A Review of PGD and Internet of Things in Healthcare applications

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Abstract

The fields of computer science and electronics have merged to result into one of the most notable technological advances in the form of realization of the Internet of Things (IoT). The impact of IoT in healthcare, although still in its initial stages of development has been significant. This paper attempts to review and understand the applications of PGD and IoT in personalized healthcare to achieve excellent healthcare at affordable costs. We have explained in brief how IoT functions and how it is used in conjunction with wireless and sensing techniques to implement the desired healthcare applications.

Keywords: Internet of Things, PGD, Personalized health care, Ubiquitous computing, Wireless Sensor Network.

1. Introduction

In striving to improve outcomes and reduce costs, health care providers have long struggled with several nagging problems— most notably, their interactions with their patients are sporadic, giving them little insight into the daily decisions and activities that have a huge impact on patient health. Providers could be much more effective in supporting their patients' health if it was easy, or even automatic, for information and feedback to flow between patients, providers, and caregivers. Fortunately, new technology is making that increasingly possible.

Over the last two decades, the data-driven suite of technologies dubbed the Internet of Things (IoT) has transformed some industries and disrupted others,1 with increasingly sophisticated analytical capabilities fundamentally altering the ways businesses serve customers.2 Health care providers have lagged behind other industries in adopting IoT innovations and using available customer data to inform decision making, but the shift is taking place.3

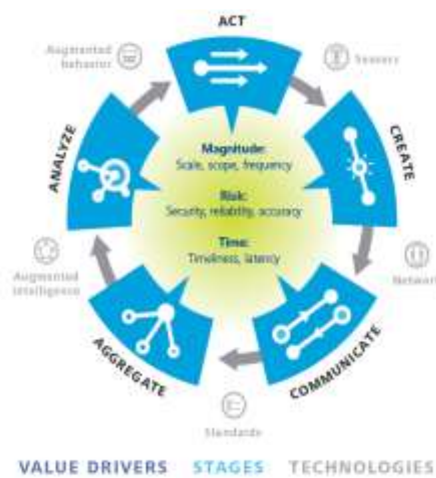
Where data about consumers have been critical to the transformation in retail, in health care the key is patient-generated data (PGD), defined as "health-related data created, recorded, gathered, or inferred by or from patients or their designees to help address a health concern."4 PGD includes patient reported outcomes, medical-device data, and wearables data, in addition to the application of consumer-generated data in a health care setting. Of course, patients make the bulk of their health care decisions outside a clinical setting, and most of those decisions are lifestyle choices rather than doctor-advised medical actions. Cumulatively, these decisions have a major effect on an individual's health, and employers, insurers, and health care providers have much at stake in changing patient behavior. After all, it has been estimated that in the United States, everyday behaviors lead to conditions that cause 40 percent of premature deaths.5 Given that digitally collected patient-generated data are more reliable than the self-reported alternative, IoT applications can be critical to improving and personalizing health care, even encouraging behavior changes before they result in illness.6

Not only can IoT technologies help organizations improve health management, the personalization of care and improved patient engagement through IoT technology will make health organizations more competitive and attract more customers in an ever more consumer-driven market Health care's transition to embracing IoT technologies, while not the first of its kind among consumer-facing industries, faces unique challenges. The IoT is about data and in its most mature form will be an ecosystem of a diverse set of organizations, companies, and consumers, all creating and using different types of data—some significantly more sensitive than others. Complexities arise when non-health organizations are players in an ecosystem that creates and transmits sensitive health information. Thus, the benefits of the IoT and PGD will rely upon an effective answer to this and other complexities, including market adolescence, clinician adoption, big-data challenges, and regulatory modernization.

2. PGD and the IoT Value Loop

Many industries are experiencing meteoric growth in available information with the potential to inform decision making, and health care is no exception. The new breed of digital PGD is increasingly generated by IoT technologies and associated business processes that offer the ability to track activities, identify choices, evaluate outcomes, and act in circumstances that were previously effectively beyond reach and influence.

The technologies that enable the IoT promise to turn almost any object into a source of information about that object. This creates both a new way to differentiate products and services and a new source of value that can be managed in its own right. However, PGD itself is hardly new—doctors have gathered data on patients' ailments and histories since Hippocrates. To understand what IoT technologies have changed and what remains the same requires a model of information flow through the patient-care team interaction. Indeed, realizing PGD's full potential requires a framework that captures the series and sequences of activities by which organizations create value from IoT-generated information: the Information Value Loop.



