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Design and Implementation of an Advanced Electrical Power Inventory and Monitoring System for Enhanced Resource Management

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A B S T R A C T

The inventory Management and Monitoring System is essential in several industries as it effectively monitors and tracks sales, purchases, supply and demand. Inadequate inventory handling not only causes consumer dissatisfaction but also has substantial financial consequences, including tied-up capital, slugging sales, and strained work relationships. This study aims to solve the urgent requirement for efficient inventory management, with a specific focus on electrical maintenance. This include managing supplies, devices, equipment, services, and power usage. Using an Agile software development process, this study developed and implemented a cutting-edge Inventory System specifically built to meet the distinct electrical maintenance requirements. Using Java, HTML, CSS, PHP, PhpMyAdmin, and MySQL, the study developed a powerful platform that includes key functionalities such as Messaging, Supplies Inventory, Job Orders, Repair Records, and Wattage Consumption tracking. This interdisciplinary method expands the scope of inventory management beyond conventional sales and products while also improving efficiency and precision in electrical maintenance operations. The result reveals a system that is easy for users to understand and use and a detailed manual that provides all the necessary information. This system enables organizations to make the best use of their resources and improve their operations efficiently.

RESUMO

O Sistema de Gestão e Monitoramento de Estoque é essencial em diversos setores, pois monitora e rastreia com eficácia vendas, compras, oferta e demanda. O manejo inadequado de estoques não só causa insatisfação do consumidor, mas também tem consequências financeiras substanciais, incluindo capital imobilizado, vendas lentas e relações de trabalho tensas. Este estudo visa solucionar a necessidade urgente de uma gestão eficiente de estoques, com foco específico na manutenção elétrica. Isso inclui o gerenciamento de suprimentos, dispositivos, equipamentos, serviços e uso de energia. Utilizando um processo ágil de desenvolvimento de software, este estudo desenvolveu e implementou um Sistema de Inventário de última geração construído especificamente para atender aos distintos requisitos de manutenção elétrica. Usando Java, HTML, CSS, PHP, PhpMyAdmin e MySQL, o estudo desenvolveu uma plataforma poderosa que inclui funcionalidades importantes como mensagens, estoque de suprimentos, pedidos de trabalho, registros de reparos e rastreamento de consumo de potência. gestão além das vendas e produtos convencionais, ao mesmo tempo que melhora a eficiência e a precisão nas operações de manutenção elétrica. O resultado revela um sistema de fácil compreensão e utilização pelos usuários e um manual detalhado que fornece todas as informações necessárias. Este sistema permite que as organizações façam o melhor uso dos seus recursos e melhorem as suas operações de forma eficiente.

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Introduction

The Electrical Power System of Rizal Technological University (RTU), a state university based in Mandaluyong and Pasig City, Philippines, is grouped into three (3) main feeder circuits. First, the 1- 750kVA, three-phase (3ø), 34.5kV/20kV-240V/120V, Vault type, PDT newly upgraded pad mounted and largest capacity transformers which supply the Main Academic Building (MAB), Research and Development Building (R&DB) and the Senator Neptali Gonzales Academic Hall (SNGAH), mainly located in front of the MAB, nearly along Boni Avenue, Mandaluyong City, Philippines. Second is the three (3) - 333 kVA, three phase (3ø), 34.5kV/240V, pole mounted, which caters to the Dr. Lydia M. Profeta Building (DLMPB) / formerly Industrial Technological Building (ITB)/Admin Building, Gonzales Dormitory, and partial of part of the Old Building particularly the Mechanical Laboratory Building located along Sacrepante Street, Boni Avenue, Mandaluyong City. Third is 3 - 333 KVA, 34.5 kV/ 220V, three (3) phases which supply the Old Building (OB) and the RTU gymnasium and Dr. Josefena V. Estolas Building (DJVEB) and formerly Industrial Technological Complex (ITC).

