POLYGEIA

STUDENTS SHAPING GLOBAL HEALTH POLICY

MOBILE BASED DATA COLLECTION METHODS TO ASSESS THE PROGRESS OF THE HEALTHCARE SUSTAINABLE DEVELOPMENT GOALS

CASE STUDY BASED POLICY RECOMMENDATIONS

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Executive Summary

The Sustainable Development Goals (SDGs) replaced the Millennium Development Goals as global targets at the end of 2015. The 17 goals focus on priority areas to enhance the quality of life of the global population. In addition to carrying out these goals, it is crucial that the progress towards their completion is monitored. Without efficient data monitoring, it is not possible to determine whether implemented policies have been effective, or if it is necessary to use different tactics to work towards a goal. This is particularly true for Goal 3 - 'to ensure healthy lives and promote well-being for all at all ages.' The SDGs are objectives that will exist in an age in which a data revolution has occurred and thus the difficult but exciting task of assessing their impact will require innovative methods that make full use of newly available technologies.

One such technology that has the potential to improve the standards of data monitoring globally is the mobile phone. There are now over 7 billion mobile-cellular subscriptions in the world, spreading to remote corners of the globe, with 95% of the world's population reached by cellular network. With this in mind, this paper assesses three mobile phone-related technologies that could revolutionise how we collect and analyse healthcare data; Short Message Service (SMS) and survey applications; Global Positioning Systems (GPS) and Geographic Information Systems (GIS); and wearable technology. These technologies may provide the ability to not only collect data much more efficiently than previously, but also to collect new forms of data that have not been collected before.

An example based critical analysis of these three technologies leads to policy recommendations made on the basis of the risks and benefits of each. The use of SMS and survey applications is both assessed as a tool to be used by health workers by which they can send data collected from the public to a central site and also as a means for patients themselves to submit data virtually in the form of surveys. Within GPS and GIS, two key applications are considered; disease surveillance and health services accessibility. Wearable technology is primarily assessed through its ability to monitor the signs of non-communicable diseases, in particular, Parkinson's disease, atrial fibrillation and hypertension.

This paper finds that these three technologies are capable of revolutionising both the quality and the quantity of healthcare data collected to enable the SDGs, in particular Goal 3, to be monitored sufficiently. Their implementation into data collection programmes is therefore recommended alongside further research to allow their full potential to be realised. This represents a huge task for the international community, and will require a great deal of political impetus. However, the benefits associated with efficient monitoring of the SDGs together with the limitless potential that these technologies harness outweigh the costs of such programmes.

ACKNOWLEDGMENTS

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Polygeia is a global health think tank giving students the opportunity to engage in research and policy making. This is achieved through three core aims: to research and disseminate high quality policy papers and follow up on their implementation where possible, to develop the skills of researchers through policy workshops and mentoring programmes, and to engage students and others with the global health issues on which Polygeia is working. Polygeia also provides policy makers and others with the opportunity to commission evidence based global health policy. More information can be found at http://www.polygeia.com .

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KEY FINDINGS: POLICY RECOMMENDATIONS

The critical analysis of multiple case studies concerning various forms of mobile phone related technology leads this paper to make the following 17 policy recommendations. The recommendations fall into 4 target areas:

TRAINING AND EDUCATION

Policies advocating increased training or education of key groups of individuals

- Establish and implement training programmes to educate local researchers and public health officials to use, adapt, and interpret the results of medical GPS and GIS technologies for both research and operational uses
- Involve patients in the long-term monitoring of their medical conditions through the use of SMS surveys
- Train nursing staff and other patient-facing staff in GP surgeries to use wearable technology, such as ECG and blood pressure monitors

INVESTMENT

Policies advocating increased investment in, or development of, new technologies and existing infrastructure

- Put the infrastructure in place to allow mobile phones to be used to collect data on a large scale to enable efficient monitoring of the progress towards the SDGs
- Increase access to smartphones and their associated wearable technology for target populations
- Improve infrastructure within the community to allow doctors and other healthcare professionals to easily access any data collected by wearable technology
- Increase investment for the establishment of a central globally linked medical GIS database that facilitates data access for relevant stakeholders
- Develop and improve GIS analytical methods and techniques to process and evaluate qualitative data

COLLABORATION AND AWARENESS

Policies advocating increased cooperation between stakeholders or increased awareness of key technologies

- Support multi-sectoral collaboration in the collection of and processing of geospatial data
- Assign a team of statisticians and other professionals to analyse the data gathered by wearable technology
- Raise awareness of the various healthcare applications and benefits of medical GIS and GPS technologies

- Promote the integration of commonplace mobile transponders as new sources of geospatial data

Best Practice

Policies advocating changes to current best practice

- Make wearable technology a larger part of at-home health monitoring, especially for patients with multiple comorbidities
- Establish or develop better data sharing best practices across all relevant sectors
- Do not neglect paper-based data collection
- Use basic models of mobile phones unless there is a specific need for the multimedia capabilities of a smart phone
- Use mobile applications in preference to SMS unless only small amounts of basic information are collected

INTRODUCTION

With the advent of the new millennium came a set of 8 goals, proposed following the signing of the UN Millennium Declaration by world leaders, called the Millennium Development Goals (MDGs), designed to help focus efforts to combat the abject poverty, famine and diseases affecting world's poorest populations (1). The progress of these goals was assessed using more than 60 different indicators, such as contraceptive prevalence rate and infant mortality rate (2). Although great progress has been made in some areas, much has yet to be achieved.

As the 2015 expiration date for the MDGs drew closer, focus shifted towards the future. The Sustainable Development Goals (SDGs) are a set of 17 goals, targets, and indicators that will guide agendas and policies across the globe during the coming 15 years (3). The SDGs build upon the progress made on the MDGs and address areas in which they were found lacking. They have been designed to be broader than the MDGs, by also encouraging economic development and sustainable growth, rather than focussing on single-minded targets. With 169 proposed targets and 304 indicators (4), finding efficient and reliable mechanisms to measure the progress and assess the overall impact has been a fundamental concern from the beginning, particularly with regards to healthcare metrics. Thus, it is of no surprise that a significant portion of the preliminary planning and discussion has been centred on the use of modern technology to carry out such purposes (5).

Accurate and complete data collection is paramount to both the monitoring and the implementation of the SDGs. The introduction to the open working group proposal for the SDGs stipulates the importance of data collection; "There is a need to take urgent steps to improve the quality, coverage and availability of disaggregated data to ensure that no one is left behind" (6). Unfortunately, there are a number of hindrances to the efficient collection of data, particularly in developing countries. These include deficiencies in infrastructure and the inefficiencies of paper-based data collection, as well as the effects of poor terrain and extreme weather conditions in some countries.

However, the ways in which mankind collects, stores and analyses data have changed dramatically since the launch of the MDGs and the implications of this for international development have not yet been wholly explored. There is great potential for new technology to transform the way that progress towards the SDGs is assessed and part of this is a direct consequence of the global investment in data that was spurred by the work of the MDGs. Key areas for technological improvement identified by the UN include unfilled 'data gaps' and 'future-proofing' measurement systems to cope with change (7).

The widespread use of mobile phones makes them a powerful means of collecting and reporting data from both rural and urban areas around the world. There are now over 7 billion mobile-cellular subscriptions in the world, with 95% of the world's population reached by cellular network (8). The developing world is a source of more high-quality data which cellular technology will be able to provide in coming years, as long as the correct infrastructure is put in place. The mobile phone has revolutionised the way data can be accessed in even the most remote locations and it is important that authorities make use of this technology so that information can be derived from all corners of society.

