Holistic Hospital Operations Management with Industry 4.0 Technologies

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Abstract

Despite the hospitals of developing economies having the most trained healthcare professionals in the world, they are struggling to recognize the advantages of Industry 4.0 technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT). The developed economies, on the other hand, are quicker than ever to embrace them. This research addresses the shortcomings in the current literature concerning the implementation of such Industry 4.0 technologies in developing economies, proposing two holistic frameworks that allow practitioners to achieve a more managerial and macroscopic understanding of these technologies. The first framework defines the main functions of a hospital and maps the applications of AI and IoT compared to the character of the functions. The second framework provides an AI and IoT based network diagram of entire hospital. The novel feature of the frameworks is that each framework can be customized to suit the specific requirements of a hospital.

Keywords
Industry 4.0, Artificial Intelligence, Internet of Things, Smart Hospitals.

1. Introduction

One of the main sectors in every country in the world is the healthcare sector. Despite the COVID-19 pandemic, the Indian healthcare sector played an important role in creating substantial income and jobs for the country. One of the few markets in the health care industry during the pandemic proliferated. The health services business and the healthcare product industry are included in this sector. India's strategic advantage in this field is at a lower expense than its western rivals, resulting from highly trained specialists. Nevertheless, looking at the speed with which the developed nations in their healthcare systems take the help of two major Industry 4.0 technologies – Artificial Intelligence (AI) and the Internet of Things (IoT) – emerging nations such as India need to succeed as a pioneer in global healthcare quality. These innovations will reduce costs by supplying the already skilled workers with reliable, fast, and cost-effective assistance.

In the current health care activities, the Government of India also aims to include several technical interventions in a way to compete and to exceed international health expectations. The Engineering Export Promotion Council (EEPC), India, and the NID (National Institute of Design) met in November 2020 to improve and encourage the healthcare product industry, particularly after the pandemic, to meet the demands of the nation's healthcare sector (PIB Delhi, 2020). The initiative was designed for the medically equipped industry as the post-Covid19 Design Intervention. However, it is far more important to know the function and how the surgical equipment is used in hospitals than the instruments themselves.

Studies have shown that, as a consequence of the lack of understanding about the adroitness of technologies, organizations wishing to undertake digital transformation usually refuse to implement them (Stentoft et al., 2020; Wee et al., 2015). Although in silos, the recent literature addresses systems, models, and methods to implement several new

technologies. However, it will only be successful if digital change is carried out in the operations of the organization and not in silos. This requires a holistic system in which new technology can be adopted in hospitals in all their main functions.

1.1 Objectives

This research seeks to provide systematic frameworks for using leading Industry 4.0 technologies – AI and IoT – in the hospitals for enhancing their service operations. The next section shall discuss the existing literature on the use of novel technologies in healthcare sector, followed by the research gaps identified from the literature review. Thereafter, we propose the two comprehensive frameworks with a vision to address the identified gaps, followed by conclusion and directions for future research.

2. Literature Review

2.1 AI in Healthcare

The technology of AI has great promise in every field of medicine, from operation to psychology and radiology (Topol, 2019). The X-rays, CT scans, and photos of internal bodies can be examined even more precisely and faster across large image databases by using machine-learning-algorithms (Choy et al., 2018; Giger, 2018; Kohli et al., 2017). In order to improve innovative decision support tools for treatment decisions, AI technology, such as natural language processing (NLP), are now available so that signs can be related to the most possible symptoms (Iroju and Olaleke, 2015; Putra et al., 2019). Due to AI's ability to distinguish sequence and anomalies of data from time series, it is a remarkable application in developing intelligent medical devices such as oxygen levels, insulins, blood pressure and so on to monitor and regulate oxygen saturation levels (Metcalf et al., 2016; Papa et al., 2020). Furthermore, AI has also played an important part in advanced operations. Though the AI breakthrough has been fairly recent in surgery, the strength of this technology cannot be underestimated both before and during the operation as regards internal imaging, navigation, identification and computer assisted guidance (X.-Y. Zhou et al., 2019). The use of AI in the early diagnosis and treatment of intra-luminal ailments with endoscopic methods has increased recently. Simultaneous Location and Mapping (SLAM) is one of the many methods for managing endoscopic motion into the expected area of interest. Endoscopes include robotics that can simultaneously create a three-dimensional chart of their environment and monitor them and their camera on this map (Grasa et al., 2013; Song et al., 2018). In addition to the purely medical viewpoint, there is a substantial increase in understanding the effects of AI on the health system, especially in administrative and organisational practises. The use of AI tools such as speech recognition and chatbots will be easiness for tasks such as billing operations, patient prioritisation and the appointment of clinical personnel depending on complex variations of the number of patients to be served (Rajkomar et al., 2019). These technologies are also strongly used in psychological and psychological fields (Graham et al., 2019; Luxton, 2014).