Currently, the electrical power inventory and monitoring system has been done manually using record log books and partial electronic data record keeping. Maintenance and monitoring practices are done conventionally with forms and pens. Hence, good decisions need good information that is derived from raw facts. These raw facts are known as data. Data will likely be managed more efficiently when stored in a database/ collection information. In this study, the researcher developed a database system and evaluated the electrical power inventory and monitoring system of materials, supplies, and equipment in the RTU Boni Campus, which is expected to result in digitalized data management. This institution has to keep this type of data and much more, and just as importantly, it must have that data available for important requirements to some accreditation bodies and decision-makers when necessary.

With this in mind, the researcher endeavored to study the possibility of developing and evaluating an Electrical Inventory and Monitoring System for RTU. This system utilizes the Agile Project Management Model to enhance energy consumption and maintenance practices at RTU Boni Campus in the Philippines.

The primary goal of this research is to create a comprehensive system that streamlines the inventory management and monitoring of electrical devices across campus buildings. This involves identifying and understanding the various stages involved in the development process, and ensuring that the system is agile and adaptable to changing requirements.

Specifically, the study aims to establish an in-depth understanding of energy consumption patterns by profiling the inventory of electrical devices across different campus buildings. Through this, the research seeks to implement effective monitoring practices to optimize energy usage and resource allocation.

Furthermore, the study aims to introduce innovative approaches to inventory and monitoring, to enhance maintenance processes and improve the reliability of electrical systems on campus. Additionally, evaluating the PPDO inventory archive maintenance system will provide insights into its effectiveness in managing electrical inventory data.

Lastly, the research endeavors to create a user-friendly and comprehensive user manual for the electrical inventory and monitoring system. This will ensure that stakeholders can efficiently and effectively utilize the system. Through these objectives, the study aims to contribute to the improvement of energy management practices at RTU Boni Campus.

Research Methods

The researcher employed the developmental research method to systematically design, develop, and evaluate instructional programs, processes, and products, ensuring internal consistency and effectiveness. This method involved the creation of new procedures, techniques, and tools through meticulous analysis of specific cases, categorized into Type 1 and Type 2 studies. Type 1 studies encompassed system design, development, and evaluation, often validating design or development techniques or tools. Type 2 studies focused on a specific design, development, or evaluation model or process. Specifically, the Agile System Development Life Cycle was utilized for this study, emphasizing adaptability to changing requirements and rapid delivery of product features to enhance customer satisfaction.

In addition, the descriptive method was employed to identify information pertinent to the study, focusing on the current condition of the phenomenon under investigation. This involved utilizing the descriptive survey method to describe the current electrical maintenance practices in the institution, particularly concerning energy-consuming devices in various buildings. Data collection methods included counting, roving, and referencing existing as-built plans for certain buildings.

The study involved a total of fourteen (14) Physical Plant Development (PPD) personnel, six (6) Electrical Engineering Faculty (EEF), twenty-eight (28) Computer Engineering (CpE) students, twenty-six (26) Information and Communication Technology (ICT) students, sixty (60) Electrical Engineering Students (EES), and ten (10) Electronics students (ES) as respondents, categorized into four groups: EEF, PPD personnel, ICT & CpE students, and EES & ES. Respondents were selected using Slovin's Formula with a 5% margin of error. These respondents played key roles in evaluating the developed electrical power and monitoring system, ensuring its effectiveness and relevance to the needs of both PPD personnel and academic beneficiaries.

Design and Development

In practice, there are two (2) approaches to identifying the forecast. The first is based on the premise that what happened in the recent past will indicate future expectations; statistical techniques are used to produce the forecasts. The second is more subjective, relying on customer opinion and intentions, surveys, sales representative's estimates, use of indicators, and technological forecasting. Inventory demand forecasting uses a short time horizon, excluding techniques involving a leading index or the electrical maintenance operation supplies for a year. The researcher used the developmental research method to systematically study designing, developing, and evaluating instructional programs, processes, and products that must meet the criteria of internal consistency and effectiveness (Hajjar, 2018). Specifically, the researcher used the Agile System Development Life Cycle to develop the system.