Within this framework, information passes through stages enabled by specific technologies to create value. An act is monitored by a sensor, which creates information. That information passes through a *network* so that it can be *communicated*, and standards—whether technical, legal, regulatory, or social—allow that information to aggregate across time and space. Computational methods of analytical support, which we call augmented intelligence, are collectively used to *analyze* information. The loop is completed via augmented-behavior technologies that either enable automated autonomous action or shape human decisions in a manner leading to improved action.

In health care delivery, PGD passes through the same value loop as it informs behavioral and treatment changes to improve health, extend access, and reduce costs (see table 1).

As information flows around the loop and creates value, bottlenecks may occur at different points that inhibit value creation.8 By targeting these bottlenecks, organizations can not only maximize IoT-generated value but also gain a strategic advantage over competitors in controlling a key portion of the value loop. Several bottlenecks may inhibit the realization of the benefits from PDG use in health care delivery. By examining the technology's different uses in care delivery and the cross-cutting bottlenecks that each of those uses encounters in the value loop, strategies emerge that will allow organizations to navigate the nascent world of PGD, gain a strategic advantage, and maximize the benefits of increased data-driven decision making.

Stage	PGD Example
Create	• Medication adherence data created by a sensor-enabled pill bottle • Blood glucose levels created by a home monitor • Step count quantified by wearable pedometer
Communicate	• Blood glucose levels shared via Bluetooth and the Internet
Aggregate	• Blood glucose levels tracked over time for an individual or a high-risk population
Analyze	• Patient, caregiver, and/or doctor alerted when patient has not taken his or her medication • Patient, caregiver, and doctor shown trends in blood glucose levels and key factors affecting these levels, informing future care planning • Patient, caregiver, and doctor shown trends in step counts
Act	• Adhering to medication regimen • Keeping blood glucose levels within a healthy range • Staying active • Quitting smoking

Table 1. The Value Loop and PGD

3. Applications of PGD to improve health care

Health care organizations typically adopt technologies slowly, requiring a greater degree of evidence to demonstrate significant impact and efficiency. As PGD's use increases, three areas in particular offer a growing evidence base for value in improving health outcomes, reducing cost, and expanding access to care:

1. Short-term care planning
2. Chronic-disease management and home care
3. Population-based evidence creation

PGD—whether generated via mobile technologies, medical devices, or patients' personal computers—carries tremendous potential to lower costs and improve outcomes by helping patients track key health information while assisting providers in more effectively tailoring treatments for the individual or public overall. These technologies save health systems money by lowering readmission rates, reducing appointment no-shows, and promoting adherence to care plans.

In the coming decades, demographic changes will increase opportunities to apply IoT technology to support wellness and health care for particular segments of the population. An aging Baby Boomer generation will drive market growth for technologies, such as glucose monitors and motion sensors that allow them to manage their chronic conditions and age within their own homes. As health care systems begin to shift toward bundling payments and developing accountable-care organizations, providers are increasingly rewarded or compensated based on health outcomes. PGD not only provides ways to streamline care delivery and improve outcomes—it may help to define value in the context of care.

3.1 Short-term care planning

The transition from an acute illness or surgical event back to normal health represents many challenges for patients, and the quality of short-term care is a major determinant in recovery. Traditionally, patients' treatment and recovery have been informed by printed or handwritten doctor's notes and discharge forms. PGD presents a significant opportunity to customize care and support patients throughout their treatment and post-operative care plans through greater education, reminders, and monitoring/early detection. Care-plan-specific mobile apps monitor patient actions, such as following their physical-therapy or wound-care plans. This information passes through a data network that providers, patients, and caregivers can analyze, aggregate, and communicate to facilitate augmented intelligence about their care plans and augmented behavior, such as adhering to a medication regimen or understanding post-procedure instructions.

Researchers have shown that increased support substantially promotes care-plan adherence and improves quality outcomes while lowering costs through reduced hospital readmissions and office visits. 11, 12 In addition to the costs directly associated with readmission, a portion of the Affordable Care Act specifically penalizes hospitals for high readmission rates within 30 days of discharge, providing additional incentive for providers to embrace new means of supporting patients after direct care ends. 13, 14

Type of Data	Current State	Ex. of IOT opportunity	Benifits
Patient Care Plan	Follow-up care after an acute event is often limited to post-visit instructions, phone calls, and in-person appointments	Text reminders based on a patient's unique post-treatment care plan[15] • Apps that guide individuals through their personalized care plan[16] • Alerts for caregivers regarding important deadlines, such as medicine regimens and upcoming appointments[17]	Improved recovery and early detection of complications, leading to cost savings through reduced hospital readmission and associated penalties

Table 2. Short-term care planning

When collected and monitored across an entire patient population, PGD can also support identification of high-risk individuals who are most prone to complications and potential readmission. This enables care teams to make targeted interventions with particularly susceptible patients, thereby more effectively allocating clinical resources for the greatest effect on improving quality and reducing cost.