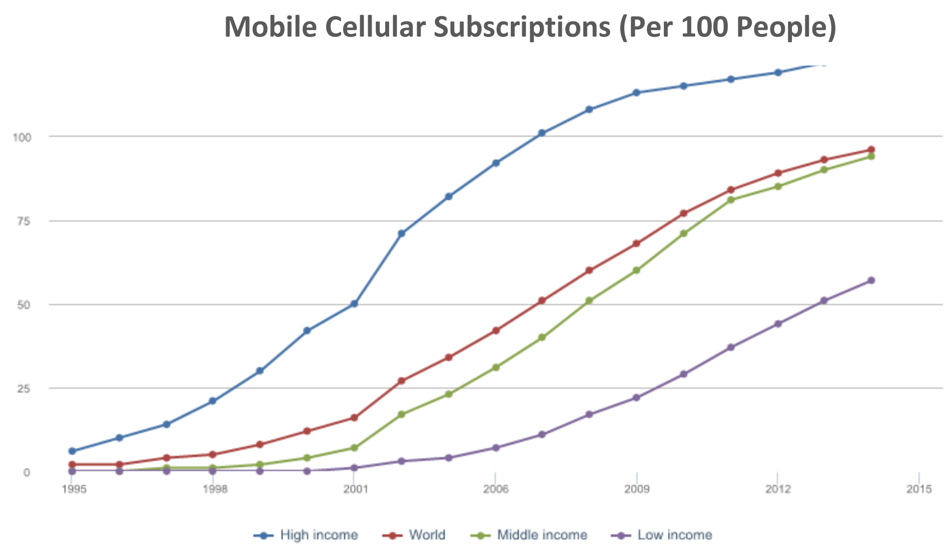

Figure 1: a graph showing mobile phone subscriptions (per 100 people) derived from the UN World DataBank (9).

There is a clearly a need for adaptable, reproducible and personalised methods of data collection to assess such targets on a global scale and so this paper will examine three different methods of data collection using mobile phones and their associated technology and how they can be used to assess the progress of the Sustainable Development Goals, in particular Goal 3, to "ensure healthy lives and promote well-being for all at all ages."

Key areas likely to be involved in these processes include the use of wearable technology in generating vast amounts of highly personalised data, and that of mobile phones as a tool for conducting surveys in regions previously unconnected to the electronic world. Such technology is particularly important for a set of goals that encompass the requirements of nations at completely different stages of development.

CASE STUDY ONE:

MOBILE SURVEYS

BACKGROUND

This section will explore the potential uses of mobile phones as data collection tools in assessing the progress of the SDGs, specifically the use of surveys sent by short message service (SMS) or via a mobile phone survey application.

Paper-based data collection is still commonplace in developing countries; this can result in inadequate data transmission. In a South Africa-based study focused on a public health programme to reduce mother-to-child transmission of HIV, Mate et al found that data was only actually reported 50.3% of the time and was only accurate 12.8% of the time. The major source of data inaccuracy was data collation in clinics, prior to sending it to a central register (10, 11). A study by Burger et al also found that 91.7% of South African death notification forms contained at least one major or minor error (12). The registered causes of mortality within a country will influence policy-making to improve health and if this basic data is lacking, interventions can only be very limited in their efficacy.

In order for data collection to be as efficacious as possible, there needs to be an adequate infrastructure in place. A study carried out in Ghana, Kenya, Rwanda, Tanzania and Uganda found that less than 65% of hospitals have even the most basic of infrastructures such as reliable sources of water and electricity. This reduced to between 7 and 35% for health centres (13). The provision of electricity is important when considering electronic storage of data.

Another problem with paper-based collection is the need to collect the data at a central site for analysis. Not only is this time-consuming, but poor transport systems in developing countries can contribute to slow data flow. This is compounded by the effects of weather on these transport systems. For example, in Tanzania, transport is a major problem in the rainy season, particularly in rural areas (14).

There is an extremely high penetrance of mobile phones globally (15), but the ability of the most basic models to perform text messaging is crucial. The portable nature of mobile phones also enables responses from both patients and health workers wherever they are, compared with, for example, computer-based data collection. In a study of a web-based Asthma diary, although patients appreciated the diary, its use decreased with time as it did not integrate into their daily lives (16). This illustrates the benefits gained from the use of a portable technology.

In comparison to voice-based data collection, there is no need for an operator to be available at all times and, although still troublesome, SMS is less affected by a poor connection than voice-based collection. SMS also appears to be the cheapest form of data collection when compared with voice and electronic forms with one study finding the cost per patient to be $2.99, $4.59 and $7.89 respectively (17). Overall, these attributes make SMS an attractive substitute for paper-based data collection.

	Advantages of paper-based data collection	Advantages of mobile phone-based data collection
Input	• Easier to enter free-form notes or diagrams • No charging or credit top up required • No network coverage required	• Language can be changed easily • Convenient as everything is stored on the phone • Easier editing of questionnaires
Storage	• No eSecurity problems	• Easier back-up of data • Immediate transfer saves time
Cost	• No large investment costs	• Lower transport and resource costs

Figure 2: a table showing some of the advantages of both paper-based and mobile phone-based data collection

EXAMPLES

It is important to note that there are a wide variety of uses for SMS and survey applications in data collection. This section will focus on two different uses; as a tool to be used by health workers by which they can send data collected from the public to a central site and also as a means for patients themselves to submit data virtually in the form of surveys.

Some examples of the use of mobile phones by health workers include; the detection of adverse events in sex workers following the administration of metronidazole (18), the collection of general health information from HIV positive pregnant women (19) and the collection of data for the integrated surveillance and response strategy for the World Health Organization (14).

Mobile phones have also been used for the collection of basic sociodemographic information from households (20). Community health workers (CHWs) went from household to household in a peri-urban settlement in South Africa, carrying out face-to-face interviews. Data was collected through a survey application on basic mobile phones and automatically uploaded to a central server. In demonstrating the use of mobile phones by health workers to collect census information, it also shows that this can be carried out in a developing country with a phone, without smartphone capabilities, using a basic programming language such as java.

The possibilities for collecting data directly from patients are in essence limitless, but this section will focus primarily on two particular domains including; monitoring sexual behaviour (21) and the severity of asthma symptoms (22). During a 2 month study by Anhøj & Møldrup, patients received text messages daily, firstly with a reminder to take their medication, and then with questions relating to their recent asthma control regarding peak flow, recent symptoms and inhaler use. This demonstrates how surveys can be used to monitor the severity of asthma symptoms, however in reality this could apply to any chronic illness. For monitoring sexual behaviour, Lim et al (21) compared paper, online and sexual diaries in young people by measuring response rates, timeliness, completeness and acceptability.

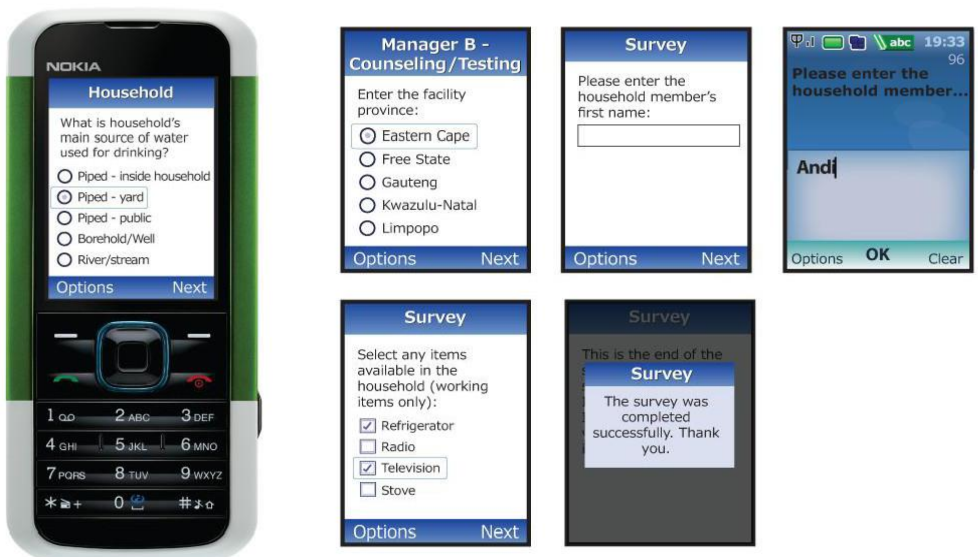

Figure 3: screenshots of the mobile phone survey used by Tomlinson et al (20) to collect sociodemographic data from households in South Africa

CRITICAL ANALYSIS

Whilst these examples show the potential for SMS or survey applications to be used for data collection, there are several factors to be considered prior to their widespread implementation as policy tools.