The researcher also used the descriptive method to identify information regarding the study. The descriptive method focuses on the present condition of a phenomenon (Manjunatha, 2019) that gathers information about the present existing condition. Evaluating and gathering energy consumption data were done in actual counting, roving, and use of the existing as-built plans in some buildings. Likewise, physical actual counting, aggregation, clustering, and analysis were also considered.

The inclusion of an electrical e-file for existing buildings was not within the scope of this study. However, it is worth noting that such a system could serve invaluable purposes, including record-keeping for troubleshooting and maintenance purposes. Additionally, adherence to the latest Philippine Electrical Code (PEC) is imperative to ensure that electrical works and practices are executed in accordance with current standards and regulations.

Results and Discussions

1. The Stages Undertaken in the Development of Electrical Inventory and Monitoring System Using the Agile Project Management Model

The stages undertaken in developing the Electrical Inventory and Monitoring System using the Agile Project Management Model are the physical actual counting, aggregation, clustering, and analysis for collecting and building the electrical energy profile, the same with the development of the system/software. The researcher found that after the stages, the data in all connected electrical loads have led and built an electrical energy profile as one part of the main requirements of the study. Complete data of the whole of RTU Boni Campus, Philippines, was established in the magnitude of the consumed kW in each electrical consuming device for a month was computed.

The overall loadings of all the buildings in RTU Boni Campus, Philippines, include the total kilowatts per consuming devices, such as load lightings of different types of lighting loads,

the ACU loads, the ventilation loads, and the multi-media equipment loads which are identified as follows: (a) lighting load has a total number of two hundred six thousand seven hundred ninety-two (206.792 kW) watts (Fluorescent lamps, LED bulb, CFL); (b) ACU window type which has four hundred twelve point ninety one kilowatts (412.91 kW) and Split type ACU which has one thousand thirty-one point eighteen kilowatts (1031.18kW); (c) Ventilation has one hundred eighteen points twenty kilowatts (118.20 kW); (d) Multimedia equipment which has two hundred sixty-five point fifty six kilowatts (265.56kW) with total kilowatts of one thousand six hundred twenty one point seventy three kilowatts (1621.73kW). The total energy consumed by the six buildings is nine hundred seventy-six thousand six hundred twenty-five point twenty-eight kilowatts hour assuming it operates only sixteen hours (16 hrs.) a day for thirty (30) days a month (976,625.28 kWH).

2. The Inventory Profile of the Energy-Consuming Devices

The researcher gathered data in the different RTU Boni Campus, Mandaluyong City, Philippines buildings about the energy-consuming devices in terms of lighting, air conditioning, ventilation, and multi-media equipment to produce electrical energy profile using physical actual counting, aggregation clustering, and data analysis and interpretation. The study revealed that the highest percentage of lighting loads came from the fluorescent lamp, which was type T5-28 watts, which contributed at around 38 percent, and the very least lighting load was T8-20 watts. The different wattage of fluorescent lamps, LEDs, CFLs, and LED bulbs in the six (6) buildings considered in the study has resulted in the more number of fluorescent lamp T5 with 28 watts at around two thousand seven hundred eighty-one pieces (2781 pcs) which are installed at the DJVEB, DLMPB and few at the OB. The numbers of fewer units in terms of lighting loads were fluorescent lamps T8-20 watts, which can be found on the stairs. The larger number of lighting loads installed was at the SNGAH with six one thousand eight hundred forty-eight pieces (61,848 pcs), which was a combination of LED fluorescent lamp T8-24 watts, LED bulb, and fluorescent lamp, T8-28 watts. The highest kW consumption was the ACU (Appendix B), among other electrical loads. The orbit fan has contributed a 70% amount, among others, to the electrical system, which follows that kW consumption is high compared to the wall and stand fans. The other ventilation equipment has a kW of 14.25 & 20.85 kW, which is 12% and 18% of the total consumption capacity for this Cluster. It was clearly visualized that orbit fans have a larger number being utilized in the operation.