2.2 IoT in Healthcare

The IoT is a series of sensors linked to each other through wireless networks, so that sensor instruments can not only log and track environmental entries but can also communicate with each other via pre-set protocols and take data-based decisions. Recently, the researchers' interest in studying IoT's healthcare applications has increased. Various reports address both the technological and administrative aspects of hospital IoT implementation. In addition to a systematic study of the avant-garde network architectures, the authors of (Dhanvijay and Patil, 2019) recommend an IoT healthcare system, which uses the Wireless Body Area Network. Effective control of health metrics, inventory management and service efficiency were the main management issues.

By supplying remote health control services, IoT will help distress the already overwhelmed healthcare systems due to COVID-19. In remote rural areas and in periods of natural calamities, the advantages of IoT-based remote health monitoring framework may be further expanded. In (Ghosh et al., 2016) authors have suggested elegantly an Arduino and Phidgets Interface Kit architecture for concerned caregivers in the home who can communicate to physicians over the Internet and support doctors in monitoring patients' conditions remotely. In (Jamil et al., 2020), the authors attempt, by an effective combination of IoT and Blockchain, to solve the problem of remote health tracking. The model is used to protect the security and confidentiality of the data gathered and shared over the internet using remote sensing capacities and smart Hyperledger features from the Blockchain system.

The Ambient Assisted Living is further future use of IoT. (AAL). AAL is a newly developed research field with a view to creating a holistic ecosystem, particularly for the older and specially capable, for close and remote healthcare systems (Bacciu et al., 2014). In an effort to achieve the AAL goals by using sensors, cable networks and wearable devices, the authors of (Rashed et al., 2018) have developed a robust multi-layered IoT healthcare architecture. Studies like the IoT protocol architecture (Minoli et al., 2017) for IoT-based device security presented by AAL.

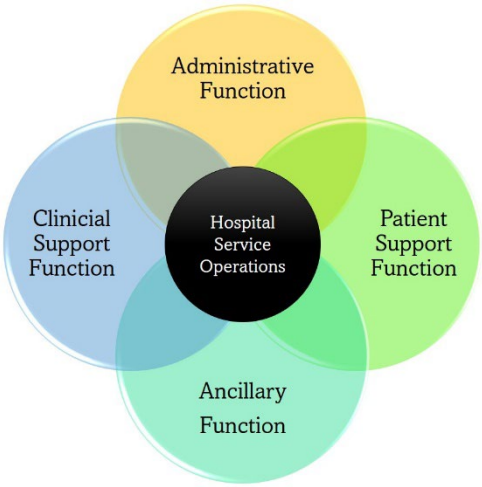
3. Research Gaps

Two main research gaps have been identified based on the examples drawn out of the current literature:

1. Most of the research dealing with AI in healthcare seem to be a challenge. This methodology continues to lead to a more siloed understanding of the present state of science. Moreover, most of the research in this field is of a technical nature and focuses less on administrative consequences. There is also a lack of studies that provide a holistic and regulated panorama of AI implementations in the hospital supply chain.
2. Most of the research concerning the use of IoT concentrate on the scientific aspects of IoT and analyse the microscopic view. Yet emerging-economic hospitals continue to struggle to comprehend the concept of IoT. In a hospital, administrators and physicians appear to be overwhelmed by which technologies may be used to strengthen the management function. In this respect, the technology in the context of the internal hospital operations must be seen macroscopically.

4. Proposed Frameworks

The authors suggest an exhaustive method to help clinicians classify hospital roles as well as the technologies appropriate to the activities within each broad role to resolve the gaps found and addressed in the previous section.