To realize such value of PGD in short-term care planning, health care providers will not only need to embrace new digital technologies to further engage patients after and between episodes of care—they will need to adopt business and staffing models that support such continuous patient engagement and care management.

3.2 Chronic-disease management and home care

Chronic-disease management and home care present high-impact areas in which increased use of PGD can provide immediate results. However, the chronically ill, frail, and elderly currently rely at best on discrete and intermittent interactions with their doctor over long periods of time to manage their conditions and, at worst, must live in long-term care facilities instead of in their own homes in order to manage their health conditions.

With IoT, patients can use sensors such as fall detection devices and remote glucometers to *create* information ranging from acute injury to diabetic coma, which is passed through provider data *networks* and communicated with set *standards* and *aggregated*, leading to augmented intelligence about patients and augmented patient behavior, such as healthy dietary habits and medication compliance.

Additionally, as in post-operative care planning, the organization-wide collection and analysis of PGD for chronic-disease management and home care enable providers to monitor patient populations and identify and intervene with individuals most at risk for deteriorating health.

Chronic-disease management

Chronic-disease management will likely be a key area for IoT applications to help deliver cost savings and health-outcomes gains. With chronic-disease management driving 86 percent of direct health expenditures, providers have an untapped resource to realize cost and quality improvements through the collection and use of PGD.18

Type of Data	Current State	Ex. of IOT opportunity	Benefits
Longitudinal clinical data	Patients often manage their chronic diseases through sporadic clinical visits	Blood glucose monitoring[19] • Tidal volume monitoring for chronic obstructive pulmonary disease[20] •Weight monitoring for congestive heart failure[21]	Provides remote analysis and triage to determine whether patients' readings put them at risk of health crises and in need of intervention; reduces costs through decreased urgent-care visits
Behavioral and wellness data	Patients often lack resources to automatically and interactively manage behavioral and wellness information outside of appointments	Activity monitors[22] • Depression symptom tracking[23] • Interactive food logs[24]	Promotes healthy behaviors through increased info and engagement

Table 3. Chronic-disease management use cases

Home care

As the population ages, providers will spend a greater proportion of medical expenditure on the elderly.32 With nursing-home and assisted-living costs already high and trending upward,33 health organizations have every reason to encourage more elderly individuals to live independently in their own homes by helping to mitigate risks that accompany home living.

Home monitoring of an aging population via apps, sensors, and other devices helps people to live at home safely by proactively identifying those who can no longer live safely at home, and by providing a range of support services for those that do. For example, IoT can provide early detection and rapid response to medical emergencies, support patients' adherence to often-complex medication regimens, and offer the elderly and their caregivers greater confidence. By improving patient-facing technologies and analytics, providers can identify when an individual deviates from his or her normal routine, when a caregiver or family member should check in, or when emergency response is appropriate.In particular, home monitoring—far more broadly capable than the traditional Life Alert-style audio system35—has the potential to greatly reduce the incidence of death and hospitalization incurred by falls.36 According to the Centers for Disease Control, falls are the leading cause of both fatal and nonfatal injuries in adults 65 and older.37 One out of three older adults falls each year,38 though less than half of them mention this to their providers.39 In 2013, direct medical costs due to falls reached $34 billion.40 Furthermore, people who fall are more likely to eventually be admitted to long-term care facilities,41 with yearly costs averaging over $80,000.42 IoT-based home monitoring devices have the ability to cut costs and improve outcomes by preventing falls by predicting the likelihood of a fall and observing movements and pressure distribution.43.

Type of Data	Current State	Ex. of IOT opportunity	Benefits
Home activity data	At-risk elderly individuals are often placed in the full-time care of caregivers, nurses, or nursing facilities	• Detecting whether an individual got out of bed in the morning45 • Determining whether an individual took his or her medicine46	Reducing costs by enabling individuals to live in their own homes instead of in assisted-living facilities while minimizing the risk of independent living in a way that reassures loved ones

Table 4. Home care use case

In order to achieve such benefits of PGD in chronic-disease management and home care, organizations will need to take a more active role in supporting patients' ongoing health, driven not only by a greater body of evidence of how PGD can be used to inform care management decisions, but also a commitment on the part of individual clinicians to putting this data to use and fostering ongoing relationships with patients for their health.