Benefits

Electronic Storage

A significant benefit of data collection via SMS is that the data is immediately stored electronically, thus minimising the potential for errors. This benefit is also seen in GPS/GIS and wearable technologies, as will be discussed later. Curioso et al noted that the use of mobile phones meant health workers were not burdened by stacks of paper, which could get misplaced (18). Electronic storage is also useful for patient-completed questionnaires, particularly where the information is of a sensitive nature. Lim et al found that SMS and online diaries were considered more private than paper diaries and considerably more convenient (21).

Time

Mobile phone use also allows for data to be collected in a timely manner so that when policies are implemented they are still relevant to the situation on the ground. This is particularly relevant in remote settings, where there may be a long delay before the data is available for analysis (18). This is exemplified by “SMS for Life” in both Tanzania (23) and Kenya (24), a project that uses text messaging to send weekly stock counts of anti-malarial medications to a system accessed by district managers. As the data was available immediately, re-distribution of medication allowed a reduction in the number of stock-outs, from 78% of health facilities at the beginning of the Tanzanian study to 26% after 21 weeks. This may also reduce the burden on health workers, who have more time to carry out their clinical duties rather than transporting paper forms (14).

Troubleshooting

Mobile phones allow for problems to be identified and fixed much quicker. This is of particular relevance if an error was noted in a questionnaire. Paper forms would need to be recalled and re-printed whereas an SMS questionnaire or mobile application could be more easily re-programmed (19). They also enable surveys to be carried out with more ease in a multilingual environment. Rather than carrying multiple paper surveys, it is possible to simply change the language on an SMS questionnaire (20).

Real-time surveillance

With regards to patient completed SMS surveys, there is an opportunity to collect data as events occur and without requiring a large number of health workers. These benefits are also applicable to wearable technology. This could potentially increase the accuracy of data collected as reducing the time between an event and data collection may cut down recall bias. This was demonstrated by the Danish daily SMS survey to monitor the severity of asthma (22). The SMS diary became an integral part of the patients’ lives which suggests that this sort of data collection could be carried out long-term to determine the level of control of various chronic conditions. It is important to note that this is only likely to be useful for highly motivated patients.

CHALLENGES

NETWORK COVERAGE

Arguably one of the biggest challenges with using mobile phones as data collection tools in developing countries is the poorly developed mobile network infrastructure and the potential for inadequate network coverage. This limitation affects all three of the technologies discussed in this paper. Pascoe et al discovered particular coverage gaps in Tanzania and the necessity in some areas to send reports from certain points with good coverage (14). Similarly, in a Zambian SMS-based study, two health centres were omitted as a result of difficult phone access (25).

COST

Mobile phones are potentially quite valuable items, particularly in developing countries. As a result, there is a risk of health workers who are in receipt of mobile phones being targeted by thieves (20), thus impacting upon long-term cost effectiveness. However, the overall use of mobile phones is likely to be cheaper than paper-based surveys in rural areas due to the lower transport costs involved (14), and SMS has been found to be up to 60% cheaper than the use of electronic forms and voice-based collection (17).

DATA SECURITY

A potential problem with electronic data storage is the issue of reduced data security. In particular, the multimedia capabilities of mobile phones used in data collection studies has been identified as a source of anxiety in participants, with worries centred on the potential use of a phone camera to photograph them; thus breaching patient confidentiality (19). It is important to ensure good data security, and also to reassure the participants of this. GPS and GIS technologies also face challenges within this area, as will be discussed in the next section.

POTENTIAL TO SKEW DATA

The increasing prevalence of mobile phones across the world allows for their use as data collection tools. However, a potential confounding factor is that mobile phone ownership has been shown to be significantly associated with age, socioeconomic status, level of education and occupation (19). It may be the case that areas with a lower prevalence of mobile phone usage may in fact have an increased or decreased incidence of particular diseases. Although the majority may own a mobile phone, the use of mobile phone surveys has the potential to exclude those who are already disadvantaged, leading to skewed data and policies that may not benefit the most vulnerable.

POLICY RECOMMENDATIONS

In light of the critical analysis, listed below are five policy recommendations for the widespread implementation of mobile phone survey based data collection.

Put the infrastructure in place to allow mobile phones to be used to collect data on a large scale to enable efficient monitoring of the progress towards the SDGs

SMS and mobile applications enable more time to be spent on actually collecting data rather than on transportation back to a central site and, by reducing the number of times data is collated, they potentially increase its accuracy. This paper therefore recommends the integration of mobile phones into the routine collection of data from populations where possible. It is important to develop systems and infrastructures early in the course of a data collection programme to enable smooth transitions to the use of mobile phones.

Involve patients in the long-term monitoring of their medical conditions through the use of SMS surveys

The studies into monitoring of sexual behaviour (21) and asthma (22) suggest the possibility of using SMS to monitor and improve the management of an array of conditions, and thus both contribute to and monitor the progress towards the completion of SDG 3. Taking SDG Goal 3.4 as an example, "By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being", it would be possible to use SMS monitoring to assess the severity of chronic heart failure, asthma or depression with simple text messages whilst also providing reminders to take medication and seek medical help if symptoms deteriorate.

Do not neglect paper-based data collection

The importance of paper-based data collection should not be undermined by the use of mobile phone technology. Mobile phone technology may not be universally applicable in all regions, and so it is important to also improve the infrastructure to allow for effective paper-based collection too. An assessment must be made to determine whether a mobile phone-based or paper-based method would be more beneficial for any data collection programme, taking into account cost, the services available and the type of data collected. For example, if network coverage was very poor in a region, a paper-based system may be more appropriate.

Use basic models of mobile phones unless there is a specific need for the multimedia capabilities of a smart phone

The use of basic mobile phones is more than adequate for the majority of data collection. It is therefore recommended to use such phones over smartphones on the basis of cost, potential for theft and ease of use.

Use mobile applications in preference to SMS unless only small amounts of basic information are collected

Where simple data is being transmitted, such as medication stocks or new cases of a particular disease, SMS is preferred as it is more straightforward and is unlikely to require many hours of training. However, when there are more variables to input, a basic mobile phone application may be better suited to prevent the need to send large numbers of text messages.

Case Study Two:

Global Positioning Systems and Geographic Information Systems

Background

Based off the previous case example of mobile surveys, this case study will look into geographic information systems (GIS) and global positioning systems (GPS) as two other key mobile-based technologies for assessing the progress of healthcare SDGs. With a long-standing history, the idea of utilising geographic spatial information for healthcare purposes is deeply-rooted in medical geography, dating back to the 5th century B.C.E when Hippocrates first detailed the relationship between human health and the environment (26).

With advancements in cartography and geographic tools over time, medical geography has become an intrinsic aspect to many modern public health practices (27). For example, the London cholera outbreaks of the mid-19th century have become one of the most famous historic examples of such developments. At the peak of the outbreaks, John Snow, notably regarded as the father of epidemiology, physically mapped the geo-spatial distribution of cholera incidences in the central and peripheral boroughs of London. Based on the spatial information extrapolated from the mapped disease incidences (Fig. 4), he was able to not only identify the exact source of the outbreak but also eventually help prove cholera's true mode of transmission - water (28). Whilst the idea of using hand-drawn maps may have been an inefficient and time-consuming process, it ultimately established the basic theory and groundwork for the eventual development and adapted use of geo-spatial technologies in healthcare. During the latter half of the 20th century, revolutionary advancements and developments in computer technology and information processing systems spurred the development of GIS, GPS and other remote sensing technologies.

