a wide range of uses. Through the use of piezoelectric technology, the project seeks to generate energy by harnessing the power produced by human walking vibrations [21].

In large cities, there is a lot of walking, particularly in the hubs of community activities like offices, trade centers, and educational institutions.The goal is to create a sidewalk that is as innovative as possible while also drawing people to walk on it. To achieve this, piezoelectric sensor technology will be used to turn the street into an independent power source, and the average number of walkers as well as the average power of each step will be counted. The design uses four parallel piezoelectric pieces in one piece of media, and an average of 3207 steps per minute is required for the source of energy [22].

Cement-based piezoelectric sensors for traffic monitoring are reliable because, as demonstrated by laboratory tests, their voltage magnitude is linearly proportional to the applied pressure. Using the mechanical-electrical model and accounting for the charge-leakage property of the piezoelectric sensor in addition to vehicle speed, a series of on-site road tests conducted by a 6.8-ton van and a 10-ton truck demonstrate the ability to predict weight-in-motion in vehicles. The error of the 6.8-ton van's repeated weigh-in-motion measurements is less than 1 ton in the speed range of 20 km/h to 70 km/h. The findings show that embedded piezoelectric sensors based on cement and the related measurement system are capable of monitoring smart traffic in a number of ways, including flow traffic [23].

Piezoelectric technology is being explored as a renewable energy source for rumble strips. These strips are designed to generate electrical energy from mechanical energy produced by vehicles passing over them. The piezoelectric road deceleration strip device described by Chen et al. utilizes piezoelectric units to convert mechanical energy into electric energy, offering advantages such as a simple structure, low cost, and high energy conversion efficiency [24]. Hall et al. present a piezoelectric energy harvester device with elongated strips of piezoelectric units that can be selectively connected to power management circuitry, allowing for efficient energy harvesting from variations in vibration magnitude or modes [25]. Wang et al. propose a road piezoelectric power generation deceleration strip that incorporates d33 and d15 piezoelectric energy harvesting pieces to generate power through extrusion and shear force, respectively [26]. These studies demonstrate the potential of piezoelectric technology for generating renewable energy from rumble strips.

C. Traffic Counting Systems

A traffic counting detector is a system or tool used for surveillance and traffic control that tracks and measures the amount of vehicle traffic on roadways. In addition to improving traffic flow and road safety, these detectors also support law enforcement. Car Detection and Counting: These detectors recognize and count cars traveling through particular regions using image processing techniques. They offer up-to-date data on vehicle density, speed, and flow by examining real-time traffic situations. Intelligent traffic management system design is aided by the data gathered.

Traffic count is important because it provides data on the number of vehicles on the road, which is crucial for traffic management and planning. It helps authorities understand traffic flow, congestion levels, and peak hours, allowing them to make informed decisions about road infrastructure improvements and traffic control measures [27]. However, surveillance video cameras have become a popular alternative for vehicle counting, as they provide videos that can be processed using computer vision techniques. This allows for accurate and cost-effective vehicle detection and counting [28].

Smart Traffic Management System is the name given to the technology-enabled traffic control. A system known as "smart traffic management" uses sensors and centralized traffic signals to control traffic flow in a metropolitan area based on demand. Additionally, the main goals of STMS are to monitor and regulate speeds, control daily traffic congestion, lessen traffic accidents, enforce traffic laws and regulations, and lessen vehicle pollution. Utilizing the most recent developments in Internet of Things (IoT) technology, including networking hardware, wireless applications, cameras, sensors, and cameras, STMS are automated systems. By dynamically modifying control mechanisms like traffic lights, expressway on-ramp meters, effective public transportation lanes, highway message boards, and speed limits, IoT systems can optimize traffic flow and increase safety [24].

BACKGROUND OF THE STUDY

The lack of utilization of renewable energy through road infrastructures and of improvement in the traffic monitoring system is one of the main problems that the Philippines faces, which has a significant connection to the situation in the

Province of Pampanga. Studies on piezoelectric devices which use footsteps to generate renewable energy that are embedded into stairs, walkways and pedestrians are already existing in which they are successfully working and effective for use. As transportation increases, the amount of vibration produced by vehicles also increases. These vibration losses can be converted into renewable energy. This renewable energy can be harnessed through the use of a technology called Piezoelectric Harvesting Devices. This innovative device can be embedded in the Rumble Strip to harness more kinetic energy produced by the vehicle passing through it and convert it into electrical energy.

The City Public Order and Safety Coordinating Office, or CPOSCO in San Fernando Pampanga, has a traffic surveillance system, which is a great help in spotting the movement of traffic and informing the public of this situation. CPOSCO has a Closed-circuit television (CCTV) surveillance system that serves as a monitoring system of traffic flow, and it is a live broadcast through the social media application, which informs people on traffic situations in those particular areas of the city. The existing CPOSCO surveillance system for traffic data collection is not a record of traffic data but an advisory to the public about the traffic situation in certain areas of the city that the office focuses on. Furthermore, the road intersections along San Vicente Apalit Pampanga proposed a traffic management system which includes manual vehicle counting. Given its current state, the Apalit Crossing definitely need a safe and effective traffic management system. Manual counting, traffic surveillance system, road widening, parking management system, and public transport plan are some of the many solutions proposed and implemented by local government units to improve traffic conditions in the Pampanga [29].

The vibrations of the vehicles they produce on the road are wasted, it can be utilized as a source of renewable energy which is under SDG 7 to power something beneficial rather than wasting it and not using it. The enhancement of road markings like the Rumble Strips in highways with the application of energy harvesting devices in it and the implementation of Smart Traffic Management System (STMS) is an approach to enhance the traffic solutions and also apply new energy sources of electricity.

II. METHODOLOGY

A. *RESEARCH DESIGN*

This study will develop a prototype of Rumble strips with embedded Piezoelectric Harvesting Device as a source of renewable energy from the kinetic energy of vehicles to power or generate the Traffic Counting Detector and to test if it works with the generated electricity.To assess the resistance of the set design of Rumble Strips with an embedded Piezoelectric harvesting Device, Empirical testing involves experimentation where the design of the Rumble Strips with Piezoelectric Harvesting Device (PEH) should not be damaged during the Application and Kneading process, this kind of testing will enable researchers to draw conclusions from empirical findings by using all the data that will be gathered from this experiment or first-hand observation as evidence[30].The researchers will also use an experimental method since this study presents an innovative approach towards sustainable energy generation by designing rumble strips with embedded piezoelectric harvesting device and theoretical data, on the other hand, will use equations, or simulations without direct observation. In order to verify or validate theories or hypotheses by observation and experimentation, empirical testing is an important method in this study.