3.3 Population-based evidence

Not only can providers use PGD at the point of clinical care to promote health and wellness in individuals—they can analyze PGD at the population level to better understand how certain health determinants affect patient populations. Currently, studies with PGD conducted at the population level are largely limited to health underwriting and risk analysis—not health management and disease prevention.48.Greater embrace of IoT applications can enable the discovery of not only what patients are most at risk in the long term but also how to personalize care as these patients pursue their wellness goals, and what factors not typically measured in a clinical encounter most impact patients' health. This occurs via the creation of sensor, mobile, online, and other data at the create stage, which organizations eventually aggregate and analyze to augment behavior in the form of more informed and nuanced clinical guidelines and policy.

Type of Data	Current State	Ex. of IOT opportunity	Benefits
Clinical and nonclinical data	Evidence-based care determination often comes from data collected through surveys and clinical studies not utilizing Internet-enabled devices	Understanding the unique causes of a disease, patient profiles that may be more responsive to certain treatments, or patients who suffer more serious side effects[49, 50]	Improved treatment guidelines to reflect variances in certain patient populations through the use of larger population sample sizes and mobile technology.

Table 5. Population-based evidence use cases

4. Challenges and recommendations

Despite strong prospects for IoT applications' use in health care, there are challenges that will shape how providers integrate PGD into clinical care. The use cases explored above involve the creation of different types of data for varying patient populations, while also offering distinct benefits. Short-term care planning demands *periodic* data collection about a broad range of activities, such as taking painkillers after a knee-replacement surgery or completing rehabilitation tasks, all to facilitate recovery and compliance. Chronic-disease management and home care focus on *continuous* data streams to effectively manage a narrow set of known issues, such as blood glucose levels over time. Lastly, population-based data involves gathering *larger volumes* of data on whole patient populations to inform treatment guidelines.

Despite these dimensions of difference, challenges to fully realizing the potential and creating the most value from PGD scenarios are very similar, as these applications of PGD face similar bottlenecks along the IoT value loop. Examination of these bottlenecks reveals actions that organizations can take to both mitigate the challenges and unlock the most value from the use of PGD in care delivery.

Challenge No. 1: Lack of clarity regarding where to use PGD, given its nascence in supporting clinical care

PGD can inform a wide range of health scenarios, and the evidence base is still evolving, favoring some solutions over others. Reflecting a bottleneck at the value loop's *act* phase, organizations face uncertainty about how to prioritize potential uses of this new technology.

Recommendations:

- Prioritize validity, repeatability, and scalability of recognized uses when delivering analytics solutions over those that discover new uses for PGD. The tendency in a rapidly evolving environment is to follow a myriad of interesting ideas, which can lead to pilots that never grow into robust, enterprise-wide programs. For implementation, instead of investing in fresh, untested IoT areas, leading health organizations are refining and perfecting currently acknowledged use applications. This strategy is helping build an evidence base to develop the most impactful programs.
- Build a portfolio by identifying high-value use cases in patient populations. While providers have shown some success in conceiving, developing, and managing PGD-intensive programs in an ad hoc manner, the most successful programs are run by organizations that are proactive in building a portfolio of programs around specific needs in their respective patient populations. This ensures that the technology's highest-value uses aren't being overlooked and that patients have a seamless and consistent experience across programs.

Challenge No. 2: Clinical reluctance to change care paradigms

If organizations successfully integrate PGD into the health care system, it is likely to fundamentally alter how clinical care is delivered. Traditional providers may resist to some extent, due to the particular nature of health care decisions and associated costs: Specifically, transitioning to a new clinical environment utilizing PGD requires adjustments to the clinical workflow and reimbursement models for clinicians, and without a well-communicated evidence-based justification, clinicians may be reluctant to adopt new IoT-based applications. Furthermore, with the availability of new data to diagnose and treat patients, it is uncertain to what extent providers will be held liable for acting on all information available to them—including diverse PGD—and how they will be responsible for identifying and addressing outlying readings. The key is *analyzing* the new data.

Recommendations:

- Establishment of standards of care built on a strong evidence base recognizing individual variability can be critical to supporting clinicians in the use of continuous data from patients rather than punctuated measurement. To date, the Office of the National Coordinator for Health IT (ONC) Federal Advisory Committees is providing recommendations about the inclusion of this type of data in stage 3 of Meaningful Use, which supports the adoption and use of electronic health records (EHRs). In December 2013, ONC convened a Technical Expert Panel on Patient-Generated Health Data (PGHD) to "identify good practices that can reduce concerns and risks and to encourage providers to implement PGHD".52
- Align PGD use with provider workflow and reimbursement. In every industry, workers do their jobs in the manner that best makes sense to them. If a tool does not fit the workflow, it will not get used no matter how advanced it may be. Therefore, to achieve maximum adoption, health care organizations should align and integrate any program affecting clinical care delivery, including those programs using PGD, with both clinician and patient workflow. Without broad buy-in, the data will be insufficient to be aggregated and analyzed. Included in this recommendation is the alignment of provider incentives with PGD use.
- Invest heavily in change management to maximize the return on new PGD-intensive use cases, communicating the evidence base to care teams to make the case for change in support of the alignment of incentives above.

