# Cross-Sectional Investigation of Implementing Ubiquity Mobile Maintenance Management Systems: The Healthcare Clinics Case

# ABSTRACT

# Recent studies regarding mobile maintenance management systems focus on one organization's specific industries, processes, and technologies. However, there is a recognized need for further investigation of mobile maintenance management systems in decentralized organizations with branches across the country. This study is based on data gathered from the organization's information system. We examined the effect of implementing real-time mobile maintenance management systems. Cross-sectional investigation showed unique preventive and corrective maintenance analysis via eight repair types in healthcare clinics. In addition, the findings showed by gamma analysis that after implementing the new system, the duration of maintenance times had reduced significantly in all maintenance types. Additionally, the results of the poisson analysis indicated that the users adopted the new system by increasing the number of service calls. Embracing the new system strongly affects simultaneously maintenance time and extent of use, mainly in three repair types (1) carpentry, (2) electrical, and (3) sanitation. The operational contribution is the feasibility of using a digital maintenance system according to the organization's needs and types of maintenance and repairs. Furthermore, the research facilitates practical knowledge to managers in decentralized organizations.

# 1. Introduction

The research aim is to investigate the effect of implementing Information communication technologies (ICT) in service organizations. The study examines the improvements in various operational activities by analyzing the gap created in several maintenance indicators before and after implementing the Mobile Maintenance Management Systems (MMMS). The cross-sectional analysis performed in various maintenance and repair types allows for imparting specific insights.

A study that examines the integration of digital systems in service organizations and is based on real-life maintenance data adds to research knowledge in ICT and maintenance fields. The information obtained in the research provides valuable insights and practical tools for managers. The practical knowledge will assist in deciding on the degree of economic viability in implementing a digital system that serves the maintenance activity. Also, an in-depth examination of the findings of using a digital system will improve the ability to decide which combination of maintenance and repair types contributes significantly to improving maintenance efficiency.

Many studies regard to maintenance management systems (Fu et al., 2004; Labib, 1998; Mendes et al., 2022; Wienker et al., 2016). Yet, MMMC is a new classification that was hardly explored (Sumaila & Bahsi, 2022), but there is limited literature concerning mobile apps (Jantunen et al., 2010; Schoenherr, 2016; Shiau et al., 2019). The small number of quantitative studies in the field stems from the difficulty of retrieving mobile app data. Also, organizations are reluctant to share internal data with external parties (Zhang et al., 2016).

Research on MMMS usually focuses on a specific domain (Arnaiz et al., 2006; Costa & Lopes, 2021; Jantunen et al., 2010; Lin et al., 2011; Selvakumaran et al., 2022; Sumaila & Bahsi, 2022). For instance, Lin et al. (2011) developed MMMS based on Radio Frequency Identification (RFID) for a Taiwan construction lab to improve instrument inspection maintenance. Jantunen et al. (2010) identified the importance of MMMS on the shop floor. Olasumbo et al. (2019) analyzed a case study of implementing MMMS in a production environment to minimize breakdown in production. The MMMS improved communication, knowledge, data gathering, and support to the production line. Sumaila and Bahsi (2022) explored MMMS for the automotive industry. These studies' common ground is analyzing MMMS in a centralized organization for a specific area. Our research contributes to investigating MMMS implementation in a complex and decentralized organization. Therefore the main research question is, does the implementation of MMMS system improve the performance of a maintenance department in eight types of activities in a decentralized organization? The uniqueness of the current study is by addressing the facilities' maintenance activities in two dimensions (1) corrective and preventive maintenance and (2) under the lances of eight types of maintenance activities in a decentralized large healthcare organization with branches across the country. To the researcher's best knowledge, MMMS has not been explored in a decentralized healthcare organization.

The research has three main contributions. (1) Add to research knowledge using real-life maintenance data and innovative model via cross-section analysis. According to the authors' knowledge, few research in the field were based on real-data. (2) Explore operational knowledge for decentralized organizations with the types of maintenance: corrective and preventive, that cross via eight repair types. (3) Identifying the business value of MMMS in improving service efficiency throughout operations effectiveness and the internal environment.

The following section elaborates on the literature regarding relevant technologies and maintenance activities. The third section elaborates on a general description of the healthcare clinics' MMMS. The fourth section is devoted to hypotheses development about reducing maintenance time and increasing the number of service calls. Finally, the last section is a summary with a discussion of the key findings, limitations, and implications for research and practice.

# 2. Literature review

Information communication technologies (ICT) facilitate transparency, ubiquitous in real-time via organizational systems integration, and mobile devices that enable employees to work outside the office (Ikumapayi et al., 2022; Manyika et al., 2013; Muzafar & Jhanjhi, 2020). ICT enhanced operational activities among supply chain partners in maintenance, warehousing and logistics (Hu et al., 2015). Computerized maintenance management system is a good example for ICT (Ismail, 2021). ICT for building facility management enable maintenance employees access maintenance management systems for precise information regarding faults and history (Su, 2009). Su (2009) demonstrated ERP systems that enable filed worker to conduct daily maintenance activities, enabling transparent information with minimum paperwork (Giessmann et al., 2012). ICT for maintenance activities is essential since filed workers and technicians can receive information in real time regarding the fault, developed schedule inspection as well as read machine information from a remote location (Ikumapayi et al., 2022; Muzafar & Jhanjhi, 2020).