GIS can be defined as an information processing system that can store, manage and analyse large quantities of spatially distributed data. Similarly, GPS can be defined as a navigational and locational system that utilises both satellite and ground-based radio mechanisms to accurately determine a user's location and position (29). When considering their multifunctional applicability, this case study will examine these two well-established technologies as viable assets in effectively measuring the progress and assessing the impact of healthcare SDGs over the next 15 years.

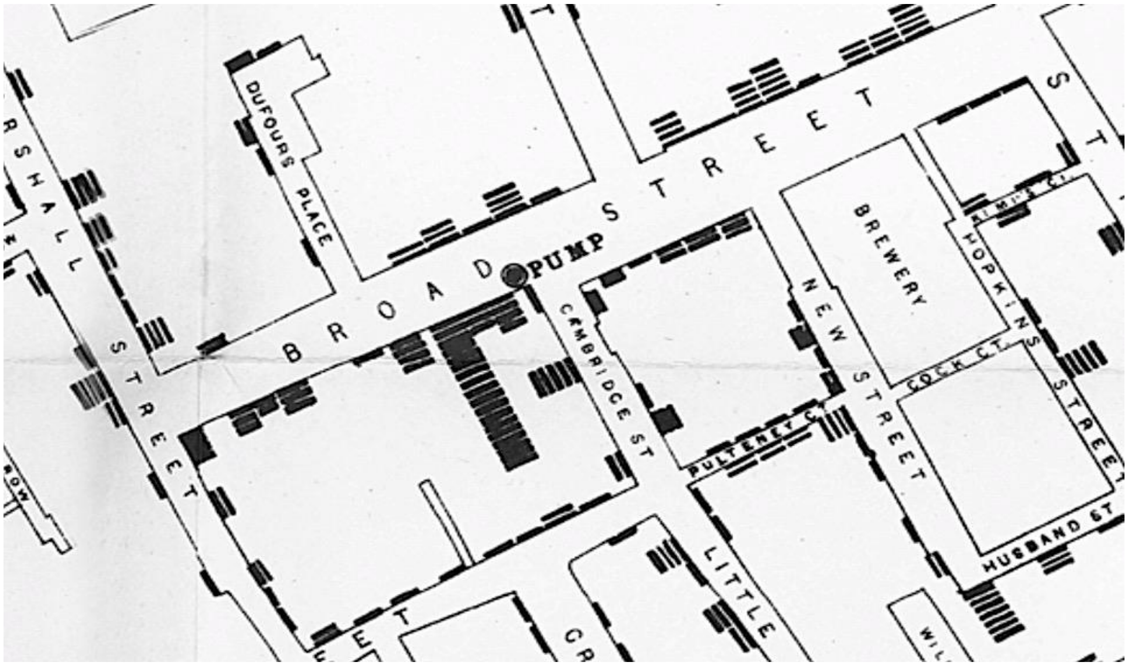

Figure 4: the original version of John Snow's cholera outbreak map as illustrated in his 1855 On the Mode of Communication of Cholera paper. Snow's mapping technique and theory served as a strong basis for many of contemporary disease mapping techniques and epidemiological practices (30).

EXAMPLES

This section will consider and introduce disease surveillance and health services accessibility as two key medical GIS and GPS applications. The general theory, mechanism and benefits of each application will be examined in an effort to describe their unique role and significance in health data collection, analysis and presentation. These case examples will elucidate their wider relevance to global health development and the SDGs later on.

DISEASE SURVEILLANCE

As a major epidemiological practice, disease surveillance is key in monitoring the progression of disease outbreaks. Modern disease surveillance techniques heavily rely on mobile GPS transponders, such as mobile phones, to relay a variety of geo-spatial health information from the specific geographic location of individual cases to the medical nature of each case (e.g. medical history, interactions and conditions)(31). Medical GIS takes the collated data and maps their overall spatial distribution (32). By mapping and identifying the distribution of disease cases, spatial analysis, combined with various statistical analysis methods, of a particular disease case allows public health officials to effectively plan and carry out intervention policies. Moreover, it also enables them to monitor and track not only the progression of a particular disease outbreak but also the efficacy and progress of the implemented policy measures. Utilising medical GIS and GPS for disease surveillance has already been well demonstrated with onchocerciasis in Guatemala and vector-borne diseases such as dengue fever and malaria in Mexico, Israel and India (33, 34). Other applications have also been extended to monitoring chronic and non-communicable diseases. For example, the United States Centers for Disease Control and Prevention (USCDC) launched its GIS surveillance programme for heart disease, stroke and other chronic diseases on a state and local level in 2007. Ever since its inception, such programmes have enabled public health officials and policymakers to create detailed health maps (Fig. 5), develop local health awareness programmes and enhance health partnerships with other chronic disease prevention units (35).

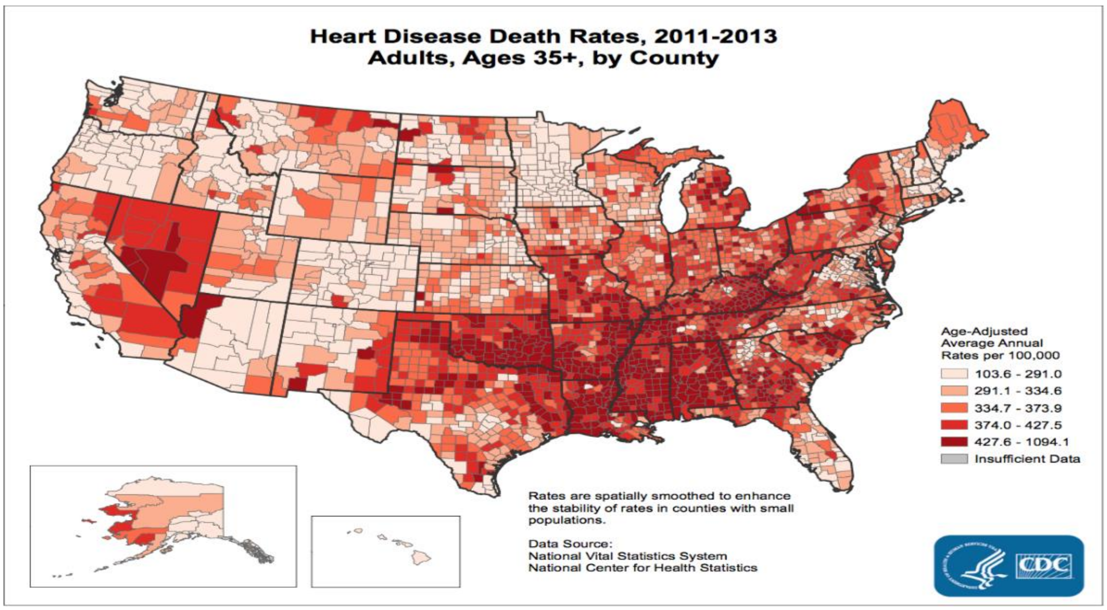

Figure 5: the densities of health disease rates across all state counties within the United States from 2011 to 2013. Although the generated disease map is not a fully accurate representation of the true disease distribution, it offers a simplistic yet powerful picture of the overall distribution within a particular geographic region (36).

