National College of Ireland
MSc Web Technologies
2010/2011

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iDiabetesCare - Enhancing diabetes care in the Cloud

Dissertation

I hereby certify that this material, which I now submit for assessment of the programme of study leading to the award of Master of Science in Web Technologies is entirely my own work and has not been taken from the work of others save and to the extent that such work has been citied and acknowledged within the text of my work.

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Abstract

Diabetes is chronic medical condition that has potentially serious health complications and puts huge pressure on existing medical services. This research will examine if a cloud-based system, called iDiabetesCare, will aid patients and medical professionals in the management of this condition.

The system design was based on a survey of diabetics and background research. A sample group (n=7) used the system over a 3-week period and were then surveyed as to their findings.

The results were that the system was found to be beneficial and offers features that patients find useful. The results must be considered to be indicative, as the sample size was too small to be considered conclusive. More study in this area is warranted, especially with the full collaboration of the medical community.

Abbreviations

AJAX - Asynchronous JavaScript and XML

SSL - Secure Sockets Layer

RIA - Rich Internet Application

HSP: Health Service Provider

HSE: Health Service Executive

1 Introduction

The management of chronic illness has always been a great challenge to the medical community. The cost both in terms of effort and money is a significant burden to even the most advanced health system.

No condition exemplifies this more than diabetes, an illness that while manageable, can result in serious long-term health complications for the sufferer. Treating diabetes requires commitment both on the part of the medical community and of the diabetic patient. The management of diabetes is extremely manual in nature and requires a discipline of monitoring and data gathering on the part of the patient, for later analysis on the part of the HSP. This is a slow process and is exacerbated by the fact that health complications are caused by poor diabetes management occurring over a period of time.

As of the time of writing, Ireland, like many Western nations, is facing a 'perfect storm' when it comes to diabetes care. Type 2 Diabetes is rapidly increasing due to lifestyle changes in the general population and poor economic conditions mean that the public health service is facing unprecedented resource shortages.

The stage is then set to find a way to help in the cost-effective management of diabetes via the use of automation. This research is aimed at examining whether a cloud-based system, constructed from widely available technologies, can help in the management of Type 2 Diabetes.

In this research, a review of previous work will establish the basis for diabetes being a serious, chronic illness, which is costly to treat and is widely on the increase. It will then show how the application of technology to the problem has proven to be beneficial in previous efforts, but most of the work has utilised bespoke systems which will not necessarily scale well. The target group was established as the 20-40 age group, as it is this demographic which is seeing a greater occurrence of Type 2 Diabetes.

A survey of diabetics established the features that would be most beneficial to the target group. Based on this, iDiabetesCare, a prototype cloud-based website was constructed from widely available technologies and services. It provides features allowing for the gathering of patient data and its analysis (to a certain extent). Digital networking facilities were also used to allow patients to network with each other.

A selected user group evaluated their system and were surveyed on their findings. The results indicate that the system, on the whole, aided them in the daily management of their diabetes. The choice of technology and the use of the Microsoft Azure platform ensure that the system is low cost and that costs will increase only as the system is scaled out.

A secondary feature of the system is to allow a HSP to gain immediate access to the daily records of a patient and to communicate with them in real time. Unfortunately, the participation of as HSP could not be secured and so this part of the system could not be properly evaluated.

The results indicate that future work in this area is worthwhile and that the system can be easily extended to facilitate chronic conditions other than diabetes.

2 Literature Review

2.1 Diabetes: What is it?

Diabetes mellitus is a chronic disorder in which the body's ability to process sugar is severely impaired. This causes raised levels of glucose in the blood and its excretion via the urine. These changes are the result of a deficiency of the pancreatic hormone, insulin.

As outlined in the Harvard Health Publications (Nathan, 2009), the majority of cells in the human body require energy to function and this is sourced from sugar. When food is metabolized, it is broken down into its constituent parts, including sugars and these are released into the blood stream as glucose.

Insulin is naturally produced in the body by the pancreas. It pushes sugar into the liver and muscle cells, promotes the storage of nutrients and also prevents the blood sugar levels from rising excessively. Insulin also increases the uptake of amino acids (which are used as the building blocks of proteins) and fatty acids (used as the building blocks of fats) into protein and fat stores. Insulin is thus one of the principal actors of the metabolism, by promoting energy storage and cell growth.

If blood glucose levels drop too low, insulin secretion will fall and the pancreas will release the hormone glucagon. This prompts the liver to convert stored glycogen (the storage molecule in which glucose is stored) into glucose and release it back into the bloodstream. Usually insulin and glucagon levels will fluctuate in a coordinated cycle to keep blood glucose levels within a narrow range. This is vital, as certain organs, such as the brain and kidneys, will depend on a consistent, steady supply of glucose.

Diabetes can result from a combination of failures:

- The cells of the body can become less responsive to insulin, which in turn causes the body to secrete more insulin to maintain normal metabolism.
- The pancreas then pumps out more insulin to compensate.
- The insulin-producing cells will eventually fail to keep up with the increased demand.
- The blood sugar levels then rise, resulting in diabetes.

Diabetes can be divided into two primary classifications:

- Type 1 - Where the ability of the pancreas to produce insulin is severely or completely diminished, usually due some form of attack on the immune system. This is currently incurable.
- Type 2 - Where cells develop a resistance to insulin. This condition is often associated with age and/or obesity. It can be treated with diet and/or insulin supplements. This is increasingly the most common form of diabetes.

2.2 The importance of diabetes management

As discussed in the Harvard Health Publications (Nathan, 2009), the most important factor in good control of diabetes is the maintenance of the individual's blood-sugar levels within a narrow range, as well as more general factors such as maintaining a healthy weight and avoiding hypertension. These are typically managed via diet and exercise, as well as a regimen of daily insulin intake and a regular testing of blood-sugars by the individual.

If the diabetic does not manage his condition well, over long periods of time (measured in years or decades) , long-term health complications are at a high risk of occurring.