Multi-media equipment such as computer desktops has a larger kW consumption because it has larger units utilized. It reaches a percentage of 95 % contribution to total Load capacity and i.e., approximately estimated to be seven hundred seventy-nine (779) units, which, of course, are installed in laboratories and offices. For the laptop and projector, the percentage was 1% and 4%, which was 1.76 kW and 9.6 kW, wherein this multi-media equipment can be found on the campus. The kW consumption of the existing RTU's account

from 2013 to 2017 is intermittently in kW usage, but perhaps it is on the average of 10,534.8 kW. The kW consumption reflected was the summation of the five different accounts owned by RTU. In 2014, the more kW load consumed, which was 11,543.8 kW compared to the other years, while in 2017, it was only 9,743.66 kW. This data can be a part of providing an Electrical Energy Profile.

In 2015, it had more energy usage compared to 2017, but the amount paid was higher in 2017. Perhaps in the year 2015, the Philippines peso had a higher value over the dollar currency, which is why the energy was cheap compared to the 2017 dollar currency exchange. It always depends on the supply and demand principle. Therefore, for 2017, the energy price was higher compared to the previous years. One reason that the researcher observed was that the SNGAH was not fully operational. The largest amount of pesos paid (Php. 37 448,489.77) was in 2017, reflecting a 26% share among the other years. The table and figure C.6 (Appendix C) show that the smallest amount paid was in 2016, amounting to Php. 21,776,959.00, which is only 15% of the five years of electrical billing because less energy was utilized for load requirements in the power system of RTU Boni Campus, Mandaluyong City.

3. The Practices Implemented in the Monitoring of the Energy-Consuming Devices

The practices implemented for monitoring the energy-consuming devices are as follows: Some buildings inside the Boni RTU Campus, Philippines, have a building supervisor under the supervision of the Head of the Physical Plan and Development Office (PPDO). The accounting office has a copy of the electrical billing of all five (5) accounts. The electrical maintenance supply for operation are procured in different ways, such as the use of petty cash for a small purchases, emergency cases, supply office involvements, and other deciding bodies; large and operational electrical maintenance supplies undergo a bidding process under RA 9184. The monitoring was done through manual record-keeping in a logbook. The following are the specific practices regarding lighting, ACU, ventilation, and multi-media equipment.

Lightings Implemented Practices

In terms of lighting, the following are the observed implemented Practices:

a. The lightings in each classroom, office, and concern area are switched off by the faculty, employees, janitors, and roving guards on duty after classes.

b. Lights in the corridors, alley, promenade, kiosk, and selected rooms have been retrofitted, and fluorescent lamp fixtures have been replaced with LED bulbs.

c. Retrofitting fluorescent lamps with magnetic ballasts to electronic ballasts, T8 to T5 lamps (36-28 watts), was implemented at DJVEB, DLMPB, and a portion of the Old Building.

d. Retrofitting of fluorescent lamps with magnetic ballast for LED fluorescent lamps with auto sensor (36-24watts) was implemented at the SNGAH.

e. Retrofitting of Gymnasium lightings, from Mercury and Halogen Lamps to LED Doom/ Spotlight and LED bulbs.

f. The Gymnasium has an ongoing project, Off Grid 31.2 kWP Solar Panel Installation, which will be expected to be energized after 120 days; it started in March 2018.

Air conditioning Units Implemented Practices

In terms of ACU the following are the observed implemented Practices:

a. All offices are advised to be on their ACU during work days from 9:00 AM to 9:00 PM only.

b. The procurement of brand new ACU without consideration as additional load of the existing power system .

c. The ACU cleaning, maintenance team to facilitate the minor repair of simple defects, such as change of capacitor, repair of power switch, etc.., were available.

d. The temporary closure of rooms with ACU and limitation/restriction of use for those rooms.

e. The cleaning of the ACU filters can maintain a good environment.

f. Gradual change of ordinary ACU to Inverter type ACU.

g. The consideration of the higher Energy Efficiency Ratio (EER) when procuring an ACU.