4.1 Framework 1: Character vs Solutions matrix of the four major functions of a hospital

Figure 1. The four major functions of hospital service operations

Any hospital's activities can be categorised widely into four different leading functions (Figure 1):

1) Administrative Function: This role includes tasks that are strictly organisationally related to the day-to-day functions of the hospital. This includes the projection of current employees, recruitment of new personnel, the management of inventories, the management of medical records, management of information systems, the maintenance of machinery and equipment, accounts, demand forecasting, management of resources and attendance systems. There are more organisational than patient-centred practises. In addition, most operations include numbers, multi-criteria decision-making, or excellent decision-making.

2) Patient Support Function: This feature mostly covers patient-related operations such as the surveillance of health metrics such as blood pressure, heart rate, SpO_2 levels, level of haemoglobin, etc., health cheques, malignancies diagnosis, treatment of diseases, operation theatre readiness and surgery. There are patient-centred practices rather than organisational activities. Moreover, most of the activities rely on the patient's vital for successful decision-making documentation and tracking.

3) Clinical Support Function: This work mostly concerns the tasks supporting the patient's care and diagnosis. The sample processing and tracking system involves image monitoring, storage and analysis, pattern identification, computerised testing, blood bank, pathology laboratories and pharmacy.

4) Ancillary Function: As the name means, this role covers the basic duties of the hospital, such as housekeeping, washing, maintenance personnel, safety personnel and systems, removal of waste and sanitation after discharge.

This framework aims at categorizing each function of the hospital service management based on the character of the function, as well as the possible technological solutions that can help enhance the function. As the functions are to be

mapped across the two dimensions, the framework takes the shape of a matrix, with the horizontal axis as a spectrum of the character of the functions, whereas the vertical axis being the spectrum across the potential technological solution catering to the function as shown in Figure 2. The character spectrum ranges from being organization-centric on the right to being patient-centric on the left. The technological solution spectrum ranges from IoT-based solutions on the top to AI-based solutions on the bottom. Additionally, several important activities within each function are plotted on the matrix based on the literature support for each of them.