Nathan divides them into three categories:

- *Microvascular disease, or conditions that affect the small blood vessels of the body (such as those in the eyes and kidneys).*
- *Neuropathic complications, or nerve damage that affects the feet and other extremities.*
- *Macrovascular disease, or conditions that affect the body's large blood vessels—in particular, plaque clogged arteries (atherosclerosis), which leads to heart disease and other cardiovascular problems.*

In short, poor diabetes management can lead to heart-attacks, strokes, amputation of the extremities and the partial or complete loss of sight via Glaucoma and Diabetic Retinopathy. It is also worth noting that continuous levels of high blood sugars (Hyperglycemia) can suppress the human immune system and exacerbate infections (Bistrian, 2001).

While the levels and types of insulin intake by the diabetic are defined by the individual, under the partial or complete supervision of a medical specialist, this has to be guided by the continuous recorded history of the diabetic's blood sugar-levels. The medical professional can check the patient's HbA1c level (which will show the average blood sugar level over a three to six month period). However, the monitoring of blood sugar on a daily basis (three to four times a day), in a self-administered fashion by the diabetic, is vital to inform both micro and macro adjustments in the levels of self-administered insulin.

In a standard scenario, the diabetic will prick his/her finger and apply a drop of blood onto a test strip, inserted in an electronic blood-sugar measuring device. Within seconds, this device will tell the individual the current blood-sugar reading. From this, the diabetic will know whether to modify insulin intake or to keep it at current levels. This is important in avoiding both the long-term effects of continuously high blood sugars (Hyperglycemia) and the short-term effects of low blood sugar (Hypoglycemia), which can lead to confusion and dizziness. This will be handled by the diabetic via the ingestion of sugar-laden food and drink or the result can be a diabetic coma. In extreme scenarios, if a coma occurs and it is not remedied by a third-party medical professional, death can occur within a matter of hours.

2.3 Diabetes is on the increase

As has been demonstrated, Diabetes is a serious condition with both short and long-term health ramifications. It is therefore disturbing that diabetes, most notably type 2, has seen a great increase in recent years.

In 2007, Sicree and Shaw drew attention to what they called an 'epidemic' of type 2 diabetes. They refer to a World Health Organisation estimate that the world diabetic numbers will increase from 194 million in 2003 to 366 million in 2030. (Sicree & Shaw, 2007) This is a significant escalation of the condition. It is notable that they blame both the ageing, and the increased urbanization of these growing populations. These are factors that are most obvious when applied to the Irish domain. Another Irish, and world factor, Sicree and Shaw emphasize is the link between an increase in obesity and an increase in type 2 diabetes.

An earlier study by Wild et al in 2004 mirrors these findings and claims that diabetes worldwide across all age groups will increase from 2.8% in 2000 to 4.8% in 2030. They attribute this to the aging of an increasingly urban population but believe that the rise in obesity will only make matters even worse (Wild et al, 2004).

This problem is replicated in Ireland. The World Health Organization notes that diabetes is one of the primary conditions that cause almost 87% of all non-fatal deaths in Ireland (WHO, 2011). A public screening process by Voluntary Health Insurance Healthcare in 2011 concluded that up to 30,000 Irish citizens could have undiagnosed Type 2 diabetes, with a further 146,000 having undiagnosed pre-diabetes (VHI, 2011).

It is of even more concern that not only is type 2 diabetes becoming more prevalent amongst adults but is also on the increase amongst children, a fact almost unheard of in previous decades.

In 2007 Haines et al performed a study of the incidence of type 2 diabetes in the under 17 age group across the UK and the Republic of Ireland (Haines et al, 2007). In a study of the incidence of diabetes reported in children under the age of 17 over the preceding five years, they had some interesting results. The incidence of Type 2 diabetes was less than Type 1 and this is to be expected, as Type 1 typically manifests itself in childhood. However, of those diagnosed with Type 2, 95% were classified as overweight and 83% were classified as obese. This demonstrates how the change in western lifestyles and the increase in obesity is increasing the frequency of Type 2 diabetes.

McQuaid et al back up these results with an earlier study in 2005 of children and young adults in Ireland (McQuaid et al, 2005). They found that Type 2 diabetes is occurring more frequently in children and the condition is presenting with characteristics typically seen in the older, more 'usual' subjects. The unfortunate conclusion to be drawn from these studies is that since poor management of diabetes over an extended period of time increases the risk of health complications, the younger suffers are at an even greater risk of such complications. This is because they will have the condition for a longer period of their lifespan and will suffer complications sooner.

The response of the medical community has not always been helpful in the sphere of diabetes prevention and treatment. Sharma et al propose the use of bariatric surgery as a means to treat obesity and therefore reduce the incidence of Type 2 diabetes (TargeTing ObesiTy, 2011). In the opinion of this author, using surgery to treat a condition that is preventable and curable by lifestyle changes is a case of treating a symptom rather than a cause. Needless to say, this method would have no effect on Type 1 diabetes. The real key is education and utilities that facilitate the management of the condition.

The conclusion to be drawn from this evidence is that diabetes is fast becoming a major threat to national health and the associated drain on health care resources is one that can be ill-afforded.

2.4 Diabetes: the Costs

The cost of diabetes manifests itself both in a potential reduction in the quality of life for the individual and in financial terms to the state.

Schering and Kasten performed a study where they found a higher incidence of cardiovascular disease amongst diabetics that could not be explained by associated factors alone (such as obesity) (Schering & Kasten, 2004). This underlies the risk of the condition and the need for a stricter regimen of healthcare. Song reiterates this and points out that diabetics, especially Type 2, display an incidence of health complications sooner than would be seen with Type 1 and have a much shorter life expectancy (Song, 2009).

Diabetes management is centred around good control and the purpose of reducing the risk of complications and the sooner it applied, the better. As Song says: ' *The principal aim of diabetes management is to prevent complications and this is even more pertinent in early-onset subjects given the potential for longer disease duration and exposure to adverse risk factors.*' (Song, 2009)

Lau highlights the fact that diabetes has a great cost in terms of quality of life and life expectancy but also concentrates on the huge financial cost to healthcare. He estimates that in 2007, 20% of all HealthCare spending in the United States went towards diabetes (Lau, 2010). The total spend on diabetes is a frightening $174 billion but these estimates do not take account of population growth and aging. Such estimates are easily applied across the western world (in a proportional fashion) and Ireland is no exception.