B. *MATERIALS AND EQUIPMENT*

The materials and equipment to be used in the development of the prototype for Rumble Strips includes thermoplastic paint (white), glass beads, primer, and liquefied-petroleum gas (LPG). For Piezoelectric materials includes piezoelectric harvesting device disc, American wire gauge #22, soldering lead and iron, and battery. For the Equipment used in the study includes the pre-heater application machine, kneading machine, digital volt meter, AC-DC Converter, and a step-down buck converter. Additionally, a Shore D Durometer equipment is needed to test the Hardness of the thermoplastic material after the application and kneading process. For the platform in testing, a simple road-like surface is needed to test after the development, to have better results and controlled environment.

C. Design Concepts

These concepts will represent as a guide from the different obtained data from local, national and other agencies especially the designs for rumble strips and the design connection of Piezoelectric Devices. This will serve as the guidelines in order to achieve the goals of the study.

- Design of Standard Rumble Strips – the study will be guided, based on the Department of Public Works and Highways (DPWH) Item 612 [31]and 618[8]
- Design and Layout of Piezoelectric Harvesting Device – as shown in the figure

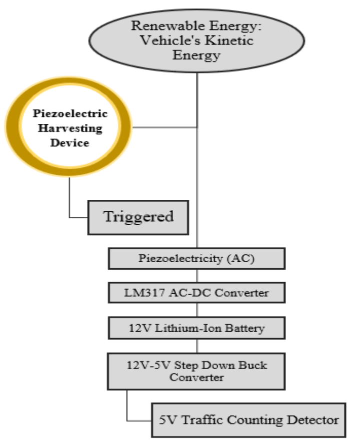

Fig. 3 System Flow Design of Piezoelectric Harvesting Devices

D. Development of the Prototype of Rumble Strips with Piezoelectric Harvesting Device

STEP 1: ***Creation of the Platform for RumbleStrips with Piezoelectric HarvestingDevices***

The whole platform where the rumble strips will be laid or placed must have the dimensions of 2 meters long, 0.5 meters wide and with a thickness of 0.1 meters.The platform serves as the foundation for the rumble strips, providing a stable base for testing and evaluation.

STEP 2: ***Connection of Piezoelectric Harvesting Devices (PEH)***

The pieces are joined using stranded wires and soldering iron to connect each PEH and test if each one of the pieces will work in a single tap. The outside part of these devices, which is gold in color, serves as the negative terminal. This outer layer acts as a protective barrier for the inner crystal part. This part of the piezoelectric harvesting device is where the piezoelectric effect takes place. When mechanical stress is applied to this crystal, it generates an electric charge. This charge is then collected by a red wire, which serves as the positive terminal.

STEP 3: ***Laying, Application and Kneading of Rumble Strips with embedded Piezoelectric Harvesting Devices (PEH)***

Piezoelectric Harvesting Devices (PEH) are for generating electricity from mechanical vibrations, such as those produced by vehicles driving over rumble strips. The process begins with the application of a layer of thermoplastic road marking primer to ensure proper adhesion. This is followed by a layer of 2-mm thermoplastic paint, which serves as the base for the piezoelectric devices. The devices are then placed on top of this layer before being covered with another layer of 8-mm thermoplastic paint with glass beads. This method ensures that the piezoelectric harvesting devices are securely embedded in the rumble strips and protected from wear and tear. Additionally, while application and kneading, the PEHs are tested after applying each of the layers to ensure that they are still working despite of highly heated thermoplastic material.

E. Research Samples

For Thermoplastic Rumble Strip with Embedded Piezoelectric Harvesting Device

It is suggested by the DPWH Pampanga 1st DEO to use at least one (1) to two (2) strips for testing. The researchers estimated the number of Piezoelectric Harvesting Device (PEH) pieces using the equation:

$$No.of\ PEH = \frac{Length\ of\ Rumble\ Strip}{\emptyset\ of\ PEH + Spacing}$$

$$No.of\ PEH = \frac{2000mm}{35mm + 25mm}$$

$$\boldsymbol{No.of\ PEH = 33.33pcs\ \approx 34\ pieces\ in\ a\ strip}$$

The obtained pieces each strip are 34 pieces of 35mm diameter in a 2-meter length spaced at 25mm. The Rumble Strip width is 100mm, making the strips into two (2) sets. So, the total number of PEH are 68 pieces in one (1) Rumble Strip with 50mm spacing between the two (2) sets center-to-center. They are connected though cathode wire as positive charge (red) and anode wire as negative (black) which are soldered using soldering iron and stranded wires to the interface of PEHs.

F. Prototype Design

The study provides the detailed specification in drawings and the 3D visual representation of the Miniature Prototype.

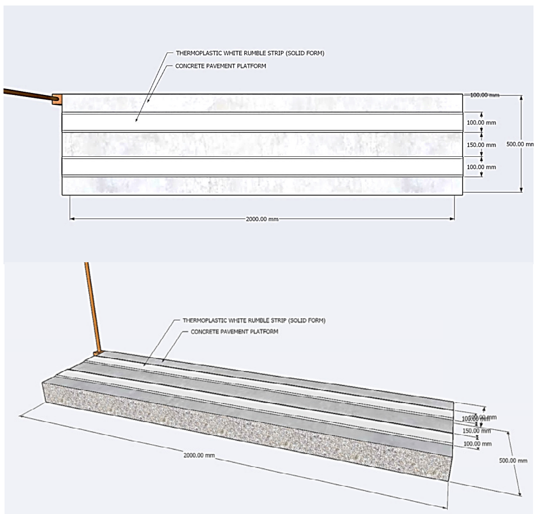

Fig. 4 Standard Design of Thermoplastic White Rumble Strip (SOLID FORM) in Concrete Pavement Platform (Top View & Isometric View)

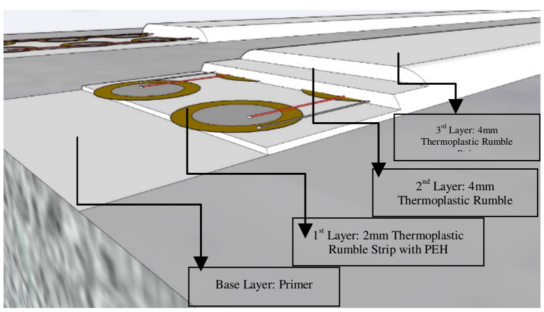

Fig. 5Detailed Design of Rumble Strips with Embedded PEH (Top View & Isometric View)

G. Research Prototype Testing

The following are the list of requirements and parameters to be considered during the testing:

(1) Resistance of the Designed Rumble Strip with Piezoelectric Device in Application and Kneading Process

(2) Hardness Test (AASHTO T 250-19)

(3) Vehicle Vibration Energy Harvesting

(4) Battery Specification Efficiency to Supply Traffic Counting Detector

The Rumble Strips and Piezoelectric Harvesting Devices are subjected to test their resistance during the Application and Kneading process; it should satisfy the goal that the piezoelectric material and its components will not be damaged during the application and kneading of thermoplastic paint.