Maintenance refers to operational and administrative actions required to keep facilities in proper conditions for efficient work (Pintelon & Van Puyvelde, 2006) with minimum costs (Kelly, 1989; Kumar et al., 2013). Facilities management is integral part in operations and maintenance activities (Bouabdallaoui et al., 2020). Above 60% of the expenses of the physical assets are related to operation and maintenance requests (Garg & Deshmukh, 2006; Liu & Issa, 2016; Madureira et al., 2017). For instance, Garg and Deshmukh (2006) indicated that electricity and maintenance costs receive the most significant share when planning the operation budget.

The high costs in operations and maintenance activities are due to inefficient work practices (Zhan et al., 2018). According to Yousefli et al. (2017), inefficiency in process and maintenance is emphasized even strongly in hospitals and clinics. As a result, employees and patients feel discomfort and dissatisfaction (Yousefli et al., 2017). According to Bortolini and Forcada (2020), the dissatisfaction mainly stems from maintenance requests such as electric heating, ventilation, and air conditioning. Business organizations and healthcare facilities have understood over the years the importance of managing operation and maintenance requests from employees and customers (Garg & Deshmukh, 2006; Madureira et al., 2017; Yousefli et al., 2017).

Maintenance management systems in industrial organizations, hospitals, and clinics mainly open requests for preventive and corrective maintenance faults (Ahmad & Kamaruddin, 2012; Chen et al., 2017; Gómez-Chaparro et al., 2020; Hamdi et al., 2012; Zaher et al., 2011). Mustapha and Agbevade (2011) stated that corrective maintenance requests are the most frequent in hospitals and clinics. Corrective maintenance (CM) requests refer to unexpected faults or not scheduled activity in equipment or machines. Faults should be fixed as quickly as possible for continued regular work (Chen et al., 2017; Sheut & Krajewski, 1994; Vathoopan et al., 2018).

Repairing maintenance requests fast reduces employee and patient discomfort and dissatisfaction (Bortolini & Forcada, 2020). Example for maintenance requests refers to problems with automated doors that suddenly do not open, broken furniture, air conditioning, and ventilation problems (Bortolini & Forcada, 2020; Gómez-Chaparro et al., 2020). Typically, maintenance requests are opened by employees that encounter the fault. Preventive maintenance requests refer to scheduled, periodic, or planned maintenance to prevent incidents and disruption by recurrent inspections of equipment and machines while they are working in good condition (Almomani & Alburaiesi, 2020; Kannan, 2020; Zaher et al., 2011). Preventive maintenance is regularly used for health care equipment's and widgets (Almomani & Alburaiesi, 2020; Gómez-Chaparro et al., 2020). Physical assets problems, electronic faults, and avoiding dangerous activities can be minimized via preventive maintenance (Balaras & Argiriou, 2002; Bortolini & Forcada, 2020; Surveyors, 2000).

Maintenance requests are generated daily, and the maintenance team amends the faults according to their priorities in the maintenance management systems (Almomani & Alburaiesi, 2020; Becerik-Gerber et al., 2012). The maintenance management system records the maintenance request with the description, urgency, location, and category of the fault (Bouabdallaoui et al., 2020; Federspiel, 2000; Gunay et al., 2019; Yang et al., 2018), such as electrical, heating, ventilation, and air conditioning (Bortolini & Forcada, 2020; Gómez-Chaparro et al., 2020). A maintenance management system is used for preventive and corrective maintenance, calculating the mean time between faults and downtime and producing reports (Almomani & Alburaiesi, 2020). Despite the integration of information systems, in most cases, the implementation was unsuccessful and did not improve the maintenance requests process (Bouabdallaoui et al., 2020; Ismail, 2021; Koch et al., 2018).

Maintenance optimization and improvement refers to analysis from mathematical models (de Jonge & Scarf, 2020). An optimal periodic inspection model for failure was based on a hypothetical example using the gamma process (Abdel-Hameed, 1987). van Noortwijk (2009) suggest using gamma process as a model for optimizing maintenance, it has been proven to be useful in determining optimal inspection and maintenance decisions. Optimal maintenance decisions can be done by using gamma process because its variety of uses (Kallen & Van Noortwijk, 2005). Another maintenance models for failure behavior of technical systems and in particular electrical and electronic faults is by using the Poisson process (Hosseini et al., 1999). The Poisson process is a good basis for research that predict the corrective maintenance of other failure process types (Andrzejczak et al., 2018).

# 3. Health care clinics' maintenance management system general description

This section demonstrates how Israeli healthcare clinics manage maintenance requests regarding physical assets and service maintenance. The maintenance team is responsible for 458 clinics in five areas. The seven most common repair types refer to (1) Building, (2) Carpentry and frames, (3) Sanitation, (4) Electrical,(5) Paintworks, (6) Air conditioning and ventilation, and (7) Refrigeration. The maintenance department is responsible for the physical assets and service maintenance requests. All maintenance requests are categorized as preventive or corrective maintenance and prioritized from low to immediate activities. Maintenance requests are addressed according to their priority. For instance, electricity faults that put employees and patients at risk have higher urgency than carpentry maintenance requests. Only employees can open maintenance requests.

The employee uses an iPad embedded with the maintenance management system and opens a service call about the faults with detailed information such as location, fault description, corrective or preventive request, repair type, and priority. The request is transferred automatically to a call center that monitors the open service calls and moves the request to the maintenance department. The maintenance department employs ten technicians and a manager, all with relevant education. The technicians receive a work arrangement for the day; usually, they go to the clinics in pairs. After the malfunction is fixed, the technicians close the request, and the manager terminates the fault. If technicians identify an additional potential problem, they open a service call with the iPad and amend it, and the manager terminates the request. The process is detailed in Figure 1. The maintenance department is measured by the average time between opening and terminating requests.