HEALTH SERVICES ACCESSIBILITY

Health service accessibility, one of the cornerstone topics of global health development, is another powerful medical GIS and GPS application. In its simplest terms, access to health services is defined by the ability of people to utilise health services when and where they need them (37). By analysing the ever-changing spatial organisation of available health services, such technologies can describe how the organisation of health services impacts the healthy well-being of people within a particular region. In addition to geographic location, it also takes local population demographic information such as socioeconomic backgrounds and ethnicity into consideration when considering access to health services. To quantify such accessibility measurements, medical GIS and GPS utilise measuring indicators such as area-based and distance-based measuring indicators. The area-based measuring indicators depict established area units such as city limits and county borders. On the other hand, distance-based measuring indicators consider physical distance, time and travel costs when considering access health services between service providers and a local population. Using these indicators, medical GIS can help produce more accurate models for understanding the intricate relationship between location-based health service supply and demand (38).

In addition to their powerful descriptive applications, medical GIS and GPS can also provide valuable geographic-based insights to facilitate the policymaking and planning process for health services (38). For example, numerous studies such as those conducted by Peleg and Pliskin (39) and Ong et. al. (40) have demonstrated how medical GPS and GIS can evaluate the geographic terrain, location of available service providers and other factors such as traffic and public infrastructure to reduce ambulance response times (Fig. 6).

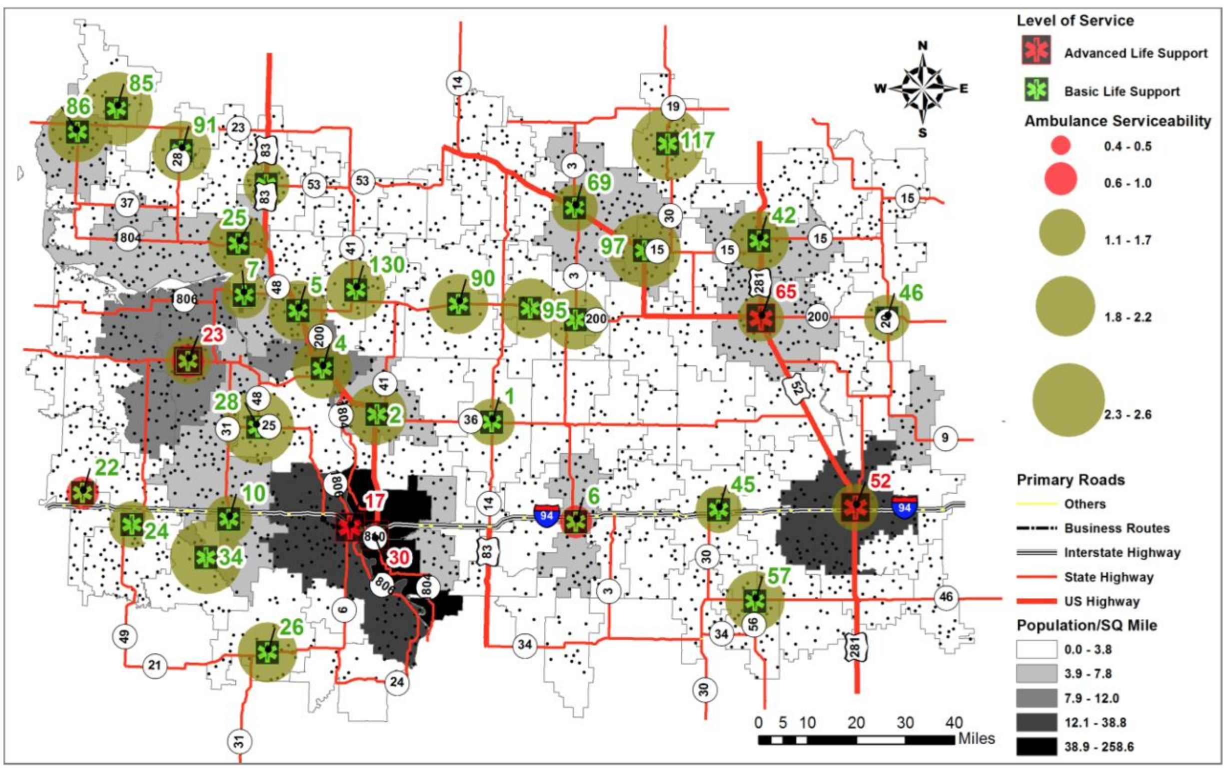

*Figure 6: the overall spatial coverage of ambulance serviceability within the city of Bismarck, North Dakota. The serviceability values were derived from the average time for random emergency incidents calculated in Lee's '*Designing Service Coverage and Measuring Accessibility and Serviceability of Rural and Small Urban Ambulance Systems' *(43).*

Within the context of global health development, this application can also be extended to maximising aid delivery in developing countries (41, 42). Another example application involves the identification of certain health service accessibility gaps. By identifying and isolating certain accessibility disparities, public health officials and researchers can further examine the underlying causes by investigating socioeconomic, cultural and other population health factors of interest. For example, Hyndman and Holman, utilising medical GIS to analyse previously collected survey data, described the relationship between the varying socioeconomic statuses of the local population and primary healthcare service accessibility in Perth, Australia. They discovered that primary health coverage was relatively equal amongst all socioeconomic classes. However, they indicated that there was a significant difference in the quality of care, measured by the availability of special services (e.g. evening walk-ins and patient choice of a doctor's gender), amongst various socioeconomic groups (38). Ultimately, the conclusions of studies such as those obtained by Hyndman and Holman's study can facilitate health service planning and organisation on a larger scale.

Critical Analysis

Whilst disease surveillance and health service accessibility represent only two practical applications of medical GIS and GPS, this section will examine their implications by analysing the key benefits and challenges of such technologies as a whole.

Benefits

Strategic Policy Planning

When bearing in mind that human health and geographic location are inextricably linked, medical GIS and GPS can serve as valuable strategic policy planning tools. Whilst such technologies have been shown to be powerful descriptive assets, they can be harnessed to provide meaningful insights for policymaking and planning (38). As discussed in the health services accessibility example, medical GIS and GPS can identify key service gaps by analysing certain population health factors and variables of interest. Moreover, the technologies serve as credible measuring indicators for the policies themselves. As a direct consequence, this allows them to identify key strengths and weaknesses and subsequently provide appropriate policy measures to amend or replace them. This feature is especially important when monitoring and assessing the SDGs.

Market Demand Analysis and Cost-Effectiveness

Similar to strategic policy planning, medical GIS and GPS can also have a pivotal role in analysing market demand and maximising cost-effectiveness. This is especially significant for policymakers and the private sector when it comes to operational analysis. Combined with health informatics, medical GIS and GPS can provide valuable health-based geographic market insights (38). For example, such technologies will be able to analyse the health services offered between two or more service providers within the region and ultimately determine whether if a service provider is investing too much in a service that is already covered in a nearby service provider. Furthermore, by analysing the demographics of patients and potential patients within a geographic region, medical GIS and GPS can also analyse the healthcare needs of a particular local population and accurately predict if a potential service or treatment will be of marketable value to the area (44, 45). Lastly, effective capital planning is perhaps one the most important benefits when it comes to cost-effectiveness (38). For example, early detection of disease clusters would not only buy public health officials valuable time but also save far more resources than if the unchecked outbreak was allowed to burgeon. This long-term cost-effectiveness is particularly compatible with the use of mobile surveys discussed in the previous case study.

Challenges

Data Accessibility and Availability

As already shown within mobile surveys case study, one of the greatest limiting factors involves the accessibility and availability of suitable data for analysis. These challenges are largely accredited to the ongoing transition to a more data-driven healthcare system. From the storage of electronic health records to task automation systems, healthcare systems have been slow in adopting information technology systems that are designed to facilitate healthcare administration, management and organisation (38). This slow adoption has not only substantially limited the amount of available data but also has impeded data collection efforts. This is especially prevalent in developing countries which lack the necessary means to collect data in the first place (41).

