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ORIGINAL

# Empirical Evaluation of Internet of Things Technologies for Advancing Healthcare Scalability and Performance

## Evaluación empírica de las tecnologías del Internet de las cosas para mejorar la escalabilidad y el rendimiento de la asistencia sanitaria

A Geetha Bhavani[1], Biswaranjan Swain[2], Jamuna KV[3]

[1]Noida International University, Department of Chemistry. Greater Noida, Uttar Pradesh, India.
[2]Centre For Internet of Things, Siksha 'O' Anusandhan (Deemed to be University). Bhubaneswar, Odisha, India.
[3]JAIN (Deemed-to-be University), Department of Forensic science. Bangalore, Karnataka, India.

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**Corresponding Author:** A Geetha Bhavani

## ABSTRACT

The Internet of Things (IoT) is transforming the healthcare sector by introducing interconnected technologies that enhance remote monitoring, resource management, and service delivery. Its ability to improve scalability and performance makes a critical component of modern healthcare, particularly in addressing growing demands and resource limitations. The goal is to evaluate the role and importance of IoT technologies in improving healthcare scalability and performance, based on insights from healthcare providers and statistical analyses. To gain insights, opinions from 43 healthcare providers were collected, focusing on the significance of IoT in healthcare operations. Regression analysis, ANOVA, and paired t-tests were used to assess the relationships between IoT implementation and its impact on service quality, efficiency, and scalability. These statistical tools provided a robust framework for analyzing the benefits and challenges associated with IoT technologies. The analysis revealed that IoT significantly enhances healthcare scalability and performance. Key outcomes include improved patient monitoring, optimized resource allocation, cost-effective service delivery, healthcare service efficiency and patient satisfaction and experience. Healthcare providers emphasized the importance of IoT in meeting the needs of underserved regions and managing increased demand. Statistical tests validated these observations, demonstrating strong correlations between IoT adoption and improved operational outcomes. The statistical tests indicated healthcare service efficiency had the most significant impact through the paired t-test ($t = 8,92$, $p = 0,000$), regression analysis ($\beta = 0,65$, $p = 0,000$), and ANOVA ($f = 10,8$, $p = 0,001$), highlighting IoT's role in optimizing healthcare operations. IoT technologies play a pivotal role in modern healthcare by addressing challenges related to accessibility, affordability, and service efficiency. By leveraging connected devices, healthcare systems can deliver better outcomes, meet growing demands, and achieve sustainable improvements in scalability and performance.

**Keywords:** Internet of Things (IoT); Healthcare Scalability; Statistical Analysis; Smart Healthcare Technologies.

## RESUMEN

El Internet de las Cosas (IoT) está transformando el sector sanitario al introducir tecnologías interconectadas que mejoran la monitorización remota, la gestión de recursos y la prestación de servicios. Su capacidad para mejorar la escalabilidad y el rendimiento lo convierte en un componente crítico de la sanidad moderna, sobre todo a la hora de abordar las crecientes demandas y las limitaciones de recursos. El objetivo es evaluar el papel y la importancia de las tecnologías IoT en la mejora de la escalabilidad y el rendimiento de la asistencia sanitaria, basándose en las opiniones de los profesionales sanitarios y en análisis estadísticos.

Para ello, se recogieron las opiniones de 43 profesionales sanitarios sobre la importancia de la IO en las operaciones sanitarias. Se utilizaron análisis de regresión, ANOVA y pruebas t pareadas para evaluar las relaciones entre la implementación de IoT y su impacto en la calidad, eficiencia y escalabilidad del servicio. Estas herramientas estadísticas proporcionaron un marco sólido para analizar los beneficios y retos asociados a las tecnologías IoT. El análisis reveló que IoT mejora significativamente la escalabilidad y el rendimiento de la asistencia sanitaria. Entre los principales resultados se incluyen la mejora del seguimiento de los pacientes, la optimización de la asignación de recursos, la prestación de servicios rentables, la eficiencia de los servicios sanitarios y la satisfacción y experiencia de los pacientes. Los proveedores sanitarios destacaron la importancia del IoT para satisfacer las necesidades de las regiones desatendidas y gestionar el aumento de la demanda. Las pruebas estadísticas validaron estas observaciones, demostrando fuertes correlaciones entre la adopción de IoT y la mejora de los resultados operativos. Las pruebas estadísticas indicaron que la eficiencia de los servicios sanitarios tuvo el impacto más significativo a través de la prueba t pareada (t = 8,92, p = 0,000), el análisis de regresión (ß = 0,65, p = 0,000) y ANOVA (f = 10,8, p = 0,001), destacando el papel de IoT en la optimización de las operaciones sanitarias. Las tecnologías IoT desempeñan un papel fundamental en la sanidad moderna, ya que abordan retos relacionados con la accesibilidad, la asequibilidad y la eficiencia de los servicios. Mediante el aprovechamiento de los dispositivos conectados, los sistemas de salud pueden ofrecer mejores resultados, satisfacer las crecientes demandas y lograr mejoras sostenibles en la escalabilidad y el rendimiento.