The Rumble Strips with embedded PEH are to test its Hardness based on the AASHTO T 250-19. The Hardness test will use Shore D Durometer as per the ASTM D2240-15 to determine the classification of the Rumble Strips hardness based on the Scale.

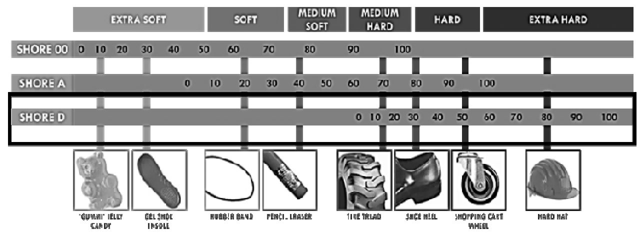

Fig. 6Each RS with PEH, are triggered andproduced amount of energy in terms of voltage as the vehicle passes through.

The vibration of the different vehicles will be harvested from Piezoelectric Devices, and the renewable energy will be converted into electricity by the AC-DC Converter and to the battery storage to power the Traffic Counting Detector.A simulation in Wide Range Simulation of RS with embedded PEH and also adopted in the study prototype are shown in the figure below:

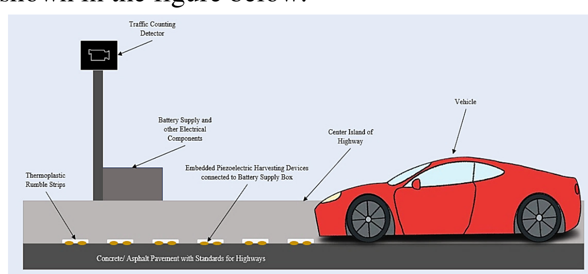

Fig. 7A vehicle approaches the sets of Rumble Strips with PEH

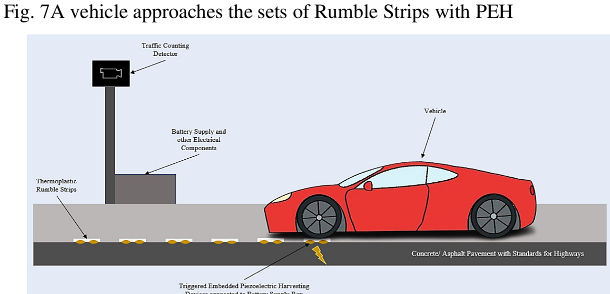

Fig. 8Vehicle pass through the first RS with PEH, triggered andproduced energy

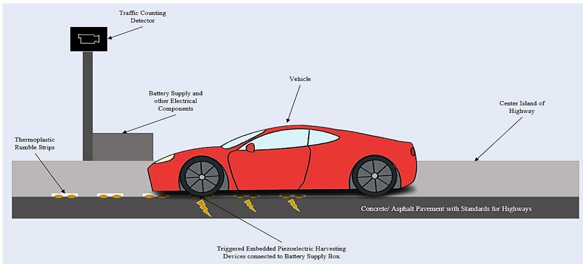

Fig. 9Each RS with PEH, are triggered andproduced amount of energy in terms of voltage as the vehicle passes through.

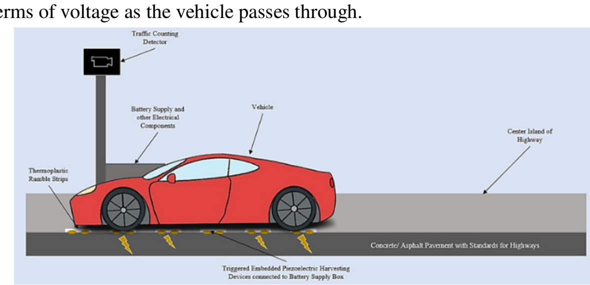

Fig. 9The set of RS with PEH are triggered andproduced energy in terms of voltage as the vehicle passes through and to be stored in the battery supply to be converted into electricity to generate the Traffic Counting Detector.

III. RESULTS AND DISCUSSION

A. Resistance of the Designed Rumble Strip with Piezoelectric Harvesting Device during Application and Kneading Process

In the study, the layered Rumble Strips design with the embedded Piezoelectric Harvesting Device are tested its resistance, showing the status of the materials during the Application and Kneading Process is shown in the table.

TABLE I. STATUS OF THE DESIGNED MATERIALS DURING APPLICATION AND KNEADING

STATUS OF THE DESIGNED MATERIALS DURING APPLICATION AND KNEADING		
LAYER	**COMPONENT**	**STATUS of RS with PEHs**
0	Primer for Concrete	Not Applied
1	2 mm thick Thermoplastic Rumble Strip 1 with Piezoelectric Harvesting Devices (PEH)	Applied
2	4mm thick Thermoplastic Rumble Strip 2	Working
3	4mm thick Thermoplastic Rumble Strip 3	Working
	REMARKS:	**WORKING**

The table I shows the sequencing of the designed layer of the Rumble Strips with PEH and its status. The table 9 presented in the experiment demonstrates that the piezoelectric harvesting devices were able to resist the heated thermoplastic material without sustaining any damage. The crucial part when applying the piezoelectric disc in the first layer of the rumble strip is the connection of the piezoelectric to the wire at the point of connection as a result the connection wire bonds strong when the rumble strip is hardened. It was observed that the wires connected to each piezoelectric device remained intact throughout the process of applying the second and third layers. This indicates a high level of durability and resilience in these materials. In addition, it was noted that the piezoelectric devices were tested using a digital volt multimeter both before and after pouring. The results showed that the PEHs are still in working condition after being subjected to extreme temperatures.