These studies concentrate on the US and Canada but the implications for Europe and thus Ireland are easy to see. In 2008, Bottomley compared the reported costs of diabetes between the US and Europe and found the trends were broadly in line (Bottomley, 2008). She reports that the typical diabetic will produce twice the cost to a HealthCare system that a non-diabetic will. The typical non-medical costs to the US economy of diabetes is in the region of $58 billion dollars. Such costs include areas such as lost work days, reduced productivity and permanent disability. Bottomley reports that a similar trend is appearing across Europe. This underlines the fact that diabetes is not only a threat to the healthcare system but potentially to the economy as a whole.

Such costs could eventually bankrupt any healthcare system and as this author has previously shown, eliminating diabetes is not a realistic medium-term option. This makes the need for lowering the cost of providing services to these diabetics a matter of priority.

2.5 Promoting better diabetes care is cheaper

It has been recognized amongst health-care professionals that there is a need to promote better self-management of diabetes amongst diabetics (Glasgow and Bull, 2001). Can programs and the tools that help improve the management of diabetes provide cost savings?

Sidorov et al have evidence that they do. As far back as 2002, this group performed a study of two groups of diabetics. One group enrolled in an opt-in disease management program and the control group did not. The results showed that patients within the program averaged health insurance claims per month of $394.62, as opposed to $502.48 for the patients who were not in the program. Additionally, patients in the program had a lower number of emergency room, visits and a higher quality of results in areas such as eye health, cholesterol and blood sugars (Sidorov et al, 2002).

A study by Brownson et al in 2009 looked at cost savings to be found in promoting and administering program of self-management to diabetics (Brownson et al, 2009). The study was organized as series or projects, each beginning with a 15-month planning phase, during which innovative approaches to reaching and engaging their respective patient populations in self-management were tested. This was followed by a 30-month implementation phase, during which the projects implemented their most successful strategies, while continuing to work on improvement strategies in patient and organizational supports. The results are interesting. The study found that while the treatment and complication costs were lowered by $3,385, this was more than offset by the $15,031 cost of implementing the program in year one and over subsequent years. However, the study also concluded that the overall costs of long-term complications were lowered and the subjects' quality-of-life was increased.

The above models also apply to Ireland. In 2009, Collins et al performed a study of diabetic patients in Ireland receiving care under three different settings; traditional hospital care, hospital/general practitioner (GP) shared care, and structured GP care (Collins et al, 2009). The results were that the structured GP care provided a better quality of care for the diabetics resulting in a better quality-of-life. The patients under the structured GP care tended to adhere to more of the 'process-of-care' measures (defined processes to ensure better diabetes management, such as a healthier diet and regular exercise) than the others. While this is encouraging, it is obvious that face-to-face GP care has limited capacity to deal with a growing diabetic population and the availability of doctors specializing in this area is not uniform across the country.

It is obvious that controlled programs provide health and cost benefits but there is still obviously a financial cost, especially in the short-term. Providing such programs also requires Healthcare resources which are limited, especially on a regional basis. In Sidorov's study, patients in the program had a higher number of visits to primary care providers. In Brownson's, short-term savings were outweighed by implementation costs. Collin's study relies on a GP network which is already under pressure from traditional health-care demands.

The key to lowering these costs is to have a way to provide the feedback and contact that patients require, without the need for constant face-to-face contact with Healthcare professionals. An automated system could certainly provide benefits here.

2.6 The use of technology to promote health care

2.6.1 Technology Research and diabetes

If educating diabetics in the better management of their condition is so vital, can technology be used to provide this in a cost-efficient manner? The evidence tends to point in that direction but equally there is more work still to be done. There are obvious benefits in online resources to manage chronic conditions, especially amongst those who live in remote areas, are too busy to regularly attend clinics or are homebound (McKay et al, 2001).

Bull et al performed a study in 2005 of 87 separate, publicly available diabetes websites hosted by governmental, health plan, commercial, pharmaceutical, and charity organizations. The results were that the majority of sites provided information only, with little in the way of social support, interactivity or professional advice. While things have moved on somewhat in the intervening years, this author believes that there is a need for a site that will provide more in the way of real-time assistance to diabetics. As Bull et al say:

There is an opportunity to go beyond static information exchange to make websites places where people can complete behavioural assessments and receive real-time feedback, support and improved access to care. (Bull et al, 2005)

In 2008, a study was performed to measure the value of targeted, internet-based education to Type 1 diabetics, to improve their ability to evaluate their blood sugar levels and to alter their regimens to better manage them (Cox et al, 2008). The study involved the users estimating their blood sugar levels at particular times during the day and completing an online questionnaire regarding what activities that they should perform based on these estimates. The users then tested their blood sugar readings using personal blood sugar measuring kits. There was a disparity shown between what the diabetics thought their blood sugar levels were at particular times and the actual reality. The study showed that an educational process would, over time, increase the ability of diabetics to anticipate their blood sugar levels.

It should be noted that iDiabetesCare assumes that diabetics are actively measuring their blood sugar levels and not blindly estimating them. It is obvious that measuring the progress of the condition is based on accurate readings and iDiabetesCare will give a means to record that data efficiently and in an economic manner. It should be noted that Cox et al concluded that internet-based resources proved to be quite cost-effective in delivering help to large numbers of users.

In 2010, a study was performed to measure if providing self-management education to adolescents via a secure web-site would have any benefits. Two groups were formed, a group to use the site in conjunction with traditional hospital care and a control group that received hospital care only (Mulvaney et al, 2010).

The site provided educational multimedia, user forums and expert question and answer sessions. An interesting point to note is that adolescents are typically embarrassed to reveal or discuss medical conditions and the anonymity of a website provided the a solution to this problem. The overall results of this six-month study were that the overall blood sugar readings for the participants improved, as well as their problem solving capabilities in regards to their diabetes. This reduced the need for professional medical intervention and the use of medical resources. While these results look promising, it has to be said that a more extensive study over a longer period of time would elicit more meaningful results. That being said, the social networking and informational aspects of the site would be a useful addition to any online resource targeted at diabetics.