**Palabras clave:** Internet de las Cosas (Iot); Escalabilidad de la Atención Sanitaria; Análisis Estadístico; Tecnologías Sanitarias Inteligentes.

## INTRODUCTION

The rapid evolution of medical technologies and increasing pressure for the affordability of patient management have required scalability and performance as fundamental strategies in current health systems.[1] Scalability is important in maintaining the ability of health infrastructures, such as Electronic Health Records (EHRs), telemedicine, and Artificial Intelligence (AI)-diagnosis to process more patient numbers and increase sets of data without compromising efficiency.[2] Performance, though focused on the sustainability of responsiveness, accuracy, and reliability in offering healthcare, particularly in real-time decision-making and emergency response.[3] Cloud, edge computing, and AI-driven automation address these challenges with more efficient data processing, interoperability, and predictive analytics.[4] Compatibility with data security, compliance, and low-latency processing remains a priority.[5] Moreover, with healthcare becoming more personalized and telemedicine gaining emphasis, scalable solutions need to support a vast array of medical applications without slowing down existing infrastructure.[6] Many explorations recognize key strategies to improve scalability and performance in health systems, considering technological innovation, resource use, and regulatory constraints.[7] Addressing the challenges is important in providing equitable and high-quality access to healthcare, especially in the situation of rising patient demands and international health crises.[8]

The main goal of the investigation is to examine how IoT technology could prevent COVID-19 occurrences.[9] Investigators with data scientists and engineers could use the collected data to forecast and stop COVID-19. The results showed descriptive statistics of IoT in empowering interoperability (Mean = 2,16) and the paired t-test (t = 2,22) for performance and functionality. The exploration involving 209 exam participants that IoT healthcare device adoption enhanced when individuals maintain data control according to the experimental findings even though real control holds no bearing was evaluated.[10] Investigation results showed that (mean = 4,26) and (mean = 4,39) were the descriptive statistics for perceived advantages and technology commitment. Current IoT applications in healthcare and how IoT devices increase health service delivery were discussed.[11] The exploration examined the problems of IoT-based healthcare along with barriers to adoption for patients and medical staff as well as interoperability, security and privacy, data ownership and control, storage solutions, compensation frameworks, and acceptability and trust in implementation.

To use of modern computing technologies, such as blockchain and the IoT to enhance healthcare systems operation has been explored.[12] Drug traceability with isolated patient observation and medical data administration served as the main investigation points for exploring IoT blockchain applications in medical sectors. Major factors that determined people's willingness to adopt IoT healthcare products were investigated.[13] Perceived Ability (PA), image, and Perceived Ease of Use (PEOU) demonstrated a notable impact on the intention of using IoT healthcare devices during the entire investigation period. Patients handling information and communication technology related to the effectiveness of IoT-based healthcare services were discussed.[14] Explorers would use those result findings to guide the deployment of next-generation IoT-based health and wellness services. An investigation on IoT-based connectivity to regulate better healthcare solution delivery

methods was determined.[15] Healthcare delivery and quality services improved through IoT technology since it enabled worldwide connections of billions of devices. It examined prospects for IoT-based better healthcare solutions that could be developed in upcoming years. The purpose of this exploration is to assess how IoT applications boost healthcare performance together with service capabilities and scalability.

## METHOD

Healthcare monitoring improves through IoT concepts, which also enhance both healthcare resource management and healthcare service delivery efficiency. The investigation examines IoT applications in healthcare scalability and performance assessment by collecting data from 43 healthcare providers and statistical results. Multiple statistical tests show that IoT adoption leads to enhance patient surveillance, more effective resource usage and less expensive medical services delivery. The findings prove that IoT technology delivers substantial benefits for healthcare accessibility combined with affordability along with operational effectiveness.