# 4. Hypothesis development

It is possible to reduce the repair time to a minimum and thus reduce the downtime of the systems (Sahoo & Liyanage, 2008). Deploying MMMS reduce the repair time by decreasing the time to communicate about production problem and by improving the quality of sharing information (Mohammadfam et al., 2014). Thus, we propose the following hypothesis:

Hypothesis 1.a: The maintenance time will reduce after implementing the MMMS.

Different preventive and corrective maintenance operations require different maintenance times (Marquez & Heguedas, 2002). Preventative maintenance based on planned times and includes regular repairs and periodic replacements can reduce repair time and downtime (Onoshakpor, 2014). Furthermore, the policy of preventive replacements performed at a fixed time is possible to implement logistics in decentralized organizations with large populations and geographical dispersion (Bajestani & Banjevic, 2016). Thus, we propose the following hypothesis:

Hypothesis 1.b: The reduce of maintenance time after implementing the MMMS will be different between corrective and preventive maintenance.

Previous studies mainly analyzed the effects of MMMS according to maintenance types (Bajestani & Banjevic, 2016; Marquez & Heguedas, 2002) and activity environment (Sidibé et al., 2016). For example, Sidibé et al. (2016) investigated a model that refers to system maintenance time according to its activity environment. To the best of the authors' knowledge, previous studies have not investigated the cross-effects against the repair types.

Thus, we propose the following hypothesis:

Hypothesis 1.c (H1.c): The reduce of maintenance time after implementing the MMMS will be different among the repair types.

Organizations that create new ways of communicating through apps increase customer engagement (Wang et al., 2015). Furthermore, enterprise applications increase communication and integration between the organization systems (Levi-Bliech et al., 2018). A study conducted in five different organizations that started using a mobile application showed improvements in responding to customer preferences (Pousttchi & Habermann, 2009). Therefore, we propose that implementing the system will increase the end users' use of the MMMS to receive maintenance services. Hence, the next set of hypotheses is proposed.

Hypothesis 2.a: The number of calls per week for maintenance service will increase after implementing the MMMS.

Hypothesis 2.b: The increase in the number of calls per week for maintenance service after implementing the MMMS System will differ between corrective and preventive maintenance.

Hypothesis 2.c (H1.c): The increase in the number of calls per week for maintenance service after implementing the MMMS will be different among the repair types.

5. Methodology

## 5.1 Data collection

Data of 6,997 records were collected during 167 weeks from the organizational databases included for each maintenance service call: Start maintenance service time, Finish maintenance service time and Repair type. Only few studies on maintenance are based a real life case (de Jonge & Scarf, 2020).

The dataset was based on a period of four years (from 1.1.2017 to 31.12.21), 2,465 records (35.2%) were collected before the implementation period (from 1.9.2019 to 30.12.2021) and 4,532 (64.7%) records were collected after it.

## 5.2 Descriptive statistics

Table 1 and Table 2 present the descriptive statistics for Maintenance time and service calls, respectively. The Repair Type column describes all kinds of repair types; the Period Time column defines the time before and after the system implementation; the next columns contain data on group sample size, the means and standard deviations of the dependent variables (DV). The DV were examined in three comparison are: (i) Total Maintenance time and service calls; (ii) Corrective Maintenance time and service calls; and (iii) Preventive Maintenance time and service calls.

**[[Place Table 1 about here]]**

**[[Place Table 2 about here]]**

## 5.3 Data analysis

H1.a-b were tested with the DVs of the maintenance's mean time before and after implementation (N = 1844 in Models (1); N = 644 in Models (2); N = 1636 in Models (3). The DVs represents the time that took the manager system to close the maintenance activities manually before implementation vis-à-vis Mobile Maintenance Management System after implementation. H2.a-b were tested with the count of maintenance activities per week as the unit of analysis (N = 1844 in Models (4); N = 644 in Models (5); N = 1636 in Models (6). A Gamma regression was used in models (1)-(3), and Poisson regression was used in models (4)-(6). The dependent variable before and after implementation was categorized as binary.

Models (1), (4) refer to total maintenance activities, models (2), (5), refer to corrective maintenance activities, and model (3), (6) refer to preventive maintenance activities (Table 3). We tested the Gamma and Poisson regressions with before and after system implementation as the principal variable.

**[[Place Table 3 about here]]**

H3.a and H3.b were tested by *t*-test for two independent samples (after system implementation and before system implementation). Table 4 presents the results of the *t*-tests for all the DVs. The first column describes the repair types. The next columns show the mean difference in the two DV in three comparison groups. (Tables 1 and 2 present the mean and SD for each DV).

**[[Place Table 4 about here]]**

Figures 2 and 3 present three panels corresponding to the three comparison groups of maintenance. The plots show the DVs' differences before and after system implementation in each repair type.

**[[ Place Figure 2 about here ]]**

**[[ Place Figure 3 about here ]]**

# 6. Findings

The results in Table 3 confirmed that the H1.a-H1.b hypotheses were significant and negative after implementing a new system for models (1)-(3) and positive for models (4) and (6). Those findings suggest that after implementing the MMMS, the mean time after implementation was reduced while the service calls of maintenance activities per week increased. The negative and positive effect result from the new system capabilities, such as availability, data visibility, and connectivity to the call center and technicians. The results in table 3 did not support H2.b with Model (5), implying that the new system did not affect the call number of corrective maintenance activities opened each week. The finding stems from the fact that failures or malfunctions have random occurrences treated by corrective maintenance (Pal & Adhikari, 2021; Scutariu & Albert, 2006).