Ayers and Kronenfeld performed a study of the use of the internet in information gathering by individuals suffering from chronic medical conditions (not limited to diabetics) (Ayers and Kronenfeld, 2007). Their findings showed that the use of the internet was primarily for gathering supplemental information regarding their conditions e.g. checking on the side-effects of prescription medications and not as a replacement for formal medical care. By patients becoming more informed about their health care, they could take a more active role in monitoring their conditions.

One thing this study did not address was the reliability and quality of medical data accessed by patients on the internet. The effects of misleading or incorrect information would be more harmful to an individual in the management of his/her condition than an absence of information in the first place. This highlights the need for patients to be assured that information that is presented to them has been vetted by a medical professional.

This point was highlighted by a 2003 study which found that while use of the internet by patients to research chronic conditions improved knowledge, decision making and reduced perceived isolation, patients were also bombarded with a large amount of information that they were not qualified to evaluate:

The Internet provides us with new ways to help people become active participants in their health. We must acknowledge, however, that those same people are faced with a quagmire of Internet health information, some correct, some incorrect. Practitioners must assist people in discerning correct from incorrect. (Bauerle Bass, 2003)

This author has highlighted the need for the emotional support of people living with diabetes. Previous reviews have shown that this is mainly lacking in a lot of online resources for diabetics. Zrebiec examined a custom-built message board system targeted at providing just such support to diabetics (Zrebiec, 2005). The ability to engage in discussions with people suffering from the same condition and to maintain the measure of distance (if wanted) provided by online social networking, was found to greatly improve the confidence and emotional robustness of participants. Surveys of users found that 76% reported the usage of the resource positively affected the management of their diabetes and provided a level of emotional support that could not be easily found elsewhere. This author believes that the use of Social Media in iDiabetesCare would be a positive feature for the patients. However, these boards must be professionally moderated, as misleading information regarding medical care can be harmful. Zrebiec's research backs this up.

It should be noted that technology does not always provide practical solutions to the challenges of diabetes, at least at current technology levels. In 2009, a study was performed to measure the effectiveness of a program of continuous glucose monitoring of Type 2 diabetics, to see if this would allow for targeted programs of diet, exercise and condition management (Allen et al, 2009). The subjects would wear an electronic Continuous Glucose Monitoring (CGM) device 24 hours a day. The device was connected to the patients via a subcutaneous connection and would record glucose readings. It is then downloaded periodically to a personal computer at a treatment clinic for analysis by dedicated software.

While the study found that the data recorded could provide insight into the diabetics regimen and provide a basis for producing individualized treatment plans, there were practical difficulties of comfort with the diabetics wearing the devices. Older patients also had trouble with entering data on the devices necessary for its operation i.e. exercise and food intake records. The study does note that some of these issues may be fixed by technological advances, however one glaring issue is that the recorded data is not available to the users and has to be physically transported to a diabetic clinic for storage and analysis. In iDiabetesCare, data from blood glucose testing devices can be downloaded to the site for immediate review by both the patient and the medical practitioner.

A primary function of iDiabetesCare is to give a user the ability to record, store and analyze his/her blood daily sugar readings. There is some precedence for this:

In 2004, Kwon et al performed a study based on a dedicated website that would allow for glucose monitoring of diabetic patients. Patients would send information about their self-monitored blood glucose levels before and after eating, and information about the types and dosages of insulin and oral anti-diabetic medication. Any detailed information the patient may have (for example, diet, exercise, hypoglycemic event, or other factors that can cause changes in the glucose level) were also recorded (H. S. Kwon et al, 2004). The results showed that patients using the system had a marked improvement in HbA1c levels over the three month trial period in comparison with the control group. The reasons for this included an increased contact with medical professionals and up-to-date feedback on their most recent blood sugar readings. It should be noted that while iDiabetesCare provides similar functionality, the system in Kwon's study did not have the social networking facilities that iDiabetesCare does.

Cho et al in 2006 performed a similar but longer study using an internet-based system of blood glucose monitoring called the 'Internet-based glucose monitoring system' (IBGMS), targeted at Type 2 diabetics (J.-H. Cho et al, 2006). All subjects were provided with an educational course in good diabetes management and then taught to use the online system. Like in Kwon's study, the patients recorded blood glucose readings, along with the details of food intake, exercise and other medications that they may be taking. Also, like in Kwon's study, patients showed a significant improvement in HbA1c levels over the course of the two years duration. The system in Cho's study also did not have the social networking facilities that this author's system will. Medical intervention took the form of bi-weekly emails from medical professionals to provide feedback to the diabetics. iDiabetesCare also provides a means for patients and their doctors to communicate. It should also be noted that the systems used in Kwon and Cho's studies are specific to the US and no such systems are available in Ireland.

Another study in 2008 focused on providing software that would advise Type 1 diabetics on insulin intake levels based on their daily blood sugar readings, food intake and exercise levels (Garg et al, 2008). This one year study also proved that such software based systems would reduce HbA1c levels and reduce diabetic hospitalizations. However, the basis of the study used PDAs preloaded with the software and pre-configured in a personalized fashion by trained medical professionals. The data on the PDAs had to be downloaded on the diabetic's visit to their treatment clinic. This means that the demand on the time of the medical professionals is not reduced and such a system of management would not scale any better than the traditional face-to-face contact between the patient and medical professional. iDiabetesCare uses the internet for uploading data and could eventually allow for tailored treatment plans to be delivered online.