Ventilation Implemented Practices

In terms of Ventilation, the following are the observed implemented Practices:

a. Installation of the orbit fans, wall, and stand fans in classrooms.

Existing Ventilation

For replacement, repair, and troubleshooting, the requestor/representative should ask/inform the PPDO personnel to take the immediate action necessary for normal operation.

New Ventilation

For new installations, the requestor should request installation of new ventilation. If no available unit is available, the PPDO should decide to request fans from the supply office by filling out a PRIV form.

b. Preventive Maintenance on the electric fans (orbit, wall, & stand)

Cleaning fans, greasing, and check-ups, this task were assigned to the janitor/janitor, and most of the time, if defective, the electrician is in dismantles the unit, but it is just for cleaning, and then the housekeeping can do the job.

Multi-media Equipment Implemented Practices

In terms of Ventilation, the following are the observed implemented Practices:

a. In the procurement process, the TOR includes the Energy Star Compliant.

b. Implementation with the use of screen saver

c. Wifi ready, at the quadrangle areas.

d. Use an LED TV set instead of an overhead projector.

e. Use of Projector

At the undergraduate school, there were some student organizations that lent projectors for payment per hour, while in the graduate school, na ID system was being implemented because there was a custodianship.

f. Use of sound system

Sound systems are divided into two categories, a) mobile and b) fixed. For mobile, some offices have a mobile sound system, which can be operated anywhere, usually portable, while other sound systems are stored in a fixed place, e.g., the sound system at the stage and plenary hall. The operator should be notified earlier before the events proper.

4. The Developed Inventory and Monitoring System for Consuming Devices

Development of the Inventory Archive

The Agile Software Development Method Life Cycle applied an iterative and incremental approach. It focused on process adaptability and customer satisfaction through rapid delivery of a working software product and was divided into separate phases: requirements, plan, design, development, release, and track and monitor.

The researcher proposed and developed a ”PPDO- Inventory Archive Maintenance System“ system. The system was developed for a Web-based Application, using PHP and some programming languages such as Java, HTML, PhpMyadmin, MySQL, CSS, and XAMPP as pre-network integrators. The first phase in the development of the evaluation of electric power and monitoring systems is the requirements definition. System development is the planning in which identifying the cause and demand and gathering necessary information and documents needed to develop the system application as well as defining the functional requirements needed by the system. The survey questionnaire provided answers on the technical aspect as well as insights on the current system/practices used in electrical maintenance.

5. Evaluation of the PPDO Inventory Archive Maintenance System about the timeliness, ease of use, and security

Data collected shows that ninety-six (96) respondents out of one hundred forty-four (144) answered moderately agree with the development and evaluation of the Electrical Power Inventory and Monitoring System; hence, the weighted mean is 4.32. The center distribution of the data is nearly on the strongly agreed, meaning the propose project is acceptable to develop. From the standard distribution normal curve, the cluster of the data is in the region where it emphasizes that the proposed system is still effective in terms of timeliness, ease of use, and the level of security is acceptable.

The center distribution of the data is nearly on the strongly agreed therefore, the proposed project is acceptable to develop. From the standard distribution normal curve, the cluster of the data is in the region where it emphasizes that the proposed system is still effective in terms of timeliness, ease of use, and the level of security is acceptable. In terms of timeliness, it was shown that the proposed system can be doable and possibly developed with the available resources. As to the number of respondents, there were four hundred thirteen (413) who answered strongly agree with Question 1. The second parameter for the system to be justified and verified is the ease of use, though the highest responses are three hundred-two (302) for moderately agree. The researcher wished to continue the system since the answers are still near to strongly agree, which the proponent interpreted as a good basis for the decision. As to the number of respondents who answered strongly agree, we have a total of 144 respondents, and it shows that the mean of the population is 4.46 and the standard deviation of 0.708719. It shows that out of 144, there around 107 respondents who are in favor because they answered strongly agree. Evidently, timeliness is a dominant characteristic.