The consequences in Table 4 show that the hypothesis H1.c is significate in various repair types. The repairs of building, carpentry and frames, electrical, other facilities, and sanitation represent that the maintenance time was reduced after implementing the new system in all three maintenance activities. The repairs type of air conditioning, paint works, and refrigeration were insignificant after the MMMS implementation. The results in Table 4 point out that hypothesis H2.c is significate. Thus, the number of calls for maintenance service after the implementation increased in three repair types: building, carpentry, and sanitation. No significant evidence was performed in the repairs type of air conditioning, other facilities, paint works, and refrigeration. Uniq outcome was found in the repair type of building that display that the number of calls for maintenance service after implementation were reduced.

# 7. Discussion and Conclusion

Our research represents two DV's of maintenance: time and service call. The DV's were analyzed with three comparison maintenance groups: total, corrective and preventive via cross-sectional eight repair types. The data was collected by SAP software and tested with three statistical models: Gamma and Poisson regressions and a t-test for two independent samples.

This research has two key findings. The first key finding refers to improved maintenance times (H1.a-H1.b, and most H1.c). After implementing the new MMMA, the duration of maintenance times has reduced significantly in all maintenance types. The negative effect strongly impacted repair types related to preventive maintenance activities. Hence, the MMMS improves service efficiency in two organizational environments. First, operational efficiency improves the internal environment. e.g., the clinic personnel receives accessible and real-time information about the patients without computer malfunctions. The medicine refrigerators work in an improved and more efficient manner and sustain the integrity of medicines and vaccines. Second, customer service improves the external environment. e.g., the patient receives administrative aid and medical treatment at the appointed time without a delay when the information and electrical systems are fluently working. In addition, when air conditioning and plumbing systems function correctly, the patient that arrives at the clinic has a more pleasant stay and experience.

The second key finding refers to the frequency of increased maintenance service calls via the new MMMS (H2.a-H2.b). The positive effect strongly impacted three repair types (1) carpentry, (2) electrical, and (3) sanitation (H2.c). The MMMS is more friendly and accessible than the old process. In addition, the clinic's employees (end users) have an easy-to-use way to request the maintenance teams in real-time. As a result, the handling maintenance activities are carried out more frequently and improve the clinic's operation (internal environment) and the patient experience (external environment).

Our research has three main limitations, which open avenues for future research. The first limitation refers to the empirical data that is based only on a single organization from the health sector in Israel. Therefore, future research should explore organizations from various industries and countries. The second limitation refers to the limited period that measures the impacts of the system implementation. Therefore, future studies should be based on longitudinal studies that will allow for measuring operational performance over a long period. The third limitation refers to the outcome of the current study. When an organization implements new ICT, managers should use restraint when redesigning operational processes. These results should be used carefully until more research explores them for various organizations.

The study contribution is both conceptual and operational. The conceptual contribution to research is using real-life maintenance data and inventive profound model analysis. The unique model investigated the impacts of implementing MMMS according to the types of maintenance and treatments by cross-comparison analysis. We examined the effects of the system by measuring the gap in maintenance time and the number of service calls per week on three levels: (1) total maintenance, (2) type of maintenance, and (3) repair type via maintenance type. As a result, we open a venue for future research in maintenance and ICT.

The operational contribution allows organizations to decide on the feasibility of using a digital maintenance system according to the organization's repairs needs and types of maintenance. The system implementation enables optimal maintenance resources to management in decentralized organizations, minimizes the maintenance department's staff, and improves operational efficiency. For instance, the standard time of several repair types can be reduced and, as a result, may decrease the human capital of the maintenance department and the waste of operational systems. The outcome is a descent overhead cost; correspondingly, operational improvement increases customer satisfaction and retention.

# 7. References

Abdel-Hameed, M. (1987). Inspection and maintenance policies of devices subject to deterioration. *Advances in Applied Probability*, *19*(4), 917-931.

Ahmad, R., & Kamaruddin, S. (2012). An overview of time-based and condition-based maintenance in industrial application. *Computers & industrial engineering*, *63*(1), 135-149.

Almomani, H., & Alburaiesi, M. L. (2020). Using Computerized Maintenance Management System (CMMS) in Healthcare Equipments Maintenance Operations. *Journal of Environmental Treatment Techniques*, *8*(4), 1345-1350.

Andrzejczak, K., Młyńczak, M., & Selech, J. (2018). Poisson-distributed failures in the predicting of the cost of corrective maintenance. *Eksploatacja i Niezawodność*, *20*(4).

Arnaiz, A., Emmanouilidis, C., Iung, B., & Jantunen, E. (2006). Mobile maintenance management. *Journal of International Technology and Information Management*, *15*(4), 2.

Bajestani, M. A., & Banjevic, D. (2016). Calendar-based age replacement policy with dependent renewal cycles. *IIE Transactions*, *48*(11), 1016-1026.

Balaras, C. A., & Argiriou, A. (2002). Infrared thermography for building diagnostics. *Energy and buildings*, *34*(2), 171-183.

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application areas and data requirements for BIM-enabled facilities management. *Journal of construction engineering and management*, *138*(3), 431-442.