As detailed earlier, the rise in obesity is a major factor in the increase in Type 2 diabetes in recent years. Added to that, weight control is an important factor in the successful treatment of Type 1 diabetes. McCoy et al performed a study of delivering an internet based weight loss program aimed at the prevention of Type 2 diabetes (McCoy et al, 2005). The online program was a 10 week, interactive service that enabled the participants to complete an online health risk appraisal and develop diets and exercise plans to suit their personal needs. Guidance was also provided on ways to successfully implement and maintain lifestyle and behavioural changes. While the majority of participants reported weight loss, it should be noted that such reporting is notoriously open to bias. Additionally, there was no direct involvement of medical professionals in the study and so no professional support was available. That being said, it is not difficult to see that there is merit in such programs. A weight management program is outside the scope of iDiabetesCare, but it could easily be added as part of future work.

2.6.2 Diabetes and the Internet

Over previous years, a number of attempts have been made by governmental, medical and charity organizations to establish websites aimed at diabetes management, with varying degrees of success.

In 2002, Mazzi and Kidd established a framework to measure the criteria that such sites should be measured against (Mazzi & Kidd, 2002). As this is a complete and measured approach, it is the intent of iDiabetesCare to adhere to these criteria. They are as follows:

Monitoring - diabetics should be able to input data into the system with the minimum of effort. There should be an option for healthcare professionals to set targets for the patients. The system should strike a balance between gathering relevant data and not reaching data overload.

Information - The system should provide a resource of meaningful information for diabetics that is professionally vetted.

Communication - the system should allow for communication between the diabetic and his/her healthcare professional. This can take the form the form of synchronous communication e.g. IM or asynchronous communication e.g. email.

Technology - The technology used must store data securely, must provide an authentication mechanism and if possible, use open data standards to allow for the delivery of services across multiple platforms; browser, smart phone, tablet etc. It must also be reliable, scalable and have the maximum possible uptime.

In 2004, Roudsari et al proposed a diabetes management system 'Diabnet' that would integrate blood sugar records storage, clinical advice and even appointment scheduling into a handheld device. device. It also provided personalization features (Roudsari et al, 2004). While positive in their conclusions, they did admit that the technology available at the time i.e. the low level of broadband penetration and the question of reliable uptime for hosted sites presented a challenge. This author believes that the advances in broadband and the emergence of cloud based computing models should solve these issues. It should also be noted that DiabNet was using a custom device that had to be supplied to each patient. iDiabetesCare does not require custom hardware.

Like Garg et al, a 2005 study proposed a PDA based system to manage blood glucose records, diet and exercise. It gave diabetics quantitative health indices based on factors such as BMI (K. S. Park et al, 2005). This author believes that a PDA based system is too restrictive for patients as the software is tied to a particular range of device platforms. Ignoring the fact that PDAs have been superseded by smart phones, a web based solution would give the maximum platform availability. It also allows for software updates without the need to push them out to user devices.

MediNet is a mobile healthcare system designed to personalize the self-care process for patients with both diabetes and cardiovascular disease (Mohan et al, 2008). A logical choice, as both conditions are interrelated. The patient wears blood glucose and pressure sensors are worn by the patient and this data is transmitted to the patient's mobile phone using a Bluetooth connection. From there, it is uploaded to the web site where a reasoning engine will analyze the data and will advise the patient of a course of action via text message. In emergency circumstances, it will alert medical professionals. While this is an interesting application of mobile technology, this author believes that expecting patients to wear monitors on their person is an intrusion and inconvenience that would not be acceptable to many. A more acceptable course of action is to allow patients to manually enter data on a site or to upload from an electronic blood sugar measurement device, as these are widely used by diabetics as a matter of course.

A similar study by Zou et al used a Bluetooth connection to upload data from a an electronic blood sugar measurement device to a website via a mobile phone (Zou et al, 2006). This data is then available for analysis by medical professionals. While this is a different implementation to iDiabetesCare, it does show that current mobile networks are feasible for the reliable delivery of medical data to a dedicated website. While this is a feature that is out of scope of the proposed implementation, it is a feature that could form part of future work.

A 2009 evaluation of 'Diabetesnet', a site for the online management of diabetes care reached some interesting conclusions (Nijland et al, 2009). It found that prompt feedback from health care professionals and the usability of the site were major factors in the willingness of the patients to engage with it. IDiabetesCare takes these factors into account.

A 2010 study analyzed the effects of the use of a internet based program to manage and advise on diabetes in the over 60 age-group (Bond et al, 2010). The most significant finding was that depression and anxiety for diabetics in the over 60s age-group was particularly acute. This can be partially explained as people who develop the condition later in life will have the hardest time adjusting to the regimen. It highlighted the fact that the communication and networking aspect of such a site is a boon to patient self-confidence. It should be noted that the test pool of subjects as limited in terms of socio-economic group however is adds to the evidence that an internet-based solution for diabetes management can be a positive force.

2.7 The suitability of the Internet

We have discussed much in the area of online diabetes care however, there is a question over how suitable is the internet as a means of delivering this service to a wide base of patients. The use of technology and its availability is not uniform across all socio-economic groups and we must avoid excluding some of these groups by concentrating on an internet-based solution. How great a challenge is this?

A US based study by Watson et al found that frequent internet users tended to be in a younger age-group and tended towards a higher level of education that non-internet users (Watson et al, 2008). Does this indicate that older diabetics would be averse to using an internet based solution to help manage their condition? The evidence does entirely support this, as all the subjects in the study did not have an aversion to technology per se. 85% used electronic blood-sugar measuring kits as part of their daily regimen. A high proportion of all the surveyed users were also keen on the idea of technology that would allow for personalized goals and medical feedback. Similarly ,all users showed an aversion to the idea of replacing doctor visits with an online equivalent, showing that an online system must act as an adjunct to existing services only.

As discussed previously, a typical behaviour of patients with chronic illnesses is to search for health related information online, however this is less likely amongst individuals with a lower level of education and income or who are older (Jensen et al, 2010). However, an older study shows that amongst diabetics, even those who are less likely to use the internet would be willing to do so to manage their condition if barriers to entrance were addressed i.e. technological education and usability of sites (Fell et al, 2000).

This author does not believe that internet usage is a major impediment to the usefulness of iDiabetesCare. It is true that individuals with lower literacy skills are less likely to use the Internet to gain health information, it has been estimated to be as low as 20% (Jensen et al, 2010) (Schillinger. et al, 2006). However, iDiabetesCare could eventually delivered in an App format in a future incarnation and could be used on a smart phone in its current. With the ubiquitous nature of internet enabled phones, the service would be widely available to all.