Challenge No. 3: Data privacy and security limitations

The increasing interconnectivity of IoT-enabled devices collecting and sharing PGD significantly increases the number of potential vulnerabilities within a system, thus creating a potential bottleneck at *sensors* and *network* surrounding the create phase of the value loop. Some PGD is stored on remote devices, and as these tools grow in number and capability, malware and data thieves will increasingly target them.53 If not credibly addressed, these privacy and security risks may undermine consumer and business confidence in IoT in health care, slowing patient and provider adoption of the technology. Security violations are a serious issue with IoT devices and communications in general, but the confidential and personal nature of individuals' health care information poses particular concerns—one high-profile data breach could derail the work of any number of engineers, researchers, and providers.54

Recommendations:

- In the face of such challenges, organizations, including those in the health space, can remain secure, vigilant, and resilient by taking several steps to safeguard PGD, as described in Deloitte's "Safeguarding the Internet of Things"55:
- Work to define standards for interoperability. Adhering to one standard only or actively getting involved with consortiums to develop a set of standards can help ensure that devices within a network can all communicate and work together safely and effectively.
- Use purpose-built devices or add-ons, rather than pre-IoT solutions. Rather than retrofitting or extending functionality of old systems in ways for which they weren't designed, companies should strongly consider wholly new, secure technologies designed specifically for the IoT.
- Develop clear responsibilities for the players in your ecosystem. Rather than sharing responsibility across a diffuse ecosystem, players should understand and define where their responsibilities begin and end. Taking an assessment of all stakeholders and assessing the potential risks at each point—and making sure the stakeholders are aware of those risks—can help make a solution more secure.
- Establish a baseline of data. Viewing IoT systems more broadly and monitoring environmental attributes such as usage, location, and access would better enable enterprises to gather a sufficient scope of data to establish a baseline, helping companies to discern what is normal and what constitutes a suspicious aberration. This in turn enables enterprises to take appropriate and effective action when data deviate from the normal range.
- Institute data governance. Enterprises should consider playing a stronger governance role by defining which data to secure, what it means to be sufficiently secure, and, by extension, which products meet that goal. Guidance around how data can be securely collected, used, and stored can help prevent unwanted breaches and prevent a risk event from snowballing into something larger, and can also outline the lines of responsibility in the event of a breach.
- Create loosely coupled systems. Ensure devices within an ecosystem are loosely coupled and resilient so that the failure of one device does not lead to widespread failure.56

Challenge No. 4: Data integration and analytical complexities

As with many emerging health technologies, there are few standards governing the configuration of PGD to promote data accuracy and integrity across platforms. Additionally, PGD consists of many different types of data collected on diverse and rapidly evolving devices, with data increasingly being collected on smart phones with or without IoT-enabled external sensors. Thus, standardizing and integrating PGD with data from EHRs presents a bottleneck at the *communicate* and *aggregate* portions of the value loop that prevent the full realization of information's value. Though developers are working on common application-programming interfaces, the challenge remains to effectively and consistently integrate PGD with other devices and platforms to support the functionality of innovative models of care.57

Recommendations:

- Actively engage the standards-development process. By taking an active role in the development of new standards for the communication of PGD, organizations may be able to both hasten standards' adoption and potentially adjust them to accommodate high-value use cases.
- To engage in the value loop with PGD in advance of fully vetted and accepted data standards, it is critical to incorporate flexibility into the platform that will collect and exchange PGD. While this flexibility may

add to the cost of early adoption, it may prevent the platform's obsolescence if standards evolve that are incompatible with the implemented PGD platform.

Conclusion

As the examples in this paper make clear, the long predicted IoT revolution in healthcare is already underway. And, as new use cases are emerging, they continue to address the urgent need for affordable, accessible care. Meanwhile, the IoT building blocks of automation and machine-to-machine communication continue to be established. The addition of the service layer forms the complete IoT infrastructure. This revolution is characterized by providing end-to-end processing and connectivity solutions for IoT-driven healthcare.

Acknowledgment

The authors wish to acknowledge Ms.Ipsa Hota and Ms. Deepty Thakur for their guidance in research work. We would also like to express our gratitude towards Prof. Mr. S.N.Mishra for his valuable time and assistance in helping us write this review paper.

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