### IoT for Advancing Healthcare

The implementation of IoT technology enables superior healthcare performance along with better scalability because it allows instantaneous data collection through remote monitoring systems that can automatically handle resources. Healthcare operations become more effective because connected devices collect patient vital signs as well as enhance hospital processes to make treatment plans more optimized and reduce staff workload. Telemedicine technology enabled through the system provides enhanced medical access to areas without sufficient healthcare services. Healthcare services improve their decision-making abilities through smart sensors and cloud computing to reduce costs while providing high-quality patient care at the required service scale. Figure 1 illustrates the IoT-Enabled smart healthcare system.

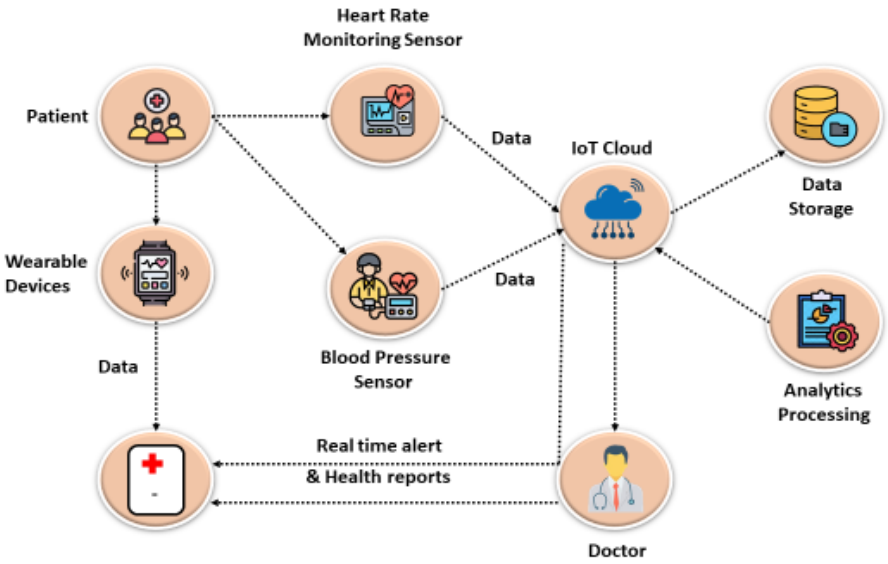


**Figure 1.** IoT-Enabled Smart Healthcare System

### Data Collection

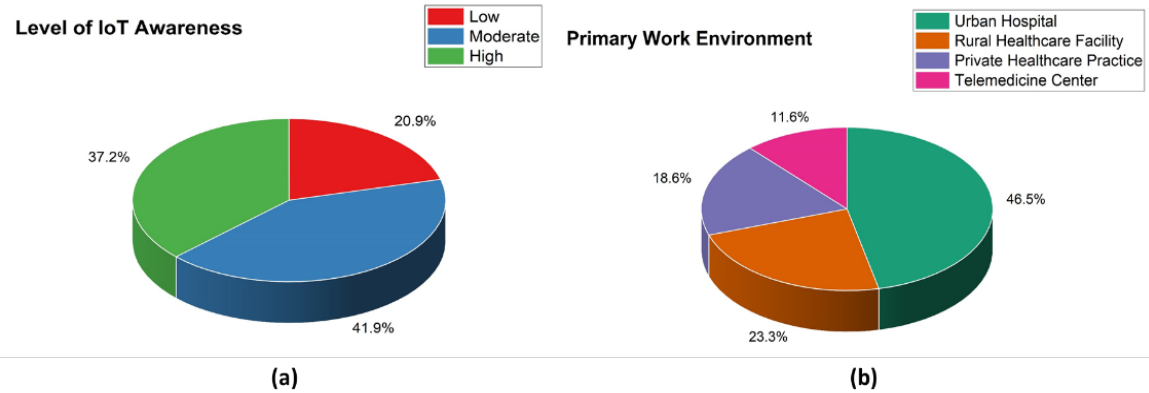


**Figure 2.** Distribution of Participants by Demographic variables (a) Level of IoT awareness and (b) Primary work environment