In an Irish context, there is currently a drive on to educate older users in the use of the internet (Age Action, 2011). Action is being taken by the Irish government to up-skill those who have been left behind by the advances in internet technology (Silicon Republic, 2011). As stated previously, there is a large rise of Type 2 diabetes in the 20 to 30 age-group and this is one that is particularly comfortable with the use of internet technology. It is also of significance that iDiabetesCare is not intended to replace traditional forms of care but to complement them. Diabetes services will always be available to those who resist internet technology. Bearing all that in mind, the focus of this study is on Type 2 diabetics in the 20-40 age group, as this is a group that is growing the most and which is most likely to be technology literate.

2.8 Technology Choice

IDiabetesCare is a web based application that will allow diabetics to record data, engage in social networking and have contact with medical professionals. As shown earlier, such a system will need to have a very high level of uptime and will also need to be cost-effective. For this reason, a cloud computing model has been chosen.

So what is cloud computing? Cloud computing describes both a platform and a type of application. A cloud computing platform could can provision, configure, reconfigure, and de-provisions servers as needed. Servers in the cloud can be physical machines but are typically virtual machines. Clouds will typically include other computing resources such as storage area networks (SANs), network equipment and firewalls. Cloud computing also denotes applications that are extended to be accessible through the Internet. Such cloud applications will also use large data centres that host Web applications and Web services. An Internet connection and a browser is all that is needed to access a cloud application (Boss G et al, 2007), (Rajan & Jairath, 2011).

With iDiabetesCare, the clinics and hospitals that will be using the system will not have to buy the hardware to host the site and will not have to maintain it. Instead, they will lease the application and will only be changed according to usage. This ensures that the medical organizations will get the maximum return on their investment (Wang & Tan, 2010). Jaeke and Luhn also back this up:

A key aspect in cloud computing is that customers do not buy the software application, platform and underlying infrastructure. Instead, they can lease the cloud computing services temporarily and then return them. The costs incurred in purchasing IT services shift from capital-intensive outlays to money-saving variable costs.(Jaeke et Luhn, 2009)

The system will be designed as a Software as a Service (SaaS) application but will be built using a Platform as a Service (PaaS) platform. This is because it is a particular application aimed at a particular domain. The multi-tenancy nature of a SaaS system would seem ideal for an application that will have multiple implementations, that may not always be able to share data e.g. when used by medical establishments in different countries. The SaaS model can support self-contained databases (Hong, 2010). In the proposed implementation, this would take the form of partitioned Azure table storage.

An underlying Infrastructure as a Model framework is also needed to provide scalability and resilience. The Microsoft Azure offering has been chosen as the platform upon which to build this application. This is because it both offers IaaS and PaaS capabilities and that will suffice as to providing a means to develop a SaaS application (Bojanova & Samba, 2011). Unlike implementations such as the Google AppEngine, it provides an unmodified version of the .Net framework and associated software that make it easier to find resources with skills to develop and maintain the application (Bojanova & Samba, 2011).

Another consideration is that Azure does not provide the same level of vendor lock-in that vendors such as AppEngine does with its customized Python and Java runtimes. This is one reason that Cloud applications can sometimes be un-palatable to organisations (Hofmann & Woods, 2010). It is notable that it is now possible to deploy Azure applications to platforms other then the native Microsoft one. AppHarbor are now providing an Azure hosting service (AppHarbor, 2011). Unlike offerings such as Google AppEngine, Azure supports vertical as well as horizontal scaling. Amazon EC2 also offers this capability but with the overhead of having to install and configure runtime environments and other required software (L. Zhao et al, 2010).

As well as cost, another important aspect is reliability and uptime. Cloud computing allows for the elastic provision of computing resources within short periods of time, so the analysis of large amounts of patient data can be managed. A cloud platform has built in redundancy and an application can stay running even when it suffers multiple node failure (Shufen Zhang et al, 2010). Of course, the software itself will need to be designed to handle node failure in a graceful manner.

One concern that people consistently have with cloud computing is the perceived or real lack of security. This will be discussed in detail in the Architecture section.

3 Research Background

3.1 Hypothesis/Research Question and Objectives

3.1.1 The Problem Area

As mentioned previously, poorly managed diabetes can lead to long-term health complications, such as blindness, poor circulation and nerve damage that leads to limb amputation and heart-disease. Regular monitoring of the diabetic's condition by health-care professionals is of vital importance. In a typical scenario, the diabetic will meet with a HSP every two to six months. The HSP will then review the log of the diabetics daily blood sugar readings and advise as to what changes are required to the management regime.

There are a number of problems with this scenario:

- It can be difficult for the diabetic to submit to the discipline of the regular recording of blood-glucose readings, as well as diet and the regular application of insulin. This is especially the case when an individual develops diabetes as an adult and must make significant changes to his or her 'established' lifestyle.
- The frequency of visits to health-care professionals are measured in months but poor management of diabetes has a cumulative and ongoing detrimental effect on the diabetic's health. In other words, if a diabetic has to wait six months before getting advice as to how to improve their diabetes management, that is six months of damage done to the individual's health.
- The costs in both time and money of providing these face-to-face medical services to an increasing population of diabetics is high and in Ireland, as in many countries, poor economic conditions and budget cuts makes this increasingly challenging. An unfortunate side-effect of this is that the pressure on services will increase the likelihood of diabetics developing long-term health complications, the costs of which will impact the health service for many years.

3.1.2 User Survey

While there are a number of issues as presented above, it was considered necessary to survey the targeted user-base to find out who they are and what they would find most useful from a solution.

To that end, an online questionnaire was created using the 'surveygizmo' site (http://www.surveygizmo.com/). The survey (available in the appendices) consisted of a series of questions in a dichotomous and Likert response format. The survey gathered data in three main areas:

- Details about the individual.
- Details about how the individual manages his or her diabetes.