B. Hardness of Thermoplastic Rumble Strips with Piezoelectric Harvesting Device (AASHTO T 250-19)

The Rumble Strips markings are exposed to weather conditions and it is crucial to determine the hardness of the Rumble Strips especially it is incorporated with embedded Piezoelectric Harvesting Device materials which are needed to covered when vehicle approaches to the markings. The Durometer Scale's sample measurements are five (5) within a single strip, it should be assessed in numerous areas of the material to measure its hardness. The following are the Hardness Test made, considering different environmental conditions:

a.Laboratory Condition / Room Temperature

TABLE II. LABORATORY CONDITIONS FOR HARDNESS TEST

LABORATORY CONDITION		
RECORDS	DUROMETER READINGS	SHORE HARDNESS SCALE REMARKS
1	67	EXTRA HARD
2	59	HARD
3	71	EXTRA HARD
4	72	EXTRA HARD
5	70	EXTRA HARD
AVERAGE:	**67.8**	**EXTRA HARD**

The table II shows the recorded values of hardness and classification of the Rumble Strip with Piezoelectric Harvesting Device (PEH) based on laboratory conditions or room temperature. The rumble strip is examined in five (5) separate parts, notably 67, 59, 71, 72, and 70. The calculated average is 67.8, and using the Shore Hardness Scale,the Rumble Strip with Piezoelectric Harvesting Device is classified as Extra Hard.

b. Dry Condition – Daylight Peak Hour (12:00PM @43°C)

TABLE III. DRY CONDITIONS – DAYLIGHT PEAK FOR HARDNESS TEST

DRY CONDITION – DAYLIGHT PEAK HOUR (12:00PM)		
RECORDS	DUROMETER READINGS	SHORE HARDNESS SCALE REMARKS
1	54	HARD
2	46	HARD
3	49	HARD
4	50	HARD
5	57	HARD
AVERAGE:	**51.2**	**HARD**

The table III shows the recorded values of hardness and classification of the Rumble Strip with Piezoelectric Harvesting Device (PEH) based on dry conditions or daylight peak hours (12:00PM) at a 43°C temperature. The rumble strip is examined in five (5) separate parts, notably 54, 46, 49, 50, and 57. With a computed average of 51.2, the Rumble Strip with Piezoelectric Harvesting Device is categorized as Hard on the Shore Hardness Scale.

c. Dry Condition – Afternoon (05:00PM)

TABLE IV. DRY CONDITIONS – AFTERNOON FOR HARDNESS TEST

DRY CONDITION – AFTERNOON (05:00PM)		
RECORDS	DUROMETER READINGS	SHORE HARDNESS SCALE REMARKS
1	57	HARD
2	63	HARD
3	55	HARD
4	58	HARD
5	54	HARD
AVERAGE:	**57.4**	**HARD**

Table IV illustrates the hardness and classification of the Rumble Strip with Piezoelectric Harvesting Device (PEH) based on temperature measurements taken in the afternoon condition. Five (5) distinct sections are investigated in the rumble strip which are: 57, 63, 55, 58, and 54. The Rumble Strip with Piezoelectric Harvesting Device is categorized as Hard on the Shore Hardness Scale based on its computed average of 57.4.

d. Wet / Rain Condition

TABLE V. DRY CONDITIONS – AFTERNOON FOR HARDNESS TEST

WET CONDITION – AFTER RAIN		
RECORDS	DUROMETER READINGS	SHORE HARDNESS SCALE REMARKS
1	62	EXTRA HARD
2	54	HARD
3	56	HARD
4	55	HARD
5	60	EXTRA HARD
AVERAGE:	57.4	**HARD**

The table V shows how the Rumble Strip with Piezoelectric Harvesting Device (PEH) is categorized and how hard it is depending on temperature that are taken in wet conditions or after rain. Five (5) sections in the rumble strip are tested and have the results of: 62, 54, 56, 55, and 60. The determined average is 57.4, and on the Shore Hardness Scale, the Rumble Strip with Piezoelectric Harvesting Device is classified as Hard.

C. Vehicle Vibration Energy Harvesting

In this study, the collection of energy from Rumble Strips with Piezoelectric Harvesting Devices (PEH) during Vehicle Vibration Harvesting are converted into electricity using LM317 AC-DC Converter. The converter will then deliver the converted electricity to the Lithium-Ion Battery as a storage of electricity, following by the regulation of 12 volts to 5 volts Step Down Buck Converter and will then generate the Traffic Counting Detector or a camera. The flow of electricity is regulated since the capacity needed to power a camera is in 5 volts only.

Repeating the experiments multiple times ensures consistency in the results. Stated otherwise, it should confirm that the experiment yields almost identical results each time the independent variable is set to the same value. Every time an experiment is conducted, it is referred to as a run or trial. The number of trials that are planned should be specified in the protocol of the study [32].

For an accurate data, the study considered six (6) trials each vehicle. For each trial with ten recorded volts by the digital multimeter, they are all added to obtain the total voltage collected in a single wheel, followed by multiplying them with respect to the number of the wheels of the specific vehicle, and multiplying them to two (2) Rumble Strips with Piezoelectric Harvesting Devices (PEH) as per the prototype design and ten (10) for the standard number of Rumble Strips used in highways as per the guidelines of the Department of Public Works and Highways (DPWH) Maintenance Section.

Ohm's Law [33] is the relationship between the current (I) flowing through a resistance (R) and the potential drop across its volts (V). The current is directly proportional to the potential difference across the resistance and is inversely proportional to the resistance. The general formula of Ohm's Law is,

$$\boldsymbol{I = \frac{V}{R}}$$

The Ohm's Law may be stated as: The potential difference V across a resistance is directly proportional to the current I flowing through the resistance and the resistance R, or simply the equation:

$$\boldsymbol{V = I \times R}$$

Where: $V = Volts$
$I = Current\ in\ Amps - hour\ (Ah)$
$R = Resistance\ in\ Ohms\ (\Omega)$

The given battery provided the Current (I) which is 12.8 Ah and a Resistance (R) of 250 Ohms (Ω). Using the equation above, the voltage (V) can be obtained and serves as the capacity of the battery to sustain the needed volts of a single equipment that needs to be generated.