Bortolini, R., & Forcada, N. (2020). Analysis of building maintenance requests using a text mining approach: building services evaluation. *Building Research &amp; Information*, *48*(2), 207-217. <https://doi.org/10.1080/09613218.2019.1609291>

Bouabdallaoui, Y., Lafhaj, Z., Yim, P., Ducoulombier, L., & Bennadji, B. (2020). Natural Language Processing Model for Managing Maintenance Requests in Buildings. *Buildings*, *10*(9), 160. <https://doi.org/10.3390/buildings10090160>

Chen, Y., Cowling, P., Polack, F., Remde, S., & Mourdjis, P. (2017). Dynamic optimisation of preventative and corrective maintenance schedules for a large scale urban drainage system. *European journal of operational research*, *257*(2), 494-510.

Costa, R., & Lopes, I. (2021). Productivity Improvement in Manufacturing Systems Through TPM, OEE and Collaboration Between Maintenance and Production: A Case Study. IFIP International Conference on Advances in Production Management Systems,

de Jonge, B., & Scarf, P. A. (2020). A review on maintenance optimization. *European journal of operational research*, *285*(3), 805-824.

Federspiel, C. C. (2000). Predicting the frequency and cost of hot and cold complaints in buildings. *HVAC&R Research*, *6*(4), 289-305.

Fu, C., Ye, L., Liu, Y., Yu, R., Iung, B., Cheng, Y., & Zeng, Y. (2004). Predictive maintenance in intelligent-control-maintenance-management system for hydroelectric generating unit. *IEEE transactions on energy conversion*, *19*(1), 179-186.

Garg, A., & Deshmukh, S. (2006). Maintenance management: literature review and directions. *Journal of quality in maintenance engineering*, *12*(3), 205-238.

Giessmann, A., Stanoevska-Slabeva, K., & De Visser, B. (2012). Mobile enterprise applications--current state and future directions. 2012 45th Hawaii International Conference on System Sciences,

Gómez-Chaparro, M., García-Sanz-Calcedo, J., & Aunión-Villa, J. (2020). Maintenance in hospitals with less than 200 beds: efficiency indicators. *Building Research &amp; Information*, *48*(5), 526-537. <https://doi.org/10.1080/09613218.2019.1678007>

Gunay, H. B., Shen, W., & Yang, C. (2019). Text-mining building maintenance work orders for component fault frequency. *Building Research & Information*, *47*(5), 518-533.

Hamdi, N., Oweis, R., Abu Zraiq, H., & Abu Sammour, D. (2012). An intelligent healthcare management system: a new approach in work-order prioritization for medical equipment maintenance requests. *Journal of medical systems*, *36*(2), 557-567.

Hosseini, M. M., Kerr, R. M., & Randall, R. B. (1999). A hybrid maintenance model with imperfect inspection for a system with deterioration and Poisson failure. *Journal of the Operational Research Society*, *50*(12), 1229-1243.

Hu, Y.-C., Chiu, Y.-J., Hsu, C.-S., & Chang, Y.-Y. (2015). Identifying key factors for introducing GPS-based fleet management systems to the logistics industry. *Mathematical Problems in Engineering*, *2015*.

Ikumapayi, O. M., Kayode, J. F., Afolalu, S. A., Nnochiri, E. S., Olowe, K. O., & Bodunde, O. P. (2022, 5 - 7 April). A study on AI and ICT for Sustainable Manufacturing. Proceedings of the International Conference on Industrial Engineering and Operations Manageme, Nsukka, Nigeria.

Ismail, Z.-A. (2021). The requirements for maintenance management systems (MMS) at Malaysian polytechnic: a case study. *Journal of quality in maintenance engineering*.

Jantunen, E., Giordamlis, C., Adgar, A., & Emmanouilidis, C. (2010). Mobile devices and services. In *E-maintenance* (pp. 227-246). Springer.

Kallen, M.-J., & Van Noortwijk, J. M. (2005). Optimal maintenance decisions under imperfect inspection. *Reliability Engineering & System Safety*, *90*(2-3), 177-185.

Kannan, M. V. (2020). *Improving industrial corrective maintenance by efficient realization of self-diagnosis in automated production systems reusing their engineering data* Technische Universität München].

Kelly, A. (1989). Maintenance and its management.

Koch, C., Hansen, G. K., & Jacobsen, K. (2018). Missed opportunities: Two case studies of digitalization of FM in hospitals. *Facilities*.

Kumar, U., Galar, D., Parida, A., Stenström, C., & Berges, L. (2013). Maintenance performance metrics: a state‐of‐the‐art review. *Journal of quality in maintenance engineering*.

Labib, A. W. (1998). World‐class maintenance using a computerised maintenance management system. *Journal of quality in maintenance engineering*.

Levi-Bliech, M., Naveh, G., Pliskin, N., & Fink, L. (2018). Mobile technology and business process performance: The mediating role of collaborative supply–chain capabilities. *Information Systems Management*, *35*(4), 308-329. <https://doi.org/https://doi.org/10.1080/10580530.2018.1503803>

Lin, Y.-C., Cheung, W.-F., Hsieh, Y.-C., Siao, F.-C., & Su, Y.-C. (2011). Developing RFID-Based Instruments Maintenance Management in Construction Lab. In *Designing and Deploying RFID Applications*. IntechOpen.

Liu, R., & Issa, R. R. (2016). Survey: Common knowledge in BIM for facility maintenance. *J. Perform. Constr. Facil*, *30*(3), 04015033.

Madureira, S., Flores-Colen, I., de Brito, J., & Pereira, C. (2017). Maintenance planning of facades in current buildings. *Construction and building materials*, *147*, 790-802.

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., & Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy* (Vol. 180). McKinsey Global Institute San Francisco, CA.