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**Table 1.** Demographic data of Variables

| Variable | Categories | Frequency (n=43) | Percentage (%) |
|---|---|---|---|
| Gender | Male | 25 | 58,1 |
| | Female | 18 | 41,9 |
| Age Group | 25–34 | 10 | 23,3 |
| | 35–44 | 15 | 34,9 |
| | 45–54 | 12 | 27,9 |
| | 55+ | 6 | 14,0 |
| Years of Experience in Healthcare | 1–5 years | 8 | 18,6 |
| | 6–10 years | 12 | 27,9 |
| | 11–15 years | 14 | 32,6 |
| | 16+ years | 9 | 20,9 |
| Professional Role | Physician | 12 | 27,9 |
| | Nurse | 10 | 23,3 |
| | Healthcare Administrator | 8 | 18,6 |
| | IT Specialist in Healthcare | 7 | 16,3 |
| | Other Healthcare Personnel | 6 | 14,0 |
| Level of IoT Awareness | Low | 9 | 20,9 |
| | Moderate | 18 | 41,9 |
| | High | 16 | 37,2 |
| Primary Work Environment | Urban Hospital | 20 | 46,5 |
| | Rural Healthcare Facility | 10 | 23,3 |
| | Private Healthcare Practice | 8 | 18,6 |
| | Telemedicine Center | 5 | 11,6 |

The exploration gathered data from 43 healthcare providers using both surveys and interviews that examined how IoT affects healthcare operational processes. The participants included members of healthcare staff who used IoT-driven healthcare solutions. The surveys collected numerical data about service efficiency, scalability and resource optimization methods, but the interviews gave qualitative information about implementation difficulties and advantages. The analysis of participant characteristics through demographic data enables explorers to properly determine IoT adoption relationships with healthcare efficiency, operational impact, and scalability. Table 1 describes the demographic data of variables. The distribution of participants by (a) level of IoT awareness and (b) primary work environment are represented in figure 2.

**Structure of Questionnaires**

Patient Monitoring: Four questions are included in this part and it measures to extent IoT increases real-time monitoring and early detection and decreases the necessity for face-to-face check-ups.

1. How effective is IoT-based monitoring in tracking patient vitals in real-time?
2. To what extent has IoT improved early detection of health issues?
3. How reliable do you find IoT devices for continuous patient monitoring?
4. Has IoT integration reduced the need for in-person patient check-ups?

Resource Allocation: This section contains four questions that evaluate the role of IoT in optimizing medical resources, inventory, allocation of staff workload, and minimizing wastage or shortage within healthcare organizations.

1. How has IoT contributed to optimizing the allocation of medical resources?
2. Has IoT improved the efficiency of inventory management in your facility?
3. To what extent does IoT assist in managing staff workload effectively?
4. Has IoT helped in reducing resource wastage and shortages?

Cost-Effective service delivery: It contains four questions that describe how IoT can reduce the cost of healthcare, reduce hospitalizations, lower operational costs, and offer low-cost and affordable medical services.

1. Has IoT implementation led to a reduction in overall healthcare costs?
2. To what extent has IoT minimized unnecessary hospital visits and admissions?
3. Has IoT-based remote healthcare reduced operational expenses?
4. How effective is IoT in delivering affordable and accessible healthcare services?

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Healthcare service efficiency: Four questions are included in this part to monitor IoT's effect on emergency response times, workflow coordination, treatment decision-making, and patient data accuracy.

1. Has IoT improved response times for emergency healthcare services?
2. To what extent has IoT enhanced workflow and coordination among medical staff?
3. Does IoT contribute to better decision-making in treatment and diagnosis?
4. How significantly has IoT improved the accuracy of patient records and data management?

Patient satisfaction and experience: This section contains four questions that focus on IoT-enabled healthcare improvements as regards patient involvement, distant service satisfaction, overall experience, and recommending the services.

1. Has IoT-based healthcare improved the overall patient experience?
2. How satisfied are patients with remote healthcare services enabled by IoT?
3. Do patients feel more engaged in their healthcare due to IoT-based monitoring?
4. How likely are patients to recommend IoT-driven healthcare services?

**Statistical Assessment**

A statistical evaluation performed through SPSS assesses the effects of IoT on healthcare scalability and performance levels. The analysis of regression explains the relationships that exist between operational efficiency and IoT adoption levels. ANOVA performs a service quality assessment between different IoT adoption levels. The paired t-test method evaluates the changes that occur before and after implementing IoT technologies.

## RESULTS

The exploration aimed to assess the impact on key variables, such as patient monitoring, resource allocation, cost-effective service delivery, healthcare service efficiency, and patient satisfaction and experience. The statistical analyses, which include regression analysis, ANOVA, and paired t-tests are used to validate IoT's impact on healthcare efficiency, scalability, and service quality.