A Lithium-Ion Battery is used as a storage for the converted electricity of Piezoelectric Harvesting Devices in Rumble Strips. The specification of the battery consists of 12800 milliampere-hour (mAH) or 12.8 ampere-hour (Ah) and a resistance of 250 ohms (Ω). The computation shows the **Volt Capacity of the Lithium-Ion Battery** used for the study.

$$V = I \times R$$
$$V = (12.8\,Ah)(250\Omega)$$
$$\boldsymbol{V = 3200\ volts}$$

As shown in the computation, using the given specifications of the Lithium-Ion Battery, the **voltage capacity** of the given battery is **3200 V**.

Efficiency in generating camera or traffic counting detector is essential for accurate data collection. One method to determine this efficiency is by calculating the total number of vehicles that will provide vibration energy to the rumble strips with piezoelectric harvesting (PEH) and convert it into electricity. By measuring the average total voltage in ten (10) strips, we can estimate the number of vehicles needed to pass over them.

In equation shows:

$$\boldsymbol{N_v = \frac{V_{cap}}{V_{average}}}$$

Where: $N_v = Number\ of\ Vehicle$
$V_{cap} = Voltage\ capacity\ of\ battery$
$V_{average} = Average\ Voltage\ of\ the\ specific\ vehicle$

MOTORCYCLE

The table below represents the collected voltage (V) data of Motorcycle using a Digital Multimeter. Considering the six (6) trials made with respect to the ten (10) recorded voltage of the multimeter during the vehicle vibration energy test.

TABLE VI. COLLECTED VOLTAGE OF MOTORCYLE

COLLECTED VOLTAGE OF MOTORCYCLE						
RECORD	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
1	0.12	0.42	0.23	0.12	1.75	1.24
2	1.08	0.68	0.63	1.08	0.63	0.74
3	0.6	0.46	0.78	0.91	0.59	0.23
4	1.17	0.89	0.23	0.93	0.16	0.06
5	0.9	0.35	0.07	0.43	0.05	0.2
6	0.7	0.1	1.35	0.29	0.75	0.55
7	0.56	0.03	1.05	1.01	0.3	0.63
8	0.18	0.72	0.45	0.18	0.15	0.94
9	0.19	0.47	0.59	0.34	0.17	0.29
10	0.87	0.8	0.2	0.75	0.78	0.08
□ in 1 Wheel	6.37	4.92	5.58	6.04	5.33	4.96
In 2 Wheels	12.74	9.84	11.16	12.08	10.66	9.92
In 2 Rumble Strips	25.48	19.68	22.32	24.16	21.32	19.84
In 10 Rumble Strips	127.4	98.40	111.60	120.80	106.60	99.20

The table VI shows each motorcycle trials recorded that passes through a single Rumble Strips with Piezoelectric Harvesting Devices. There are six (6) trials made for motorcycle in order to obtain the volts generated by the vehicle. The total volts (V) in a single wheel of the motorcycle in each Trials are as follows: 6.37, 4.92, 5.58, 6.04, 5.33, and 4.96 in volts. Multiplying them by two (2) for two wheels, the total volts are as follows: 12.74, 98.4, 11.16, 12.08, 10.66, and 9.92 volts. Following the number of two (2) rumble strips for prototype which gives the total volts for each trial: 25.48, 19.68, 22.32, 24.16, 21.32, and 19.84 volts respectively. While for the standard of ten (10) rumble strips in a busy highway which gives a total volt for each trial: 127.4, 98.4, 111.6, 120.8, 106.6, and 99.2 volts.

The average volts stored in the lithium-ion battery from the two (2) rumble strips is 22.13 volts while for standard of ten (10) rumble strips in a busy highway have obtained 110.67 volts.

For the Optimal Number of vehicle or motorcycle,
For two (2) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{motorcycle} = \frac{3200\ V}{22.13\ V}$$

$$N_{motorcycle} = 144.6$$

$$\therefore at\ least\ 145\ motorcycles$$

For ten (10) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{motorcycle} = \frac{3200\ V}{110.67\ V}$$

$$N_{motorcycle} = 28.92$$

$$\therefore at\ least\ 29\ motorcycles$$

Using the formula for Number of Vehicles (N_v) for motorcycles, with the 3200-voltage capacity of the lithium-ion battery and the average voltage of 22.13, the acquired total number of motorcycles are at least 145 that will pass through the two (2) Rumble strips with PEH. While the average voltage 110.67 volts for ten (10) Rumble strips with PEH is, the acquired number are at least 29 motorcycles.

SEDAN

The table below illustrates the gathered voltage (V) data of Sedan considering six (6) trials with respect to ten (10) recorded voltages of the multimeter during the vehicle energy vibration test.

TABLE VII. COLLECTED VOLTAGE OF SEDAN

COLLECTED VOLTAGE OF SEDAN						
RECORD	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
1	2.97	2.88	0.13	0.22	5.22	2.96
2	3.01	5.66	0.44	2.86	6.87	7.25
3	6.94	7.71	7.13	7.25	7.79	8.42
4	6.29	10.09	7.4	8.42	8.68	8.61
5	12.48	7.72	4.6	8.61	9.71	8.02
6	17.28	7.53	6.83	8.02	8.87	5.81
7	6.28	6.03	7.95	5.81	6.74	7.05
8	4.41	2.96	6.51	1.14	7.72	4.28
9	2.45	1.79	3.09	0.41	5.94	1.6
10	1.16	0.12	0.76	0.19	4.42	0.48
□ in 1 Wheel	63.27	52.49	44.84	42.93	71.96	54.48
In 2 Wheels	253.08	209.96	179.36	171.72	287.84	217.92
In 2 Rumble Strips	506.16	419.92	358.72	343.44	575.68	435.84
In 10 Rumble Strips	2530.8	2099.6	1793.6	1717.2	2878.4	2179.2

The table VII shows each motorcycle trials recorded that passes through a single Rumble Strips with Piezoelectric Harvesting Devices. There are six (6) tests performed on sedans to find out the voltage generated. The total volts (V) on a sedan tire in each test were 63.27, 52.49, 44.58, 42.93, 71.96, and 54.48, respectively. Then multiplied by four (4) wheels, the total voltages are: 253.08, 209.96, 179.36, 171.72, 287.84, and 217.92. Following the number of two (2) rumble strips for prototype which gives the total volts for each trial: 506.16, 419.92, 358.72, 343.44, 575.68, and 435.84 volts respectively. For Ten (10) rumble strips in a busy highway are used as standard, and the total voltage for each trial is listed as: 2530.8, 2099.6, 1793.6, 1717.2, 2878.4, and 2179.2 volts.