Marquez, A. C., & Heguedas, A. S. (2002). Models for maintenance optimization: a study for repairable systems and finite time periods. *Reliability Engineering & System Safety*, *75*(3), 367-377.

Mendes, D. S. F. T., Navas, H. V. G., & Charrua-Santos, F. M. B. (2022). Proposal for a maintenance management system based on the lean philosophy and industry 4.0. *Revista Produção e Desenvolvimento*, *8*(1), e587-e587.

Mohammadfam, I., Bahmani, F., & Mahmoudi, S. (2014). Evaluation of the Implementation of a Computerized Maintenance Management System on the Maintenance and Safety KPIs. *International Journal of Occupational Hygiene*, *6*(2), 96-100.

Mustapha, Z., & Agbevade, J. (2011). Building maintenance systems of public health institutions in Ghana: a case study of La General Hospital-Accra. *Journal of Construction Project Management and Innovation*, *1*(2), 155-166.

Muzafar, S., & Jhanjhi, N. (2020). Success stories of ICT implementation in Saudi Arabia. In *Employing Recent Technologies for Improved Digital Governance* (pp. 151-163). IGI Global.

Olasumbo, M., Kanisuru, A. M., Khumbulani, M., & Innocent, R. B. (2019). E-Maintenance Management System for Optimal Functionality of Machines. In *E-Systems for the 21st Century: Concept, Developments, and Applications, Volume 2: E-Learning, E-Maintenance, E-Portfolio, E-System, and E-Voting* (pp. 209-252). Apple Academic Press.

Onoshakpor, R. M. (2014). Maintenance precepts for efficient electricity infrastructure in sub-Saharan Africa: The case of the Nigerian electricity network. 2014 IEEE 6th International Conference on Adaptive Science & Technology (ICAST),

Pal, B., & Adhikari, S. (2021). Random machine breakdown and stochastic corrective maintenance period on an economic production inventory model with buffer machine and safe period. *RAIRO - Operations Research*, *55*, S1129-S1149. <https://doi.org/10.1051/ro/2020069>

Pintelon, L., & Van Puyvelde, F. (2006). *Maintenance decision making*. Acco.

Pousttchi, K., & Habermann, K. (2009). Exploring the Organizational Effects of mobile business process reengineering. 2009 Eighth International Conference on Mobile Business,

Sahoo, T., & Liyanage, J. P. (2008). Computerized maintenance management systems: For effective plant performance. *Chemical Engineering*, *115*(1), 38.

Schoenherr, T. (2016). Mobile devices and applications for supply chain management: Process, contingency, and performance effects. *Transportation Journal*, *55*(4), 333-381.

Scutariu, M., & Albert, H. (2006). Corrective maintenance timetable in restructured distribution environment. *IEEE transactions on power delivery*, *22*(1), 650-657.

Selvakumaran, P., BASIR, M. A., & FUAD, A. F. A. (2022). LIGHTHOUSE MAINTENANCE MANAGEMENT MOBILE APPS SYSTEM. *Universiti Malaysia Terengganu Journal of Undergraduate Research*, *4*(1), 25-38.

Sheut, C., & Krajewski, L. (1994). A decision model for corrective maintenance management. *The International Journal of Production Research*, *32*(6), 1365-1382.

Shiau, W.-L., Yan, C.-M., & Lin, B.-W. (2019). Exploration into the intellectual structure of mobile information systems. *International Journal of Information Management*, *47*, 241-251.

Sidibé, I., Khatab, A., Diallo, C., & Adjallah, K. H. (2016). Kernel estimator of maintenance optimization model for a stochastically degrading system under different operating environments. *Reliability Engineering & System Safety*, *147*, 109-116.

Su, C. J. (2009). Effective mobile assets management system using RFID and ERP technology. 2009 WRI International Conference on Communications and Mobile Computing,

Sumaila, F., & Bahsi, H. (2022). Digital forensic analysis of mobile automotive maintenance applications. *Forensic Science International: Digital Investigation*, *43*, 301440.

Surveyors, R. I. o. C. (2000). *Building Maintenance: Strategy, Planning and Procurement*. RICS Books.

van Noortwijk, J. M. (2009). A survey of the application of gamma processes in maintenance. *Reliability Engineering & System Safety*, *94*(1), 2-21.

Vathoopan, M., Johny, M., Zoitl, A., & Knoll, A. (2018). Modular fault ascription and corrective maintenance using a digital twin. *IFAC-PapersOnLine*, *51*(11), 1041-1046.

Wang, R. J.-H., Malthouse, E. C., & Krishnamurthi, L. (2015). On the go: How mobile shopping affects customer purchase behavior. *Journal of retailing*, *91*(2), 217-234.

Wienker, M., Henderson, K., & Volkerts, J. (2016). The computerized maintenance management system an essential tool for world class maintenance. *Procedia Engineering*, *138*, 413-420.

Yang, C., Shen, W., Chen, Q., & Gunay, B. (2018). A practical solution for HVAC prognostics: Failure mode and effects analysis in building maintenance. *Journal of Building Engineering*, *15*, 26-32.

Yousefli, Z., Nasiri, F., & Moselhi, O. (2017). Healthcare facilities maintenance management: a literature review. *Journal of Facilities Management*.

Zaher, A., Asmar, R., Mannaa, N., Abu-Shanab, R., Deek, S., & Smaaneh, S. (2011). Developing Maintenance Management System in Al-Arabi Specialized Hospital.

Zhan, J., Ge, X. J., Huang, S., Zhao, L., Wong, J. K. W., & He, S. X. (2018). Improvement of the inspection-repair process with building information modelling and image classification. *Facilities*.