- A series of proposed features for the technical solution and how useful the individual would consider them.

The survey was made available online for a period of six weeks and invitations to participate were posted on various diabetic notice boards and newsgroups. This author also availed of contacts within the Diabetes clinic at St James Hospital, Dublin to invite willing patients to participate in the survey.

A total of 41 responses were received, with 5 being discounted due to the responses being incomplete.

The data gathered was used as a basis to design personas (in the appendices) and served as a means to decide on functionality for the solution.

As this questionnaire was dealing with private medical information, it was designed to be completely anonymous.

The following was the most notable data gleaned from the survey:

- 78% of those surveyed were in the 21-40 age group.
- While the average time that the participants have had diabetes was 14.9 years, 65% have type 2 diabetes and 41% have it for ten years or less. This is in line with the previously documented research that shows that Type 2 diabetes is on the increase amongst younger people.
- As many as 41.7% of respondents would rate their diabetic control as average at best.
- 75% test their blood-sugar 4 or more times per day and 83.3% use a written diary to record their readings. 50% use the electronic meter, implying that many use both means.
- The average number of visits to see medical professionals was only 2.6 times per annum, with 50% making such visit 3 or more times per year.
- 66.7% or participants would make adjustments to their regimen based on medical advice solely or on a mixture of medical advice and their own judgment. This would imply that while patients are not seeing their health care professionals as often as they may need to, or can, there is a need to be able to keep in close contact.

If there is a need for an application that can allow for diabetics to share data with their medical professionals, would the internet be a feasible medium? The data gathered indicate that it would.

- 66.7% use the internet between 3-6 hours per day.
- 91.7% will use a PC to access the internet (either as their sole means or as one of many).
- 75% will use the internet to seek information on diabetes, with 83.7% considering the internet as a reliable source of information (with caveats).
- 83.7% take part in social networking online, with all using Facebook and 20% using other sites such as Twitter, LinkedIn etc. 75% use diabetic online networking sites.
- 91.7% would welcome a new site that helps them manage their diabetes.

This all implies that the target audience is internet savvy and is comfortable with technology, as can be expected from the younger demographic. They also are predisposed to use social networking to help them in dealing with their condition.

It should be born in mind that the fact that the survey was available online and was disseminated via diabetic sites predisposes the results to indicate a technology literate audience. For the purposes of this research, it was decided to target the younger demographic as these are seeing the highest growth in Type 2 diabetes and to avoid the research area becoming too broad to be manageable.

In proposing a new site for diabetes management, the survey group were asked to elaborate on what it should contain. Typical answers were as follows:

- ' The meter could automatically upload all the info from a meter and pump to the cloud '
- ' I Would like more interaction between HCP and patients in a discussion forum. Find the Diabetes in Ireland discussions good but feel some HCP input would be good too- even for them to be made aware of patient's issues and knowledge as much as anything!'
- ' All new information on developments or research would be useful.'

In addition to this, the group were surveyed as to specific features and the responses were as follows:

- 75% agree or strongly agree that the site should allow the user to upload blood sugar data.
- 75% agree or strongly agree that the site should allow the user to enter food intake.
- 75% agree or strongly agree that the site should allow the user to enter exercise details.
- 75% agree or strongly agree that the site should allow the user to enter insulin intake.
- 75% agree or strongly agree that the site should allow the health care professional to view the recorded data.
- 83% agree or strongly agree that the site should allow the user to communicate with their health care professional.
- 50% agree that the site should suggest ways that the user can improve his or her regimen based on previously recorded data, however 8.3 % are against it and 41.7% are indifferent. This would suggest that there is some mistrust of an automated system giving medical advice and would jibe with the finding that 83.3% of those surveyed rely on their own judgment, either partially or completely, when making decisions regarding their regimen.
- 66.6% agree or strongly agree that the site should send out tips to improve diabetes management via media such as SMS or email.
- 75% agree or strongly agree that the site should allow the user to socially network with other diabetics.

3.1.3 Case studies and precedence

The question arises as to what work has already been done in the area of chronic illness management via the internet and especially in the area of diabetes. There is precedence and this is in addition to the other work detailed in the Literature Review.

3.1.3.1 C-Monitor

The C-Monitor system is a system developed collaboratively by several European research and medical establishments. The system is designed for a variety of chronic disease and management procedures. It provides a personalized service for patients, and serves as a communication channel between doctors and patients. It also uses a monitor (worn by the patient) to record the medical data, and an alarm system for critical situations. The system is aimed at older patients suffering from a variety of chronic illnesses, including diabetes, asthma, arthritis, heart failure, and cancer.

Wang et al analysed the system and concluded that most of the participating patients agreed that C-Monitor system provided a more valuable service than the traditional 'ambulatory' system. It was discovered that patients preferred the idea of receiving health care at home and would like to see this kind of service rolled out more extensively, so that they could avoid continuous trips to hospitals and thus improve their quality of life. (Wang et al, 2005)

IDiabetesCare provides some similar functionality but is intended more as an adjunct to traditional care rather than a replacement. It also does not require the patient to wear any form of medical monitor.

3.1.3.2 Case-Based Reasoning

Zhang et al designed a web-based system that uses Case Based Reasoning to advise of the best actions to take in when faced with numerous scenarios presented in diabetes management. They found that while the system provided valuable data to the medical personnel, it did require a level of interaction that was not always forthcoming from patients. It also recognised that the use of medical sensors with patients is cumbersome and cannot be relied upon in all scenarios. As they say '*Monitoring for diabetics must detect hypoglycaemia, but some patient's conditions, such as shakiness, dizziness and sweating, cannot be detected by sensors and the condition must be acquired from responses from the patient.*' (Yupeng Zhang et al, 2009). With iDiabetesCare, patient interaction and system use is a pre-requisite, as a chronic condition such as diabetes can only be successfully managed with a full buy-in from the diabetic

Zhang et al also recognised that the large amounts of data gathered from patients, such as diabetics, requires a level of processing that traditional IT systems cannot provide. In the proposed system, the use of the cloud allows for the potential of large-scale processing allocated in an elastic fashion.