The average volts stored in the lithium-ion battery from the two (2) rumble strips is 439.96 volts while for the standard of ten (10) rumble strips in a busy highway have obtained 2199.8 volts.

For the Optimal Number of vehicle or sedan,
For two (2) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{sedan} = \frac{3200\ V}{439.96\ V}$$

$$N_{sedan} = 7.27$$

$$\therefore at\ least\ 8\ sedan$$

For ten (10) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{sedan} = \frac{3200\ V}{2199.8\ V}$$

$$N_{sedan} = 1.45$$

$$\therefore at\ least\ 2\ sedan$$

Using the formula for Number of Vehicles (N_v) for Sedan, with the 3200-voltage capacity of the lithium-ion battery and the average voltage of 439.96, the acquired total number of sedans are at least eight (8) that will pass through the two (2) Rumble strips with PEH. While the average voltage of 2199.8 for ten (10) Rumble strips with PEH, the acquired number are at least two (2) sedans.

L300 VAN

The voltage (V) data of an L300 Van, based on six (6) trials and ten (10) multimeter-recorded voltages during the vehicle energy vibration test, is shown in the table below.

TABLE VIII. COLLECTED VOLTAGE OF L300 VAN

COLLECTED VOLTAGE OF L300 VAN						
RECORD	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
1	1.03	1.96	1.12	1.08	1.12	2.03
2	2.52	3.35	5.88	2.29	4.76	6.12
3	5.32	5.32	7.56	5.32	8.68	12.26
4	8.68	5.88	22.68	10.92	13.11	17.33
5	10.92	7.56	24.92	19.32	22.68	23.67
6	5.32	10.92	22.12	20.05	25.2	21.66
7	3.92	16.52	17.09	22.12	24.92	11.16
8	8.12	13.72	16.52	8.68	12.4	5.15
9	2.52	5.32	13.72	4.3	7.86	4.12
10	1.16	2.52	3.08	1.59	2.07	3.18
□ in 1 Wheel	49.51	73.07	134.69	95.67	122.8	106.68
In 2 Wheels	198.04	292.28	538.76	382.68	491.2	426.72
In 2 Rumble Strips	396.08	584.56	1077.52	765.36	982.4	853.44
In 10 Rumble Strips	1980.4	2922.8	5387.6	3826.8	4912	4267.2

The table VIIIshows all of the L300 Van trials that have been documented and utilize a single set of Rumble Strip with Piezoelectric Harvesting Device. There are six (6) tests performed in L300 Van to find out the voltage generated. The total volts (V) on the L300 Van each test was 49.51, 73.07, 134.69, 95.67, 122.8, and 106.68, respectively. Then multiplied by four (4) wheels, the total voltages are: 198.04, 292.28, 538.76, 382.68, 491.2, and 426.72. Following the number of two (2) rumble strips for prototype which gives the total volts for each trial: 396.08, 584.56, 1077.52, 765.36, 982.4, and 853.44 volts respectively. For the standard ten (10) rumble strips on a highway, and the total voltage for every test appears as: 1980.4, 2922.8, 5387.6, 3826.8, 4912, and 4267.2 volts.

The average volts stored in the lithium-ion battery from the two (2) rumble strips is 776.56 volts while for the standard of ten (10) rumble strips in a busy highway have obtained 3882.8 volts.

For the Optimal Number of vehicle or sedan,
For two (2) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{L300\ Van} = \frac{3200\ V}{776.56\ V}$$

$$N_{L300\ Van} = 4.12$$

$$\therefore at\ least\ 5\ L300\ Van$$

For ten (10) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{L300\ Van} = \frac{3200\ V}{3882.8\ V}$$

$$N_{L300\ Van} = 0.82$$

$$\therefore at\ least\ 1\ L300\ Van$$

Using the formula for Number of Vehicles (N_v) for Sedan, with the 3200-voltage capacity of the lithium-ion battery and the average voltage of 776.56, the acquired total number of L300 Van are at least five (5) that will pass through the two (2) Rumble strips with PEH. While the average voltage of 3882.8 for ten (10) Rumble strips with PEH, the acquired number are at least one (1) L300 Van.

PATROL 2004

The table below illustrates the gathered voltage (V) data of Patrol 2004 considering six (6) trials with respect to ten (10) recorded voltages of the multimeter during the vehicle energy vibration test.

TABLE IX. COLLECTED VOLTAGE OF PATROL 2004

COLLECTED VOLTAGE OF PATROL 2004						
RECORD	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
1	3.06	3.74	6.46	2.38	5.15	2.04
2	7.14	4.76	8.88	3.06	9.13	7.82
3	10.54	5.78	12.22	6.46	10.77	13.26
4	12.77	9.43	30.26	15.33	17.34	24.54
5	13.26	16.45	26.86	23.54	21.43	30.43
6	18.19	20.09	25.34	24.44	27.33	25.5
7	11.45	16.63	20.21	23.46	38.76	19.72
8	8.45	7.14	10.32	8.07	30.13	9.18
9	3.05	6.55	8.22	5.43	11.34	5.54
10	2.36	4.56	6.46	3.21	8.5	3.51
□ in 1 Wheel	90.27	95.13	155.23	115.38	179.88	141.54

In 2 Wheels	361.08	380.52	620.92	461.52	719.52	566.16
In 2 Rumble Strips	722.16	761.04	1241.84	923.04	1439.04	1132.32
In 10 Rumble Strips	3610.80	3805.20	6209.20	4615.20	7195.20	5661.60

The table IXdisplays each Patrol 2004 trials recorded that passes through the Rumble Strips with Piezoelectric Harvesting Devices. There are six (6) tests performed on Patrol 2004 to find out the voltage generated. The total volts (V) generated by the Patrol 2004 tire in each test were 90.27, 95.13, 155.23, 115.38, 179.88, and 141.54, respectively. Then the total voltages when multiplied by four (4) wheels are: 361.08, 380.52, 620.92, 461.52, 719.52, and 566.16. Following the number of two (2) rumble strips for prototype which gives the total volts for each trial: 722.16, 761.04, 1241.84, 923.04, 1439.04, and 1132.32 volts respectively. While for the standard of ten (10) rumble strips in a busy highway, the total voltage for each trial is listed as: 3610.80, 3805.20, 6209.20, 4615.20, 7195.20, and 5661.60 volts.