Zhang, C., Sun, Z., Heo, G., Di, L., & Lin, L. (2016). Developing a GeoPackage mobile app to support field operations in agriculture. 2016 Fifth International Conference on Agro-Geoinformatics (Agro-Geoinformatics),

# Tables

Table 1: Descriptive statistics of Maintenance time

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Repair Type | Period Time  (Before and After implementation) | DV: Maintenance time (days) | | | | | | | | |
| Total Maintenance | | | Corrective Maintenance | | | Preventive Maintenance | | |
| Sample size | Mean | SD | Sample size | Mean | SD | Sample size | Mean | SD |
| Aiֹr condition | Before implementation | 3 | 13.44 | 5.68 | 2 | 16.72 | 0.27 | 1 | 6.89 | 0 |
| After implementation | 16 | 9.73 | 7.31 |  |  |  | 16 | 9.73 | 7.31 |
| Building | Before implementation | 290 | 12.50 | 6.14 | 191 | 11.96 | 6.45 | 260 | 12.72 | 6.32 |
| After implementation | 78 | 8.66 | 7.11 | 18 | 4.61 | 5.86 | 67 | 9.45 | 7.27 |
| Carpentry and frames | Before implementation | 188 | 11.80 | 6.35 | 56 | 11.14 | 6.19 | 166 | 12.15 | 6.55 |
| After implementation | 287 | 8.75 | 5.80 | 93 | 9.00 | 6.52 | 285 | 8.76 | 5.82 |
| Electrical facilities | Before implementation | 183 | 12.06 | 6.42 | 61 | 12.50 | 7.30 | 159 | 12.23 | 6.79 |
| After implementation | 280 | 8.98 | 6.36 | 49 | 7.90 | 6.76 | 278 | 9.06 | 6.52 |
| Other facilities | Before implementation | 27 | 13.25 | 8.79 | 13 | 11.87 | 8.82 | 14 | 14.53 | 8.89 |
| After implementation | 51 | 9.41 | 8.26 | 10 | 10.80 | 6.34 | 42 | 9.08 | 8.60 |
| Paint works | Before implementation | 3 | 16.14 | 8.85 | 3 | 16.14 | 8.85 | - | - | - |
| After implementation | 37 | 11.76 | 8.29 | 3 | 9.04 | 4.99 | 34 | 12.00 | 8.53 |
| Refrigeration facilities | Before implementation | 3 | 13.27 | 9.42 | 1 | 2.54 | 0 | 2 | 18.64 | 2.13 |
| After implementation | 10 | 9.09 | 6.30 | 1 | 13.87 | 0 | 9 | 8.56 | 6.44 |
| Sanitation facilities | Before implementation | 119 | 11.29 | 6.78 | 86 | 10.91 | 6.77 | 47 | 12.22 | 7.25 |
| After implementation | 269 | 8.75 | 6.22 | 77 | 7.95 | 5.95 | 256 | 8.89 | 6.49 |
| Total | Before implementation | 816 | 12.11 | 6.46 | 413 | 11.74 | 6.70 | 649 | 12.47 | 6.62 |
| After implementation | 1028 | 8.96 | 6.44 | 251 | 8.24 | 6.38 | 987 | 9.06 | 6.57 |
| Total all | | 1844 | 10.35 | 6.63 | 664 | 10.42 | 6.80 | 1636 | 10.41 | 6.79 |

Table 2: Descriptive statistics of Maintenance calls

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Repair Type | Period Time  (Before and After system implementation) | DV: Maintenance calls (Number calls per week) | | | | | | | | |
| Total Maintenance | | | Corrective Maintenance | | | Preventive Maintenance | | |
| Sample size | Mean | SD | Sample size | Mean | SD | Sample size | Mean | SD |
| Aiֹr condition | Before implementation | 3 | 1.33 | 0.58 | 2 | 1.50 | 0.71 | 1 | 1.00 | 0 |
| After implementation | 16 | 1.06 | 0.25 |  |  |  | 16 | 1.06 | 0.25 |
| Building | Before implementation | 290 | 5.00 | 4.17 | 191 | 2.35 | 2.81 | 260 | 3.85 | 3.55 |
| After implementation | 78 | 1.42 | 0.80 | 18 | 1.00 | 0.00 | 67 | 1.39 | 0.70 |
| Carpentry and frames | Before implementation | 290 | 2.32 | 1.61 | 56 | 1.64 | 1.59 | 166 | 2.07 | 1.37 |
| After implementation | 78 | 7.29 | 4.01 | 93 | 2.17 | 1.56 | 285 | 6.64 | 3.81 |
| Electrical facilities | Before implementation | 183 | 1.98 | 1.09 | 61 | 1.39 | 0.71 | 159 | 1.75 | 0.97 |
| After implementation | 280 | 4.41 | 2.67 | 49 | 1.69 | 1.16 | 278 | 4.14 | 2.58 |
| Other facilities | Before implementation | 27 | 1.07 | 0.27 | 13 | 1.15 | 0.38 | 14 | 1.00 | 0.00 |
| After implementation | 51 | 1.12 | 0.43 | 10 | 1.30 | 0.67 | 42 | 1.05 | 0.22 |
| Paint works | Before implementation | 3 | 1.00 | 0.00 | 3 | 1.00 | 0.00 |  |  |  |
| After implementation | 37 | 1.11 | 0.31 | 3 | 1.00 | 0.00 | 34 | 1.12 | 0.33 |
| Refrigeration facilities | Before implementation | 3 | 1.00 | 0.00 | 1 | 1.00 | 0.00 | 2 | 1.00 | 0.00 |
| After implementation | 10 | 1.00 | 0.00 | 1 | 1.00 | 0.00 | 9 | 1.00 | 0.00 |
| Sanitation facilities | Before implementation | 119 | 1.39 | 0.78 | 86 | 1.30 | 0.72 | 47 | 1.15 | 0.42 |
| After implementation | 269 | 3.60 | 1.99 | 77 | 1.99 | 1.43 | 256 | 3.18 | 1.96 |
| Total | Before implementation | 816 | 3.01 | 3.07 | 413 | 1.84 | 2.10 | 649 | 2.61 | 2.62 |
| After implementation | 1028 | 4.41 | 3.45 | 251 | 1.88 | 1.38 | 987 | 4.11 | 3.26 |
| Total all | | 1844 | 3.79 | 3.36 | 664 | 1.86 | 1.86 | 1636 | 3.52 | 3.11 |