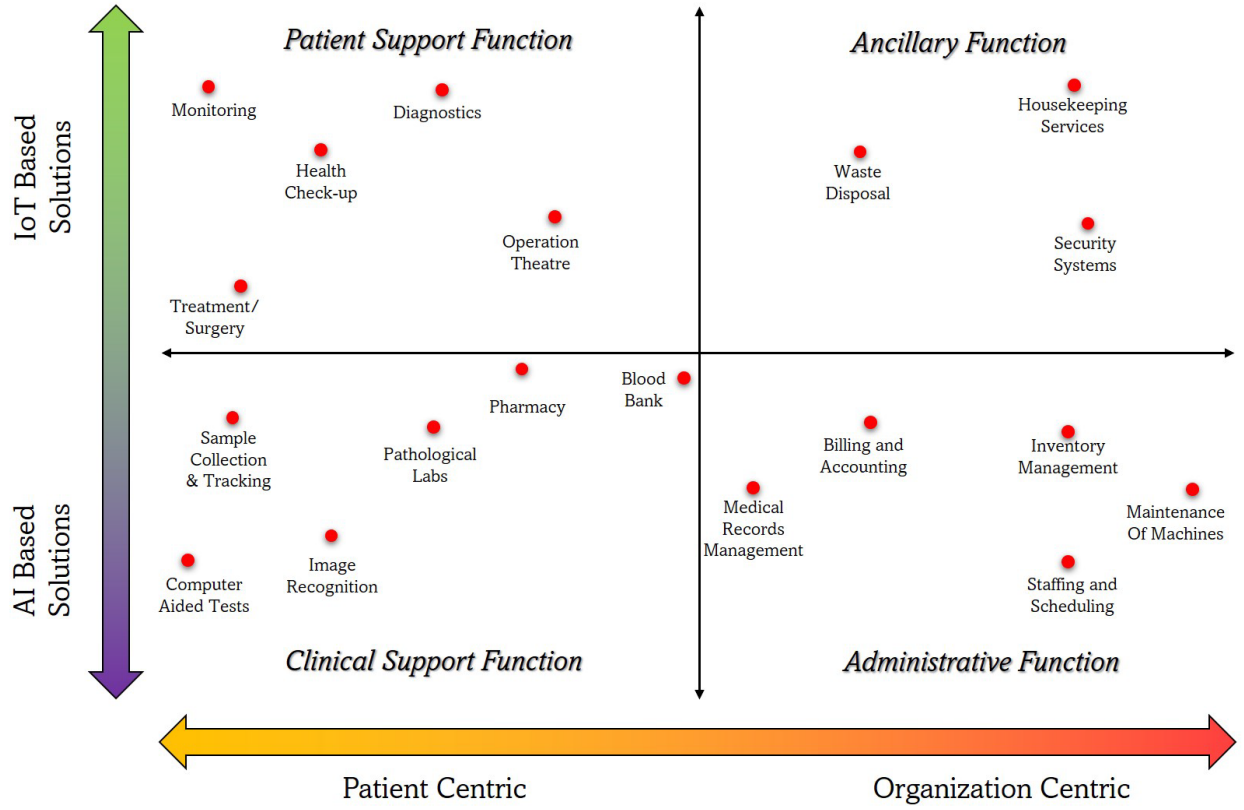


Figure 2. Character vs Solutions matrix of the four major functions of hospital service operations

A study by (Stylianou et al., 2012) has presented a novel AI based algorithm for the staffing of software management projects. The same algorithm can be adopted for solving the staffing related issues in a hospital. The projects can be equated with the tasks or patients and the software engineers with doctors, nurses, and other technicians. Along similar lines, (Jiménez-Domingo et al., 2014) have developed an AI based multi-objective genetic algorithm to improve the efficiency and enhance the personnel-task fit. The usage of AI in scheduling operations has been discussed in literature since last two decades, owing to the computational potential of AI to carry out complex algorithms with least human intervention. (Zweben et al., 1994) propose certain knowledge-based searching methods that can deal with large-scale and complex real-life scheduling problems. The authors of (Atabakhsh, 1991) believe that an AI-based system must not replace a human scheduler, rather it must extend his or her capabilities by assisting in solving the problems that a human brain simply cannot perform. Consequently, the author reviews several innovative AI algorithms for constraint-based scheduling. Such algorithms can be easily adopted in the context of hospital operations. In the field of machine maintenance, AI has the potential to offer predictive maintenance solutions. (Lee et al., 2019) put forth AI-based algorithm for predictive maintenance for monitoring two the cutting tool and the spindle motor. This algorithm can be adopted in the field of orthopaedic surgery, wherein the heavy-duty tools need to be in their best working condition at any given point in time.

AI also holds the potential to enhance the most trivial functions such as accounting. The authors of (Marshall and Lambert, 2018) propose a hypothetical case study of creating an AI and machine learning based accounting software design. The service supply chain of hospital-related equipment is filled with uncertainties. This gives rise to major

challenges for hospitals. In the field of purchasing, AI can help in identification and selection of best suppliers, as proposed by (Bahadori et al., 2020), where the authors have developed an supplier selection algorithm based on artificial neural network and fuzzy VIKOR. Certain AI based models can also process the existing medical records to predict acute critical illness beforehand and with enhanced precision than conventional early warning score systems, as proposed by (Lauritsen et al., 2020).

Studies such as (Alexander et al., 2020; Giger, 2018; Gore, 2020; Lewis et al., 2019; L.-Q. Zhou et al., 2019) clearly showcase the capabilities of AI and machine learning based models and algorithms to not only process the medical images of internal organs, but also to identify several patterns that can detect certain ailments beforehand. These can be used for pre-emptive diagnostics of patients. In order to manage the blood donation drives and blood banks, studies such as (Alajrami et al., 2019) and (S Naresh et al., 2020) have aptly described the potential of AI and cognitive computing. In the area of pathology, the rise of digital pathology has paved the way for AI to assist the technicians. Studies such as (Bera et al., 2019; Niazi et al., 2019) provide an in-depth discussion on the cutting-edge AI based tools for digital pathology. Another indispensable part of a hospital is the pharmacy. The demand forecasting of medicines in pharmacy can be promptly assisted by certain AI algorithms as discussed in (Donepudi, 2018). In an another study by (Imran et al., 2020), the authors propose an AI based tracking model for the detection of COVID-19 from cough samples using a smartphone application.