The average volts stored in the lithium-ion battery from the two (2) rumble strips is 1036.57 volts while for standard of ten (10) rumble strips in a busy highway have obtained 5182.87 volts.

For the Optimal Number of vehicle or sedan,
For two (2) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{Patrol\ 2004} = \frac{3200\ V}{1036.57\ V}$$

$$N_{Patrol\ 2004} = 3.09$$

$$\therefore \textit{at least } 3 \textit{ Patrol } 2004$$

For ten (10) Rumble Strips with PEH:

$$N_v = \frac{V_{cap}}{V_{average}};$$

$$N_{Patrol\ 2004} = \frac{3200\ V}{5182.87\ V}$$

$$N_{Patrol\ 2004} = 0.62$$

$$\therefore \textit{at least } 1 \textit{ Patrol } 2004$$

Using the formula for Number of Vehicles (N_v) for Patrol 2004, with the 3200-voltage capacity of the lithium-ion battery and the average voltage of 1036.57, the acquired total number of Patrol 2004 are at least three (3) that will pass through the two (2) Rumble strips with PEH. While the average voltage 5182.87 volts for ten (10) Rumble strips with PEH is, the acquired number are at least one (1) Patrol 2004.

D. Battery Specification Efficiency to Supply Traffic Counting Detector

The power required to use and the time of usage have an important role to know how long the battery can supply the needed power of the traffic counting detector device. The table X below shows the battery specification of the Lithium-Ion battery used in the study.

TABLE X. BATTERY PRODUCT SPECIFICATION OF THE STUDY

BATTERY PRODUCT SPECIFICATION	
Brand Name:	Jungla
Model:	3S2P
Type:	Lithium-Ion
Nominal Capacity:	12800 mAH
Voltage:	12V
Weight:	0.4 kg
Rechargeable:	Yes
Rated voltage:	11.1V-12.6V
Standard discharge current:	0.2C
Maximum discharge current:	1C
Resistance:	250 M Ohm Internal resistance
Battery standard:	18650 Lithium Battery
Size:	68*55*38mm
Packing:	12V / 12.8 Ah / 18650 Battery Pack*1
	12.6V / 1A / EU Charger *1

The traffic counting detector the device used in the study as the recipient of the generated electricity of the Rumble Strips with Piezoelectric Harvesting Device. The table XI shows the detailed Camera Specification used for traffic and security purposes.

TABLE XI. CAMERA SPECIFICATION OF THE STUDY

CAMERA SPECIFICATION	
Product Name:	Security Camera
Application:	V380 Pro
Color:	White
Product Material:	ABS + electronic components:
Product Size:	11×7cm
Image Sensor:	720P/1080P
Image/Video Quality:	1920 x 1080/1280 x 720/640 x 360
Power Supply:	DC 5V / 1.5A
Power Consumption:	5 W
Lens / Lens Angle:	3.6mm at 90°
Rotation Angle:	horizontal: 355°; vertical: 90°
Night Mode:	Infrared Night Vision + LED full color
Supported Mobile Systems:	Android/IOS

A Watt (W) is the unit of power (P) equal to one ampere (I) under the pressure of one volt

(V)[34]. So, the watt of the battery can be obtained using the formula:

$$P = I \times V$$

Where:
$P = Power\ of\ battery\ in\ Watts\ (W)$
$I = Current\ in\ Ampere\ (A)$
$V = Voltage\ of\ the\ battery$

Using the given specification of the Lithium-Ion battery of 12.8 Ah as current (I) and 12 volts (V), we obtained the Power output of Battery in terms of Wh as:

$$P = I \times V$$
$$P = 12.8\ Ah \times 12V$$
$$\boldsymbol{P_{out} = 153.6\ Wh}$$

The power output in $\boldsymbol{kWh}$,

$$P_{out} = 153.6\ Wh \times \frac{1kWh}{1000\ Wh}$$
$$\boldsymbol{P_{out} = 0.1536\ kWh}$$

A watt-hour (Wh) is a unit of energy (E) that measures the capacity of power (P in watts) moving over time (t in hours). When talking about battery life, this would mean the number of watts that an application uses per hour [35]. The Traffic Counting Detector had the given power consumption (P) of **five (5) watts or 0.005 kW**. Using the calculated Power output of the Lithium-Ion Battery of $\boldsymbol{153.6\ Wh}$, the time (t) in hours can be obtained using Electrical Energy formula in terms of Watts-hour is:

$$E = P \times t$$
$$P_{out} = P_{consumption} \times t$$

Where:
$E = P_{out} = Power\ output\ of\ Battery\ in\ Watt - hour\ (Wh)$
(Note: E as power output of battery is denoted as Pout)
$P_{consumption} = Power\ consumption\ of\ C amera\ in\ Watt\ (W)$
$t = time\ in\ hours\ (hrs)$

So, the time (t) in hours of the Traffic Counting Detector usage in the battery is calculated:

$$P_{out} = P_{consumption} \times t$$
$$153.6\ Wh = 5\ W \times t$$
$$t = \frac{153.6\ Wh}{5\ W}$$
$$\boldsymbol{t = 30.72\ hours}$$

Therefore, the period of time in hours that the Traffic Counting Detector or Camera is **operating using the 12V Lithium-Ion Battery is30.72 hours**. It is highly recommended in larger scale or wide range implementation that a larger voltage of battery should use in order to have continuous flow of electricity to the camera device.

IV. Conclusions and Recommendations

A. *Conclusions*

The Rumble Strips with an embedded Piezoelectric Harvesting Device (PEH) are a technological innovation that can potentially use the waste kinetic energy produced by the vehicle passing through the road. The wasted energy can be used to power the traffic counting detector. The design in Chapter 2F, Sample Prototype Design, was used to construct the prototype. The designed layering of the Rumble Strips with PEH resisted and is still working despite the possible damage caused during the application and kneading process of thermoplastic, where the critical parts of the design are the Piezoelectric Devices and their wiring. The hardness of the Rumble Strips satisfies the needed classification, in which it is determined as hard. It is important to know that weather or environmental conditions affect the composition of rumble strips.