**Regression Analysis**

The predictive relationships in healthcare scalability and performance changes due to IoT implementation can be measured using regression analysis. The general form of a regression analysis model is shown in equation 1.

$$Y = a + bX1 + cX2 + dX3 + \epsilon \qquad (1)$$

Where:
Y – Healthcare variable.
X1, X2, X3 – IoT service variables.
a – Intercept.
b,c, d – Slopes.
$\epsilon$ – Residual (error).

**Table 2.** Regression Analysis of IoT Impact on Healthcare Performance

| Variables | Coefficient (β) | Standard Error | t-value | p-value |
|---|---|---|---|---|
| Patient Monitoring | 0,58 | 0,12 | 4,83 | 0,001 |
| Resource Allocation | 0,42 | 0,10 | 4,20 | 0,002 |
| Cost-Effective Service delivery | 0,36 | 0,15 | 2,40 | 0,025 |
| Healthcare Service Efficiency | 0,65 | 0,08 | 8,12 | 0,000 |
| Patient Satisfaction and Experience | 0,48 | 0,11 | 4,36 | 0,003 |

Regression analysis indicates the impact of IoT-facilitated improvements on healthcare scalability and performance. Efficiency in healthcare services reflects the highest impact (β = 0,65, p = 0,000), with a high correlation for improved operational performance. Patient monitoring (β = 0,58, p = 0,001) is also a high-impact factor for improved healthcare delivery through real-time monitoring. Patient experience and satisfaction (β = 0,48, p = 0,003) also reflect a high positive impact. Resource allocation (β = 0,42, p = 0,002) is essential

for effective healthcare resource utilization, and better use of resources. Cost-effective service delivery (β = 0,36, p = 0,025) reflects the lowest yet most significant impact. All the variables reflect statistically significant p-values, indicating IoT's role in enhancing healthcare efficiency, resource utilization, and overall service efficacy. Table 2 and figure 3 illustrate the variables using regression analysis.

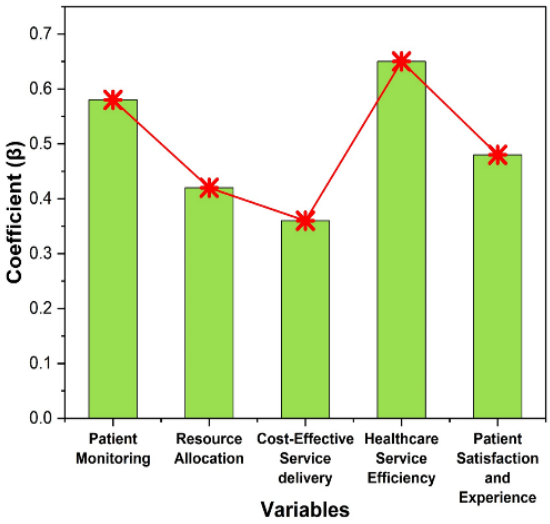


**Figure 3.** Regression Coefficients of IoT Impact on Healthcare Performance Variables

**ANOVA**

ANOVA establishes significant performance differences that result from multiple IoT implementation metrics for healthcare management scalability. The general form of the ANOVA model is shown in Equation 2.

$$F = \frac{MS_{between}}{MS_{within}} \qquad (2)$$

Where:

F is the F-statistic, a test that produces a statistical value for detecting meaningful variations between the average values of various groupings.

$MS_{between}$ Calculates the variation between various variables.

$MS_{within}$ Calculates the variation in every variable.

**Table 3.** ANOVA Test Results for IoT Impact on Healthcare Performance

| Variable | Sum of Squares (SS) | Degrees of Freedom (df) | Mean Square (MS) | f-value | p-value |
|---|---|---|---|---|---|
| Patient Monitoring | 15,2 | 2 | 7,6 | 8,5 | 0,002 |
| Resource Allocation | 12,8 | 2 | 6,4 | 7,3 | 0,004 |
| Cost-Effective Service delivery | 9,5 | 2 | 4,75 | 5,2 | 0,018 |
| Healthcare Service Efficiency | 20,3 | 2 | 10,15 | 10,8 | 0,001 |
| Patient Satisfaction and Experience | 14,6 | 2 | 7,3 | 6,9 | 0,006 |