As far as the use of IoT based solutions in hospital service operations is concerned, most of the activities under the ancillary function and the patient support function can be assisted with IoT. Studies such as (Bacciu et al., 2014; Dhanvijay and Patil, 2019; Ghosh et al., 2016; Jamil et al., 2020; Minoli et al., 2017; Rashed et al., 2018) have proposed algorithms, architectures, topologies and frameworks showing the application of IoT sensors and wireless networks for effective monitoring of the vitals of a patient. Sustainable disposal of biomedical waste is also a major challenge for most of the hospitals in the emerging economies. Studies like (Adiningrat et al., 2020; Manavalan and Jayakrishna, 2019; Shettennavar and Vithayathil, 2019) discuss the utility of IoT based application in for achieving cost optimized sustainable IoT based solutions for biomedical waste management. In the field of surgery, studies such as (Shabana and Velmathi, 2018) and (Haleem et al., 2020) present the usefulness of IoT for tele-surgery and orthopaedic surgery respectively. IoT coupled with AI can also help in advanced and smart security systems for hospital environment (Valanarasu, 2019).

4.2 Framework 1: Holistic Hospital Operations Management using AI and IoT

Based on the frameworks discussed above, the third framework aims at establishing a holistic model of the service operations of a hospital with the help of AI and IoT based technologies (Figure 3). This framework provides a network of various tasks, activities, and departments of a hospital along with the flow of data and meaningful information across several IoT sensors and AI based algorithms via libraries of Big Data.

When a potential customer comes to the reception desk, the primary personal data collected from the customer, such as his name, age, sex, medical history, socio-economic background, eating habits, etc. can be collected and stored in the Patient Big Data Storage. The patient is then admitted into the hospital, given an appointment, or sent for the clinical tests, such as radiology, pathological tests, MRI, and CT scans, where more of their data is collected and stored in the same database. For admitted patients, the IoT sensors and wearable devices measure the vitals of the patient, and this data is transmitted to the database in real-time. This real-time data, in combination with the patient's data collected in previous stages and processed by a suitable AI based algorithm, can provide the doctors with crucial insights into the probable existing as well as upcoming or developing ailments. In addition to this, the AI algorithms can look for similar cases in the past, compare the cases, and come up with a tentative remedial action as well, which can be directly fed to the doctors' desk. The doctors can then implement this tailormade remedial plan along with their own discretion.

Using IoT sensors in the storage vessel of blood banks can help in transmitting real-time data to the Clinical Department Big Data storage. This data can be processed by an AI algorithm predicting the future demands of certain blood groups. The insights thus obtained can be extremely useful for the corporate social responsibility (CSR) department of the hospital in organizing blood donation camps focussing on a specific blood group. The same database can also hold the data form the pharmacy and patient consumables such as syringe, cotton, bandages etc. from the wards of admitted patients and processed to forecast the demands. The Ancillary Department Big Storage can collect the data from cafeteria and housekeeping department to identify the consumables and forecast their demand as well. All these insights can be sent to the procurement department.

A rather innovative use of AI would be in capacity planning and demand forecasting using social media. The data stored in the Patient Big Data storage can be coupled with the user generated content from social media handles of the hospital as well as the overall domain of healthcare from websites such as Twitter, Facebook, and Instagram as an input to an

AI based Text Mining engine, which can help in identifying potential trends related to patients, diseases, or healthcare in general. For instance, in the mid of 2021, the second wave of COVID-19 in the Indian subcontinent created a massive demand for oxygen cylinders. Social media websites were the most exploited media of information that helped strangers across various cities to arrange oxygen cylinders for those in dire need. The hospitals could have collected the raw and unstructured data from these websites and figured out the demand for oxygen in exact numbers, the location where it is needed the most, and the list of potential suppliers in the nearby regions. The trends identified so can then help the management of the hospital to understand the pulse of the consumers better and help them to be prepared for a probable surge or dwindle in the demand of beds. The management can take important decisions regarding staffing, scheduling, and capacity planning based on the gathered insights. Similarly, the footage recorded by the CCTV cameras can be collected by the Ancillary Department Big Data Storage and processed by an AI algorithm developed for identification of faces, postures, and gestures pertaining to potential security threats. The insights thus obtained can be readily transmitted to the security department or control room, helping them to take prompt action immediately.