The Rumble Strip with embedded Piezoelectric Harvesting Devices for the two (2) rumble strip prototype worked and produced electricity by passing through by motorcycle, producing an average of 22.13 volts, Sedan produced an average of 439.96 volts, L300 Van produced an average of 776.56 volts and lastly, the Patrol 2004 produced an average of 1036.56 volts by the following results can power a 5-volts traffic counting detector. The Rumble Strips with an embedded Piezoelectric device are expected to produce a minimum average of 22.13 volts and a maximum of 1036.57 volts, considering the small-scale prototype, generating electrical power in an increasing approach. The renewable energy utilizing the prototype can power the 5-volts camera with a Lithium-Ion battery voltage capacity of 3200 volts and a power output of 153.6 Wh, or equivalent to 0.1536 kWh. The 5-volt camera with a power consumption of 5 watts has a working time of 30.72 hours. For the minimum volts from a motorcycle with an average of 22.13 volts and at least 145 motorcycles that are needed to pass through the two (2) rumble strips. The acquired volts from Sedan with an average of 439.96 volts, there should be at least eight (8) sedans that are needed to pass through the two (2) rumble strips. For the minimum volts from the L300 Van, with an average of 776.56 volts and at least five (5) L300 Van that are needed to pass through the two (2) rumble strips. For the obtained volts from Patrol 2004 with an average of 1036.57 volts, there are at least three (3) Patrol 2004 that are needed to pass through the two (2) rumble strips. Thus, the design is capable of powering the 5-volt camera. The viability was based on the working state of the prototype with produced 22.13–1036.57 volts.

The study concluded that the designed rumble strip with embedded Piezoelectric devices is viable in a prototype with 22.13 minimum average volts produced and in 1036.57 average maximum volts generated power theoretically stimulated. The viability of the design gave a positive chance to utilize the wasted kinetic energy produced by the vehicle passing through a road and use this energy to power the traffic counting detector that can be used to monitor traffic conditions in a specific location. In the design, the dimensions of the rumble strip are 10mm in height, 100mm in width, and 200mm in spacing. The modified section is within the rumble strip between the first and second layers of the thermoplastic paint where the Piezoelectric Harvesting device is placed. This is to allow more vibration to be produced from the rumble strip and produce more electricity from the Piezoelectric Devices embedded in the rumble strip. The study concludes that the designed rumble strip with an embedded piezoelectric device is efficient. Synthesizing, the design of a rumble strip with an embedded piezoelectric harvesting device is both viable and efficient.

B. Recommendations

The recommendation section is an important part of the research study since it offers more suggestions and potential solutions to the research topic. In this study, the recommendations are divided into two groups. The first recommendation is for improving the prototype. The other is a recommendation to improve the study. Prototype improvement recommendations are based on identified issues during construction.

Recommendation for the improvement of the prototype is based on the problems seen during the construction and testing of the prototype.

First, this study is about the design of rumble strips with embedded piezoelectric harvesting devices to power the traffic counting detectors using the vibration produced by the vehicles. It is important to acknowledge that there are other sources of vibration that can be considered for energy generation, such as the vibration in the cement which is coming from the other lanes. The rumble strip with embedded PEHs is exposed to heat, which is also a factor in the PEHs ability to produce renewable energy. Thus, for future researchers, it is essential that they consider these different factors in order to maximize the efficiency and effectiveness of the rumble strips with embedded piezoelectric harvesting devices.

Second, the current study used a 12V lithium-ion battery. The converted electricity from the piezoelectric harvesting devices in rumble strips is stored in a lithium-ion battery. It is recommended to use of a higher battery voltage for the actual implementation, in order to store more electricity and enable the traffic counting detectors to operate continuously even if there are no vehicles passing through a specific area because less energy is lost when power is delivered more effectively by batteries with a higher voltage.

Last, Internet Protocol (IP) Cameras or Closed-Circuit Television (CCTV) systems, or Traffic Counting Detectors is used to test if the renewable energy generated by the piezoelectric harvesting device using the kinetic energy produced by vehicles is enough, and this camera will generate traffic data of the vehicles. Thus, in order to make it easier to gather traffic data of vehicles passing through a specific area the researchers recommend to use a wide-range camera in actual implementation to ensure comprehensive coverage of the road network so that it is easy to track and control traffic flow. Having a wide variety of cameras improves the capacity to collect comprehensive data and insights for traffic optimization and planning. Authorities can study traffic patterns, spot bottlenecks, and make well-informed decisions to enhance traffic flow and lessen congestion by gathering real-time traffic data from various angles and places.

Recommendation for the future researchers, based on the problems seen during the computations and analysis of data.

First, the study focuses on material development combination with renewable energy, which is the design of rumble strips with an embedded piezoelectric harvesting device as a source of renewable energy to power the traffic counting detectors. It is recommended for future researchers to turn or continue the study into Transportation Engineering. The future researchers will assess the Traffic data on the particular areas where Rumble Strips are usually installed. It is advisable for them to gather the Annual Average Daily Traffic (AADT) at a particular location where rumble strips are implemented. AADT refers to the average daily traffic volume at a particular location for a whole year. The AADT is a straightforward yet practical way to measure the amount of vehicle traffic on a road.

Last is, they are advised to compute the Charging time of the Batteries that supplies the Traffic Counting Detector. AADT can help to know the frequency of vehicles, it is essential to obtain frequency factor from the traffic data analysis and the frequency of vehicles at a particular location will determine the time interval of vehicles passing through the rumble strips which leads to the obtainment of the Charging time of the battery that will supply the Traffic Counting Detectors.

The recommendation for the improvement of the study is based on the seen limitations of the study. It can be directly or indirectly related to the study topic.

The Piezoelectric harvesting device that harnesses waste kinetic energy produced by vehicles as a source of renewable energy that converted into electricity, it is found out that this device is efficient to power the traffic counting detector. It is possible to integrate other systems like the VEMON system. The VEMON system can be linked with the camera to take advantage of technology advancements and further improve the study. The researchers recommend that the renewable energy generated by piezoelectric harvesting devices and stored in batteries be utilized to power traffic video cameras, from which they can create and use the VEMON system for traffic monitoring. The Vision-Based Vehicle Counter for Traffic Monitoring (VEMON) is a traffic monitoring system that uses traffic video cameras to generate reports on vehicle counts and categorization, as well as speed and air quality assessments. One of the key features of the VEMON system is its ability to categorize vehicles based on size, type, and speed. This information is crucial for understanding traffic patterns, identifying congestion hotspots, and planning for future infrastructure upgrades. By accurately counting and categorizing vehicles, transportation authorities can better allocate resources and effectively address traffic issues.

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