The respondents positively favored the implementation of the development of the project, showing that the security issue is not a problem because it is true that any system should have a provision of protection for any created application, especially to be integrated with the network. The study's findings show that the F statistics are greater than the F critical. Therefore, the null hypothesis is rejected because there is a significant difference in the evaluation of the inventory and monitoring system among employees, faculties, and students in terms of timeliness, ease of use, and security.

Likewise, the evaluation by the Faculty, PPDO staff, and students shows that the RTU employees, particularly the EE Faculty and the electrical maintenance employee, strongly agree with the proposed system. Therefore, it will be developed. From the results, we have eighteen (18) employees out of twenty (20) who answered strongly agree. The weighted mean is high, implying that most respondents were satisfied with the given parameters, such as measuring the proposed system's timeliness, ease of use, and security level. Some did not show that they strongly agreed. Still, the majority of respondents strongly agreed.

The respondent group of Computer and information technology learners, thirty-two (32) who have the technical knowledge to judge and critique the design the functionality, timeliness, ease of use, and level of security in the proposed PPDO Archive Maintenance Inventory system strongly agreed with the measurement of the timeliness, ease of use and security level is on the acceptable level of margins. The average weighted mean is 4.19 in nature and in is not spread out there for if we would like to design. According to some, though not perfectly strongly agree, there's still always room for improvement. Meanwhile, the total number of respondents who strongly agreed was thirty-six (36) out of fifty-four (54) students who responded with the survey form.

The user's manual was created to ensure that the application's users are guided in using the PPDO-Inventory Archive Maintenance System. The manual contains step-by-step instructions and illustrations to serve as a guide to the application's users. The manual also presents the device's minimum requirements.

Table 1.

Summary Results of ANOVA

	Mean	F	p	F*crit*	Decision
Overall	4.4	3.82	0.11	3.06	Reject H_o
			F>F*crit*, p<0.05		

The table presents the summary results of an analysis of variance (ANOVA), providing key statistical metrics to assess the significance of observed differences among groups. The mean value of 4.4 indicates the average response across all groups, while the calculated F-value of 3.82 suggests variability among group means. Notably, the computed p-value of 0.11 indicates the probability of observing such differences by chance alone, while the critical F-value (Fcrit) of 3.06 represents the threshold for statistical significance. The decision to reject the null hypothesis (Ho) is based on comparing the computed F-value to the critical F-value, with the observed F-value exceeding the critical threshold. This decision is further supported by the p-value being less than the conventional significance level of 0.05. The results indicate significant differences among groups, warranting further investigation into the factors contributing to these variations and their implications for the research study.

Conclusions

The study delved into developing and evaluating an Electrical Inventory and Monitoring System using the Agile Project Management Model, targeting optimizing energy consumption and maintenance practices within the RTU Boni Campus in the Philippines. A comprehensive electrical energy profile was established through meticulous stages, including physical counting, aggregation, clustering, and data analysis, revealing detailed insights into the consumption patterns of various energy-consuming devices across campus buildings.

Notably, the study unveiled significant findings regarding the inventory profile of energy-consuming devices, showcasing a diverse range of equipment from lighting fixtures to air conditioning and multimedia equipment. Implementing effective monitoring practices proved crucial, with practices ranging from manual record-keeping to retrofitting and preventive maintenance procedures observed across campus facilities.

Moreover, the developed Inventory and Monitoring System exhibited promising results, with evaluation criteria such as timeliness, ease of use, and security garnering positive feedback from respondents across faculty, staff, and student groups. The system's effectiveness

in optimizing energy consumption and streamlining maintenance practices underscores its potential to significantly impact operational efficiency and resource utilization within the RTU Boni Campus.

Furthermore, creating a comprehensive user manual is vital to facilitate seamless adoption and utilization of the developed system, ensuring its accessibility and usability among stakeholders. Ultimately, the study's findings provide valuable insights and actionable recommendations for enhancing energy management practices and infrastructure maintenance within educational institutions, paving the way for sustainable and efficient campus operations in the future.

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