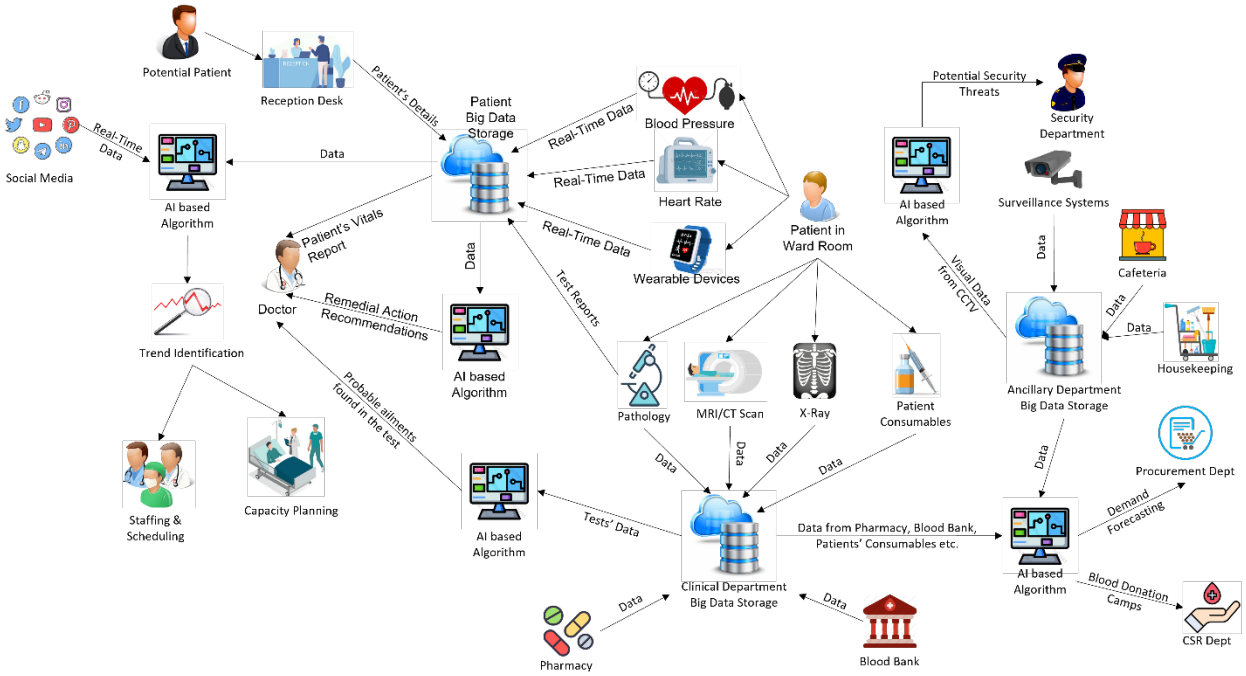


Figure 3. Holistic Hospital Service Operations Management using AI and IoT

5. Conclusion and Directions for Future Research

Hospitals in developing economies are struggling to learn, apply and harvest the advantages of technologies based on AI and IoT in their environment. The aim of this study is to recognise the shortcomings in established literature regarding the use of such state-of-the-art technology in emergence hospitals and thus to develop a mechanism to enhance the awareness of these technologies by practitioners in those economies. The lack of a macroscopic perspective of technology from a management point of view was one of the main shortcomings of current literature.

This study appropriately proposes two frameworks for the adoption of AI and IoT based solutions in the hospitals of emerging economies. The first framework aims at identifying the major functions that make up the overall hospital service operations. This not only simplifies the idea of hospital service operations for the practitioners, but also provides a backdrop over which the next framework is built. After identifying the four major functions of a hospital, the framework aims at mapping the functions across a Character vs Solutions Matrix. This matrix further clarifies the character of each function ranging from organization-centric to patient-centric, along with the kind of technological solution that can be deployed in them, ranging from IoT based solutions to AI based solutions. These frameworks are designed to serve as a map for the practitioners, doctors, and other healthcare professionals to adopt the new age technologies into their ecosystem. An elegant feature of the second framework is that it is flexible to be tailored according to the needs of a hospital. In other words, practitioners can identify the activities and tasks under a particular function that are relevant to their hospital and can use this framework as a template.

Researchers can attempt to validate and increase the structure through its use in a hospital's operations. Exploratory research may also be conducted to document and explore physicians' views on the use of AI and IoT-based technologies in hospital operations. In the analysis of developing country hospitals and urban hospitals of developing countries, the structure suggested in this study can also be expanded.

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