The results from the ANOVA outcomes indicate the statistical contribution of drivers powered by the IoT towards the scalability and performance of healthcare services. In particular, healthcare service efficiency has the highest F-value (10,8) with the lowest p-value (0,001), indicating its substantial contribution. This is followed by patient monitoring (F = 8,5, p = 0,002), which suggests its substantial contribution towards enhancing healthcare processes. Moreover, patient satisfaction and experience (F = 6,9, p = 0,006) and resource allocation (F = 7,3, p = 0,004) have substantial contributions, hence supporting the application of IoT in enhancing service quality. The last, through still statistically significant, is the cost-effective delivery of services (F = 5,2, p = 0,018). Overall, the results affirm that all factors under consideration contribute significantly towards

enhancing healthcare improvements, hence supporting the effectiveness of IoT in enhancing service delivery and efficiency. Table 3 and figure 4 illustrate the variables using ANOVA.

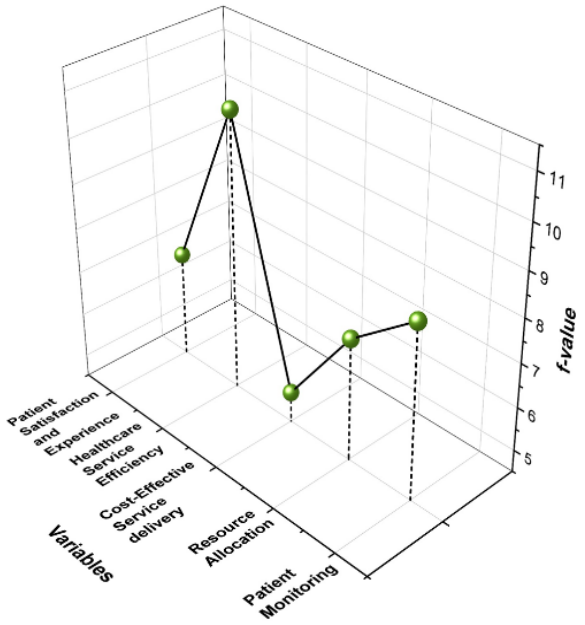


**Figure 4.** 3D Visualization of t-Values for IoT Impact on Healthcare Performance Variables

**Paired t-test**

The impact of IoT's is measured by comparing pre-implementation healthcare performance metrics comparison with post-implementation metrics using the paired t-test analysis. The general form of the paired t-test model is shown in equation 3.

$$s = \frac{\bar{c}}{t_c/\sqrt{m}} \qquad (3)$$

Where:

$\bar{c}$ = Mean of the differences between paired observations ($c_j$=$W_{j1}$-$W_{j2}$).

$t_c$ = Standard deviation of the differences, given by equation 4.

$$t_c = \sqrt{\frac{\sum(c_j-\bar{c})^2}{m-1}} \qquad (4)$$

Where:

m = Number of paired observations

s = s-statistic, which follows a s – distribution with (m-1) degrees of freedom.

**Table 4.** Paired t-Test Results for IoT Impact on Healthcare Metrics

| Variable | Mean Before IoT | Mean After IoT | Mean Difference | Standard Deviation (SD) | t-Value | p-Value |
|---|---|---|---|---|---|---|
| Patient Monitoring | 6,2 | 8,5 | 2,3 | 1,1 | 7,45 | 0,001 |
| Resource Allocation | 5,8 | 7,9 | 2,1 | 1,3 | 6,85 | 0,002 |
| Cost-Effective Service delivery | 5,5 | 7,2 | 1,7 | 1,5 | 4,95 | 0,010 |
| Healthcare Service Efficiency | 6,0 | 8,7 | 2,7 | 1,0 | 8,92 | 0,000 |
| Patient Satisfaction and Experience | 5,9 | 8,1 | 2,2 | 1,2 | 7,15 | 0,003 |

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The paired t-test shows significant improvements in healthcare performance metrics after the deployment of IoT technologies. Among these, healthcare service efficiency shows the highest mean difference of 2,7 with high statistical significance (t = 8,92, p = 0,000), reflecting significant improvements in operational efficiency. Significant improvements in patient monitoring (t = 7,45, p = 0,001) and patient satisfaction (t = 7,15, p = 0,003) are also found, thus supporting the effectiveness of IoT in improving healthcare services. Resource allocation (t = 6,85, p = 0,002) and cost-effective delivery of services (t = 4,95, p = 0,010) reflect significant but relatively lower improvements. Each variable reflects statistically significant p-values (p < 0,05), reflecting the contribution of IoT technologies to improved service quality, resource efficiency, and overall efficiency in healthcare operations. Table 4 and figure 5 illustrate the variables using a paired t-test.