Patient Data Privacy and Confidentiality

Again, akin to the mobile surveys case study, patient data privacy and confidentiality serve as major challenges for currently available data. Numerous countries have enacted strict patient privacy laws and regulations such as the American Healthcare Portability and Accountability Act (HIPAA) which have become increasingly stringent with the ongoing digitisation of medical electronic records (46). Whilst it is important to acknowledge that the personalised nature of the data requires significant amount of consideration and handling, these privacy regulations have severe limiting implications for third-party institutions that necessitate such data for their analyses (44). For publicly available data, non-harmonised data sharing regulations between agencies, institutions and countries also hamper data sharing capabilities (47).

Lack of Awareness, Understanding and Skills

Despite the multitude of empirically proven benefits and applications of medical GIS and GPS, not enough researchers, public health officials and policymakers are fully aware of their immense potential in healthcare, a significant limitation to their future expansion and widespread use. In her 2003 review paper *'GIS and Healthcare,'* McLafferty argues that the lack of awareness downplays medical GIS and GPS' capabilities and renders them as another 'mapping tool' (47). As a result, this misconception has led to a debilitating misunderstanding of their overlooked uses. Finally, many healthcare organisations lack personnel that are adept in operating , adapting and interpreting the results of such technologies (44). This is especially prevalent in developing countries which severely lack the necessary technical skills and equipment (41).

Current Technological Limitations

With the advent of 'Big data' – large quantities of data that are beyond the ability of an average database software programmes to collect, store, handle and analyse - social media has become a major source of qualitative data from Tweets to Facebook posts. Furthermore, multimedia such as high-resolution videos also constitute a significant source of data (48). Unfortunately, current GPS and GIS are still unable to efficiently process and make use of such data. As a result, this limitation serves as a significant missed opportunity when it comes to reaping the multifarious healthcare benefits of Big Data. Moreover, time representation in medical GIS analysis methods still remains primitive and underdeveloped. Whilst they are praised for the powerful descriptive abilities as shown earlier, medical GIS have been criticised for their inability to describe the dynamic determinants of population health and disease (26).

Policy Recommendations

Listed below are seven policy recommendations that address the limitations, challenges and future needs of medical GIS and GPS.

Raise awareness of the various healthcare applications and benefits of medical GIS and GPS.

There needs to be substantive efforts in showcasing the various healthcare applications of medical GIS and GPS. The lack of awareness and understanding has been a root cause for the paucity of investments, slow development and overall underutilisation of medical GIS and GPS within the field.

This initial obstacle was originally noted in the early 2000s and has been highlighted again in recent literature (27). In particular, policymakers and public health officials should be the key actors in not only increasing their use of medical GIS and GPS but also leading the effort for their widespread use. This vital task can be achieved through various methods such as encouraging the private and public sectors to sponsor such technologies within the context of global health development projects and commissioning specific technology advocacy reports and studies. The significance of this policy area will also become apparent in the wearable technologies case study.

Support multisectoral collaboration in the collection, processing and presentation of geo-spatial data.

Further data collection and processing efforts are imperative when it comes to providing a large workable data pool for research and operational uses. A significant amount of the effort will require multisectoral coordination and cooperation. This includes not only identifying relevant stakeholders and actors (e.g. public sector, private sector and NGOs) but also creating working groups and fostering partnerships, whether it is public-public or public-private in nature, to carry out various purposes (e.g. creating health maps or conducting academic research). Furthermore, multisectoral cooperation serves as an accountability mechanism that would ensure a higher standard of data quality and reliability. In reference to the disease surveillance case example, the USCDC's extensive disease surveillance programmes comprise well-defined working partnerships between individual constituent municipal health authorities, the national Department of Health and Human Services and private institutions, allowing the USCDC to efficiently obtain and analyse a wide-range of relevant geo-spatial healthcare data.

Increase investment for the establishment of a central globally linked medical GIS database that facilitates data access for relevant stakeholders.

A vital objective of multisectoral cooperation and commitment needs to be focused on establishing a common global database for promoting data collection efforts and facilitating data accessibility. As the amount and types of data increase, there is a growing need for a centralised access point for all parties of interest. Small linked health databases such as the Primary Care Service Area (PCSA) have already been created; however, a more global and flexible database has yet to be established (47).

Establish and implement training programmes to educate local researchers and public health officials to use, adapt and interpret the results of medical GIS and GPS for both research and operational uses.

This policy recommendation represents one of the core themes of this policy paper and is similarly expressed in the two other case examples. Having qualified personnel is paramount for carrying out mass data collection, analysis and presentation efforts. This is particularly true for developing countries. Tanser and Sueuer stressed that the dearth of competent personnel serves as a fundamental impediment to the implementation of many GIS-based projects in Africa. As a result, many of the current GIS health projects have been largely executed by a small number of international aid agencies (41). Thus, this paper highly recommends this course of action as both an immediate and long-term impact policy recommendation.

Establish or develop better data sharing best practices across all relevant sectors.

Like the policy recommendation above, the establishment and development of best practices serves as another key policy theme that is noted in all aspects of this policy paper. Numerous regulations heavily protect the sharing of healthcare data, especially those that pertain to individual patient medical records. Whilst bearing in mind that patient data privacy and confidentiality is of utmost importance, establishing harmonised data sharing best practices would be critical in opening up many of the unnecessary data sharing restrictions (49). Ultimately, this would promote widespread circulation and exchange of currently available data.

Promote the integration of commonplace mobile transponders as new sources of geo-spatial data.

To encourage the mass generation and collection of health-based geo-spatial data, exploiting current data sources such as mobile phones and wearable technologies would not only generate more relevant and usable data but also potentially provide new insights into the dynamic relationship between human health and the environment.

Develop and improve GIS analytical methods and techniques to process and evaluate qualitative data.

Improving GIS analytical methods and techniques is vital to shaping the technology's future direction. With growing recognition of the numerous healthcare benefits of 'big data,' the growing prominence of qualitative data is something that cannot be ignored. Finding and developing new ways to efficiently collect, process and analyse such types of data is essential to opening up new fields of untapped data and gaining a better understanding of the evolving nature of human health, behaviour and location. For example, two beneficial healthcare applications include improved disease surveillance and medication administration (49).

Case Study Three:

Wearable Technology

Background

Whilst GPS/GIS data can be used to measure the progress of the SDGs, this case study will consider the role wearable technology has in this field. The origins of wearable technology date back to the 17th century, during the Chinese Qing dynasty, when the world's first abacus ring was created, thus allowing its users to access this form of technology wherever they may be (50). Since then, wearable technology has continued to gain traction in society, albeit at a slow rate. However, in the last thirty years and with the advent of smartphones and their associated application software, this field is rapidly increasing in popularity and will continue along this trend in the coming years (51), with 2015 being declared as the 'year of wearable technology'(52).

Wearable technology can broadly be defined as 'mobile electronic devices that can be unobtrusively embedded in the user's outfit as part of the clothing or an accessory' (53) and encompasses wearable electronics and computers, as well as smart clothing (54, 55).

Wearable technology gained traction in the 1980's, when Polar® created the world's first wireless heart rate monitor, embedded in an already ubiquitous technology, the wristwatch (56). This marked the beginning of the close relationship between wearable technology and healthcare. The advantage that wearable technology has over other forms of technology is that it can constantly monitor and gather quantitative data about the user's condition, which is then put into an overall context, rather than just a snapshot in time (57, 58). This case study will focus on wearable electronics designed to measure a particular parameter (59) and collect data in the context of the Sustainable Development Goals (SDGs), especially those pertaining to healthcare. The technology can measure a number of different clinical signs, such as blood pressure and heart rate, which can be subsequently analysed and used to give an approximation of the progress of the SDGs, for example mortality rates from non-communicable diseases.