Table 3: Regression results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | H1.a- Total Maintenance | H1.b-Corrective Maintenance 0 | H1.b- Preventive Maintenance 1 | H2.a- Total Maintenance | H2.b- Corrective Maintenance 0 | H2.b- Preventive Maintenance 1 |
| Variable | (1) | (2) | (3) | (4) | (5) | (6) |
| Intercept | 2.494\*\*\* (0.022) | 2.463\*\*\* (0.320) | 2.523\*\*\* (0.025) | 1.101\*\*\* (0.034) | 0.610\*\*\* (0.049) | 0.959\*\*\* (0.039) |
| After Sys | -0.301\*\*\* (0.029) | -0.354\*\*\* (0.052) | -0.319\*\*\* (0.032) | 0.382\*\*\* (0.042) | 0.240 (0.080) | 0.454\*\*\* (0.046) |
| Before Sys | 0 | 0 | 0 | 0 | 0 | 0 |
| Unstandardized coefficients are presented, with standard errors | | | |  |  |  |
| N = 1844 in Models (1)-(2), (7)-(8); N = 644 in Models (3)-(4), (9)-(10);N = 1636 in Models (5)-(6), (11)-(12); | | | | | | |
| \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001 | | |  |  |  |  |

Table 4: Comparison statistics by repair type

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Repair Type | Mean diff. Maintenance time (days)  ((After system implementation- Before system implementation | | | Mean diff. Maintenance calls (Number calls per week)  (After system implementation- Before system implementation) | | |
| Total Maintenance | Corrective Maintenance | Preventive Maintenance | Total Maintenance | Corrective Maintenance | Preventive Maintenance |
| Aiֹr condition | 3.71- |  | 2.84 | 0.27- |  | 0.63 |
| Building | \*\*\*3.84- | 7.35-\*\*\* | \*\*\*3.27- | \*\*\*3.58- | \*\*\*1.35- | \*\*\*2.46 |
| Carpentry and frames | \*\*\*3.05- | 2.14-\*\* | \*\*\*3.38- | \*\*\*4.97 | \*\*0.53 | \*\*\*4.56 |
| Electrical facilities | \*\*\*3.08- | \*\*\*4.59- | \*\*\*3.18- | \*\*\*2.42 | 0.30 | \*\*\*2.39 |
| Other facilities | \*\*3.84- | 1.08- | \*\*5.46- | 0.04 | 0.15 | 0.05 |
| Paint works | 4.39- | 7.10- |  | 0.11 |  |  |
| Refrigeration facilities | 4.18- | 11.33 | \*\*10.08- |  | 0.00 |  |
| Sanitation facilities | \*\*\*2.54- | \*\*\*2.96- | \*\*\*3.33- | \*\*\*2.20 | \*\*\*0.69 | \*\*\*2.04 |
| Total | \*\*\*3.14- | \*\*\*3.50- | \*\*\*3.40- | \*\*\*1.40 | 0.04 | \*\*\*1.51 |
| \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001 | | | | | | |

# Figures

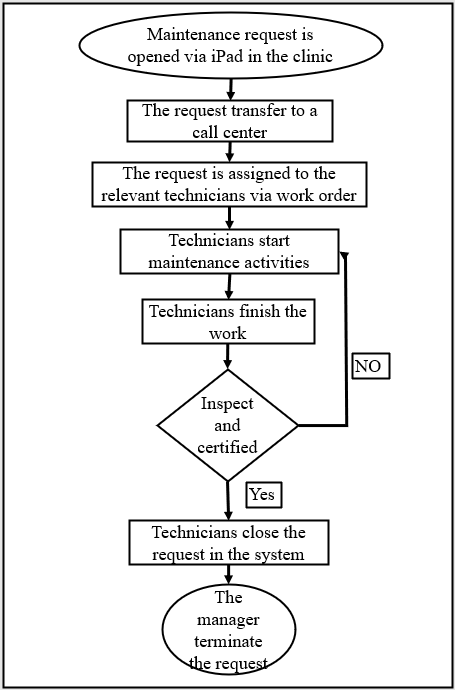
Figure 1: The detailed process of maintenance request 



Figure 2: Mean time by repair type of each Maintenance

Panel (i)) Total Maintenance (

Panel (ii)) Corrective Maintenance (

Panel (iii)) Preventive Maintenance (



Figure 3: Number calls per week by repair type of each Maintenance

Panel (i)) Total Maintenance)

Panel (ii)) Corrective Maintenance)

Panel (iii)) Preventive Maintenance)