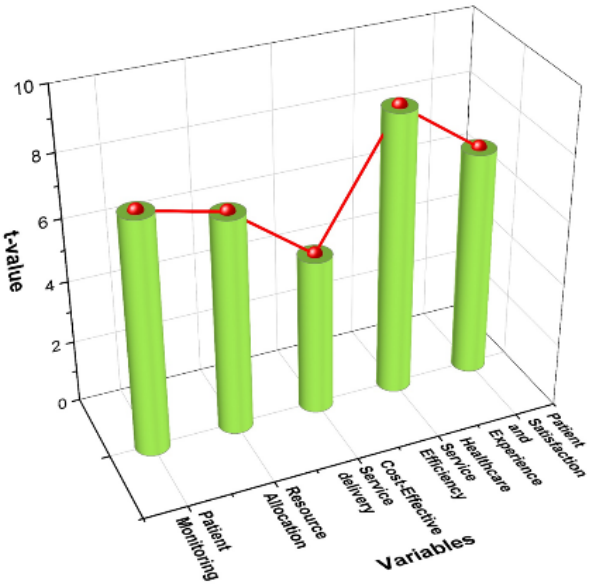


**Figure 5.** 3D Plot of t-Values for IoT Impact on Healthcare Performance Variables

## DISCUSSION

Healthcare scalability enables effective management of expanding system requirements, while performance evaluates service standards, resource management and operational effectiveness in healthcare. From regression analysis, Healthcare service efficiency was found to be the dominant predictor weighting (β = 0,65, p = 0,000), while patient monitoring weighed (β = 0,58, p = 0,001). IoT is established to have significant effects in two major pillars: operation efficiency, and patient oversight. From the ANOVA, it was found that healthcare service efficiency (f = 10,8, p = 0,001) has the greatest variance, indicating a profound influence of IoT on healthcare performance. Patient monitoring (f = 8,5, p = 0,002) seems to be important in enhancing healthcare delivery. From the paired t-tests, the mean difference in healthcare service efficiency (t = 8,92, p = 0,000), showed the greatest improvement, followed by patient monitoring (t = 7,45, p = 0,001). Healthcare delivery achieves tremendous expansion through the IoT because it enhances both service delivery efficiency and service quality. Statistical findings affirm the impact of IoT in all its aspects in patient monitoring, resource allocation, service delivery, healthcare efficiency, and patient satisfaction, thereby showcasing IoT's interference in optimizing today's healthcare flow.

## CONCLUSIONS

Healthcare IoT performance comprises the effective management of resources as well as service delivery and patient monitoring through connected smart technology systems. The exploration gathered opinions from 43 healthcare providers by surveying them to understand the effects of IoT technology on healthcare operations. The findings reveal that healthcare service efficiency has always had the highest impact across the three statistical tests employed through the paired t-test (t = 8,92, p = 0,000), regression analysis (β = 0,65, p = 0,000), and ANOVA (f = 10,8, p = 0,001). The exploration results indicate how the IoT transforms healthcare by enhancing operational efficiency as well as resource management to produce better patient results. Generalization may be limited because the exploration examined only 43 healthcare providers in its sample. The exploration analysis mainly concentrated on operational elements while neglecting long-term sustainability and security issues regarding IoT systems. Future explorations are suggested to cover the integration of AI-driven IoT solutions for predictive analytics, enhance real-time monitoring of remote locations, and mitigate cybersecurity issues. Moreover, larger sample sizes and longitudinal exploration could provide insights into the long-term impacts of IoT, helping to ensure adaptable and resilient healthcare systems tailored to future demand.

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## FINANCING

None.

## CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

## AUTHORSHIP CONTRIBUTION

*Conceptualization:* A Geetha Bhavani, Biswaranjan Swain, Jamuna KV.
*Data curation:* A Geetha Bhavani, Biswaranjan Swain, Jamuna KV.
*Formal analysis:* A Geetha Bhavani, Biswaranjan Swain, Jamuna KV.
*Drafting - original draft:* A Geetha Bhavani, Biswaranjan Swain, Jamuna KV.
*Writing - proofreading and editing:* A Geetha Bhavani, Biswaranjan Swain, Jamuna KV.

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