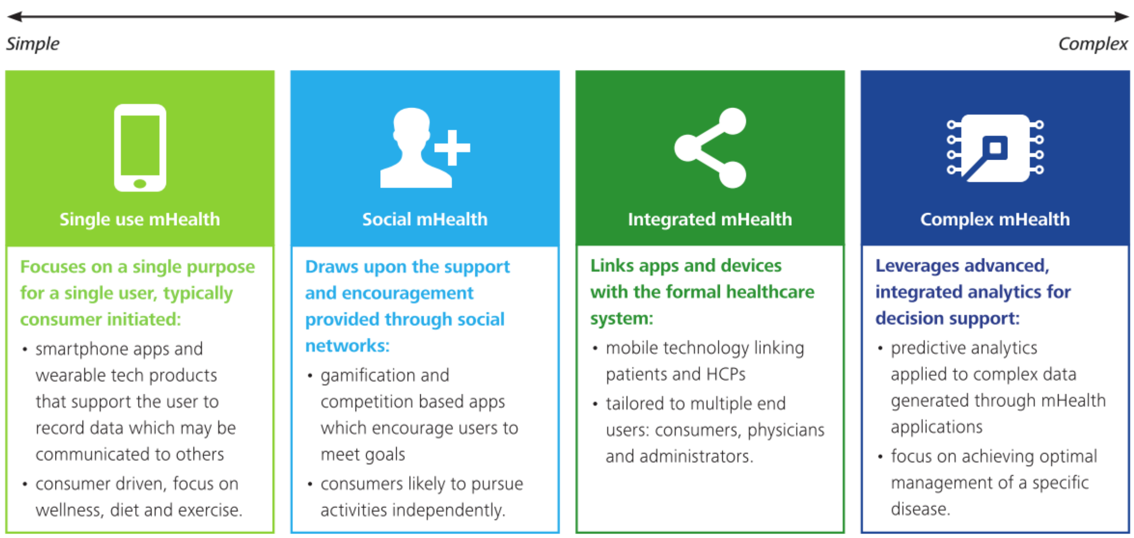

Figure 7: Wearable technology and mobiles in general have a wide range of uses, from very simple to highly complex (60)

EXAMPLES

The uses of wearable technology mainly lend themselves to monitoring non-communicable diseases (NCDs), especially in developed countries, where this technology is already in place, or about to boom. SDG 3.4 aims to 'reduce…premature mortality from [NCDs] through prevention and treatment', thus wearable technology can be effectively used to assess how authorities are faring with this goal by measuring signs and collecting data about interventions that have been taken.

FALLS AND ACCIDENTS

Wearable technology can be used to assess Parkinson's patients to see how the disease manifests itself and how it affects them (61), however the technology mentioned does not have to be limited to only this group of patients. 40% of injury deaths are due to falls, therefore the need to reduce this number is significant for the SDGs. Parkinson's Disease (PD) is a debilitating, degenerative, neurological disease, which does not necessarily result in the death of the sufferer (62).

A more common cause of mortality is from injuries and consequent infections sustained from accidental falls, which result from the motor impairments caused by this disease (64). Therefore wearable technology can be used to monitor the number of falls sustained by Parkinson's patients, giving an estimate of the morbidity rates of this disease and hopefully, the resulting data can help physicians and other healthcare professionals to prevent future accidents.

An application, iFall, has been developed which monitors and responds when a person falls, fetching them help if they need it. (65) Though useful for Parkinson's patients, this app may also be of use to groups of people who experience falls more frequently than the general population, for example elderly people (66, 67). The application is constantly running in the background, while the user operates their smartphone as normal, and detects any sudden changes in acceleration which may indicate that they have fallen. An app such as iFall may be able to reduce mortality rates from accidental falls by fetching help for the app user more quickly, with a quicker response improving the outcome for the patient. The creators of the application are trying to integrate the technology with Wi-Fi connectivity so that data can be amassed from the app. With this data authorities can see whether PD treatment is reducing the injury rate among patients and from this information, decide whether they need to take further precautions.

ATRIAL FIBRILLATION

ECGs are a common diagnostic test to measure the condition of the heart (68) and diagnose some of the more common non-communicable cardiac diseases. With diagnosis comes the ability to prevent the condition from deteriorating and leading to premature mortality, therefore ECGs may be an important tool in achieving SDG 3.4. The most common heart dysrhythmia in the UK, Atrial Fibrillation (AF) is often undiagnosed in patients (69, 70). This dysrhythmia increases the risk of stroke occurrence by almost five times (71), amongst other NCDs, and the risk of it occurring increases with age (72). A wearable technology that can detect this heart malfunction earlier may be able to reduce the disease burden of stroke. AliveCor Heart Monitor for iPhone can take an ECG in 30 seconds, and has an FDA-approved AF detector (73). The technology is also available on Android software. As shown in previous studies (74), this technology can be used with ease by nurses, thus an app such as this would make mass community screening of AF a feasible option for health authorities when planning any interventions to achieve the SDGs. Furthermore, considering that the data is collected and stored on a password-protected website, it is readily accessible to the relevant physicians.

BLOOD PRESSURE

Finally, another company, Qardio, has created a blood pressure monitor, QardioArm, which is fully integrated with its smartphone application, working on both Apple and Android operating systems (75). It is easily portable, clinically validated and gives precise feedback, as it takes three readings each time, which can be easily relayed to both family members and physicians. It is critical to monitor blood pressure, especially as people age, since high blood pressure can lead to a myriad of non-communicable diseases, such as stroke and kidney disease (76). For this reason, a wearable blood pressure monitor would be key to monitoring the progression of the SDG 3.4, 'reduce...premature mortality from (NCDs) through prevention and treatment', as it provides indispensable information on a vital sign of health, without the need for intervention by a healthcare professional. This information could indicate whether mass public health campaigns, such as those for stopping smoking, are having an effect of the health of the population.

Wearable Technology	Measurement	Function	Stage of Development
iFall app	Changes in acceleration	Can be used to detect accidental falls and consequently fetch assistance	In testing stages of development (77)
AliveCor Heart Monitor with ECG app	ECG Trace	Detect certain heart conditions, particularly atrial fibrillation, using the ECG trace	Available to buy, recommended by NICE for monitoring patients at risk of AF (78)
QardioArm	Blood Pressure	Collects data about the user's blood pressure	Available to buy, debuted by NHS England at UK eHealth week 2015 (79)

Figure 8: A table comparing the 3 examples of wearable technology discussed and their stages of development as of Oct. 2015.

Critical Analysis

Whilst these examples outline varied uses of wearable technologies in practise, there are numerous benefits and challenges concerning their implementation as policy tools.

Benefits

Remote collection

The advantages of the mass use of wearable technology for measuring the SDGs cannot be ignored. Similarly to data collection using mobile surveys and GIS/GPS information, the capability of wearable technology to accrue clinical data which can be transferred and shared across the world makes it advantageous for health authorities when measuring the progress of their policies. AliveCor Heart Monitor for iPhone exemplifies this, showing that anyone with the correct login details can access the ECG data. This data is not only relevant to the patient's physicians, as health authorities can also use it remotely to assess healthcare across the population. As with data collection with mobile surveys, the chance of privacy and confidentiality breaches may deter the use of wearable technology in this way, however in 2016, a new framework, with stringent privacy requirements, will be put in place across the EU, which will cover any technology used in the region regardless of the location of its developer (80).

Remote accessibility

Furthermore, once a patient is diagnosed with a medical condition, especially a cardiac problem, remote patient monitoring significantly decreases the chance of death or hospitalisation occurring (81). Remote patient monitoring, away from a clinical setting, can be carried out by wearable technology which is easy for the patient to use, as shown by the examples above. The data then collected will not only provide healthcare professionals with information about some of their most ill patients, but will also give health authorities a more rounded picture of the health of the population, rather than a mere snapshot each time they receive a check-up.

Challenges

Reliability

Wearable technology generally measures clinical signs, which may only indicate a disease, rather than assessing the disease itself. These clinical signs can assess health on an individual level but scaling this data up to give a reliable estimation of the health of the general population is more difficult. The information can however be tracked over time to see how trends among the population are changing and to see whether any government or alternate interventions are propitious. Although the estimates may not be wholly reliable, they do offer a time-saving opportunity to monitor progress on a macro level.

Accuracy

Another major challenge to wearable technology is its accuracy. With regards to measuring falls in PD and osteoporosis patients using an app such as iFall, the possibility of measuring false positives may be problematic, not least for the emergency services. In one study, wearable devices were found to be more inaccurate than specialist applications found on smartphones, which use the devices' internal sensors (82). However, if specialist software is used, such as the iFall application (83), steps are taken during research and development to ensure that false positives are kept to a minimum, by taking into account movement from daily activities using a two-step communication system and adjusting the sensitivity of the application. QardioArm has been clinically validated according to both British and American standards, with an accuracy of about 2% of readout value for blood pressure and 5% for pulse (84), and the device takes multiple readings, which also increases precision. Considering that these values do fluctuate throughout the day (85), it is reasonable to expect a slight discrepancy. Despite the possibility of inaccuracies of measurements, if wearable technology is used to assess trends then these slight variations will be less significant to the overall picture.

Cost and skill level required

As is also the case with both GIS/GPS and mobile survey data collection, it is important to take into account the cost, both monetary and temporal, of the mass use of wearable technology in order to measure SDG 3. Smartphones are the only phones with the appropriate capability to support the technology and their pricing can vary considerably, which may restrict their use to wealthier populations. Furthermore, many of the uses of wearable technology are more applicable to older people, who may be unfamiliar with using such software. Time will be needed to teach them how to use the technology correctly. The monetary cost may become a less significant problem as smartphone costs are decreasing year on year (86), making them accessible to increasing parts of the population. However, the price of wearable technology may still be a deterrent to their use (87). Once the technology is in place with the demographic populations, the mass data it could collect, which may otherwise require large teams of people and long time-periods, could help authorities change their health policies more easily and may save health services money in the future (88). AliveCor has been shown to be cost-effective for screening in terms of price of the technology compared to savings made from early detection (89), so subsidisation of such technology may be a viable option in return for long-term savings.

POLICY RECOMMENDATIONS

Listed below are 5 policy recommendations to help realise the widespread use of wearable technology for data collection in light of the above critical analysis.

Increase access to wearable technology for target populations

This novel technology should not be limited to more affluent communities, in order to include other populations to provide a full estimation of progress towards the SDGs. By ensuring any patients with a disease can have the appropriate wearable technology available, government health authorities can collect indispensable data which can help them to influence future policies. Policies may include subsidising wearable technology, as well as ensuring that every GP practice has access to at least one of the more cost-effective forms of wearable technology with smartphone hardware to support it. This will provide both temporal and monetary savings, with a study showing that for COPD patients using a wearable-type device, there was a saving of 40% compared to 'standard' care and a 26% reduction in the number of GP appointments needed (90).

Improve infrastructure within the community to allow doctors and other healthcare professionals to easily access any data collected by wearable technology

Wearable technology may collect vital data so it is imperative that its access is not hindered by poor internet quality and archaic electronics. Healthcare professionals and authorities should have access to up-to-date software and hardware, such as fast internet connection and usable smartphones, to ensure that changes can be implemented effectively, swiftly and with good evidence to back them. Improved infrastructure is also important for all of the other mobile technologies discussed in this paper.

Train nursing staff and other patient-facing staff in GP surgeries to use wearable technology, such as ECG and blood pressure monitors

The majority of patients are seen in the primary care setting, making this a valuable place to collect data covering a wide population demographic. The data can be collected whilst patients are waiting to see a physician or other healthcare professional and, apart from being useful in their consequent consultation, can also be sent to health authorities, providing new information daily about the health of the population. Consequently, it is vital that the relevant healthcare professionals are adequately trained to use the technology, as is also the case for GPS/GIS, to be able to gather data.

Make wearable technology a larger part of at-home health monitoring, especially for patients with multiple comorbidities

ECG and blood pressure monitoring should not be limited to a clinical setting, but should be extended to the home environment. Patients and healthcare professionals must work together to integrate the technology into their lifestyles so that there is continuous data about each patient's condition. The technology is convenient and once on, requires very little input from the patient compared to traditional monitoring methods. This data will also provide a much fuller picture of the progress of the SDGs than just the occasional check-up at a GP surgery.

Assign a team of statisticians and other professionals to analyse the data gathered by wearable technology

Unlike other uses of mobile phones, wearable technology gathers data constantly, which can only be useful if it is analysed regularly, potentially even daily. The gathered data will show trends and provide crucial evidence to support policy changes, even if used a local level. Furthermore, once the policies are implemented, there will be new data providing details on how they are faring, which can further influence the policies.

CONCLUSIONS

The SDGs represent a revolutionary agenda formulated to push humanity towards a clean, sustainable and efficient future, so finding efficient mechanisms of measuring their progress and assessing their overall impact is paramount. It is clear that this ambitious task will require innovative techniques, in particular the use of mobile surveys, medical GIS and GPS and wearable technologies. Whilst this policy paper examines these three case studies independently, it is important to recognise that they are closely related and highly compatible with each other. For example, the integration of GPS into wearable technologies can provide an additional dimension to any data that is collected. Conversely, GPS, wearable technologies and mobile phones can all serve as different types of data inputs for a central medical GIS. In addition, mobile surveys can be used to evaluate data from wearable technologies.

The current pervasiveness of mobile phones and their ancillary infrastructure already provides the foundations for implementation of the outlined technologies, however it is also important to consider feasibility factors such as the current state of a technology's development, implementation costs and implementation timeframes when evaluating the proposed policies. This paper concludes that implementing the policy recommendations of both the 'Investment' and 'Collaboration and Awareness' policy themes should be the first priority. This is crucial in not only promoting the widespread usage of the examined technologies but also establishing a working foundation for future developments. Substantial investment is required before these technologies can be fully integrated into practise. Secondly, this paper finds the policy recommendations of the 'Training and Education' policy theme as the next priority. These are essential to ensuring the necessary and appropriate personnel adapt to, utilise and interpret the results of such technologies over time. Lastly, this paper concludes that the policy recommendations of the 'Best Practice' policy theme should be the final priority. These policy recommendations will ensure that the integration of the technology is sustained but will also require global cooperation and prior investment and training before they can be feasible.

As unanimously agreed by the United Nations General Assembly on September 25th, 2015, each national government holds the greatest responsibility in leading the efforts for implementation of such policies. However, they are not the only actors that can effectively address the issue. As mentioned, multisectoral cooperation is integral to adapting and implementing such technologies to the SDGs. This level of cooperation will require a systematic identification of all relevant actors (e.g. governmental agencies and departments, NGOs and private healthcare companies) and stakeholders from the local to international level. The Cochrane Collaboration is a prime example of the work of a systematic global network of researchers, clinicians, patients, policymakers and many other healthcare professionals. Such working partnerships will, for example, be crucial in establishing a global geo-spatial data collaboration, or for the widespread promotion of mobile technologies.

Although this policy paper only considers three healthcare-based case examples as part of its scope, it is important to acknowledge that there are many other existing and emerging technologies, from electronic health records databases to novel software programme analysers. Therefore, it is vital that policymakers act prudently, and most importantly, remain open-minded when it comes to adapting to and harnessing the ever-changing nature of modern technology for practical healthcare uses and benefits. The main task in the long-term will be consistently maintaining and updating the use of such technologies.

Therefore, this policy paper finds that promoting the widespread implementation of mobile surveys, medical GIS and GPS and wearable technologies will have a long-lasting impact on the overall achievement and success of the healthcare SDGs in the next 15 years. These benefits will extend beyond the SDGs, to include improved policy making, more efficient data collection and, most importantly, improvements to healthcare across the world.

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