3.1.3.3 Haemophilia

Another research program aimed at haemophiliacs allows real-time communication between haemophilia patients and their health-care professionals. To the users it makes available information on the effectiveness of various treatments, patient clinical data, and other disease-related information. The solution also offers Medical professionals analytical tools to transform data into information and to export data to known formats such as EXCEL, PDF or XML. (Teixeira et al. 2010)

iDiabetesCare allows the patients to view analyses of their data but will not extend to medical diagnostic solutions for medical personnel. However, the application structure allows for that to be added at a later stage.

3.1.3.4 Internet-based Glucose Monitoring System

As mentioned previously, Cho et al implemented a system whereby diabetic patients used a specially designed mobile phone to upload blood glucose readings to a dedicated website for analysis. The site was subsequently monitored by health-care professionals and recommendations to improve the patient's regimen were sent out via SMS. (Jae-Hyoung Cho et al, 2010)

Three important aspects were displayed by this work:

- After three months, HbA1c levels were lowered for the vast majority of patients participating in the survey.
- Close communication between health care providers and the patients with diabetes needs to be lifelong and consistent in order to provide any benefit.
- An integration of technologies must be used in implementing any such system.

This underlines the benefits of using a web-based system for diabetes management and would suggest that the use of existing technologies in a composite or 'mash-up' fashion would make a viable alternative to developing all such technologies from scratch.

3.1.4 Research Focus

The focus of this research is to examine this question:

'Can an effective diabetes management system for type 2 diabetics be produced using a 'mash-up' of existing technologies and services?'.

3.2 Area of Proposed Contribution

The previous literature review and secondary research highlighted a number of systems developed to aid with diabetes management. What is striking about these is that they are bespoke systems, using little, if any pre-existing technologies or software frameworks. Such systems are costly to produce and are often difficult to maintain.

The importance of good diabetes management has already been discussed in detail, as has been the rise in the number of Type 2 diabetics and the associated costs. There is a need for a system that will enable this management, while simultaneously having low development and maintenance costs, so that it can be economic for use by an over-stretched health service.

3.2.1 iDiabetesCare - The Proposed Solution

Based on the research, there is a need for a solution that provides the following:

- A means for diabetic patients to record their blood-sugar readings, food intake, exercise and insulin with as little difficulty as possible.
- A means for medical specialist to be able to review these readings in a timely and cost-effective fashion, so as to allow for medical intervention and advice.
- A means to analyze these readings using an intelligent system or rules engine, so as to provide advice to patients. It should be noted that this was not as popular an idea with those surveyed but it would be advisable to have an interface in the application which can plug into such a system. This would allow for future expansion in this area as the technology evolves.
- A means to socially network with other diabetics.
- The system must be scalable, secure and accessible from anywhere.
- The system should allow for real-time communication between patient and doctor.

What the solution will not provide

- Unfortunately, it was not possible to get a commitment from medical professionals in the implementation and testing of the solution. Therefore, while the system provides a means for the medical professional to access data uploaded by the patient, no medical professional took part in the testing. The users were aware of this during testing.
- No commercial intelligent system was available to integrate with the application and a suitable open-source rules engine could not be found. Therefore, an interface with some mock rules was implemented, but the application is structured in such a fashion as to leave room for integrating a rules engine in the future.

The focus of the research was not usability, and while some usability concepts were implemented, it was not a primary focus of the application.

4 Architecture and Implementation

4.1 Requirements Identification

Based on the previous research, it was decided that the typical users and stakeholders in the system would be the following:

- Type 2 Diabetic patients in the 20-40 age group
- Medical professionals

As discussed previously, permission was sought to interview the potential users of the system, both diabetic patients and medical professionals. Unfortunately, due to reasons of confidentiality, direct contact with patients was not permitted and medical professionals were unwilling to participate directly in the project. Therefore, it was not possible to hold stakeholder interviews to identify all required functionality. Neither was it possible to hold Joint Requirements Development (JRD) sessions (JRD sessions allow for agreement amongst stakeholders and for identification of areas of functionality that have been missed in individual interviews).

It was therefore decided to use the data gathered during the user survey process and the background research to decide on the primary functionality of the system. As the project was relatively small in scope, the more traditional process of defining contract-style requirements lists was abandoned as it is time-consuming and leads to unfeasibly large volumes of documentation. Similarly, as it was not possible to review screen designs with a stakeholder group, there was no point in creating wireframes.

The output of the research is documented as follows:

- A set of personas that illustrate the target users and clarify to the developer who will be using the system. These are documented in the appendices.
- A set of Use Cases that act as contracts for the agreed system functionality. These are also documented in the appendices.

4.2 Development Methodology

It was decided to use an Agile development strategy with this project.

Agile software development is a group of software development methodologies based on iterative and incremental development, where requirements and solutions evolve through collaboration between self-organizing, cross-functional teams. Agile methods break tasks into small increments with minimal planning, and do not directly involve long-term planning. Iterations are short time frames that typically last from two to four weeks.

Each iteration involves a team working through a full software development cycle including planning, requirements analysis, design, coding, unit testing, and acceptance testing when a working product is shown to stakeholders. This intends to minimize risk and allows the project to quickly adapt to changes. An iteration may not add enough functionality to warrant a full release, but the goal is to have an available release (with minimal bugs) at the end of each iteration. Multiple iterations may be required to release a product or additional features.

As there was only one developer on this project and no team, the usual process of having Scrum meetings with a Scrum manager was not applicable. Additionally, due to time pressures and the lack of a stakeholder group, the project did not go beyond one iteration and initial designs were not reviewed with a stakeholder group. Instead, once the iteration was complete, the shippable code proceeded directly to user testing.

4.3 Application Design

- The system was developed as a cloud-based system, as this will provide flexibility, elastic scaling and reliability. It also reduce the need for on-premises hardware. NB the need for on-premises hardware is not eliminated, as personally identifiable information is intended to be stored in a database that is itself not in the cloud.
- Microsoft's Azure platform was used as the hosting platform, as this provides the (currently) most complete environment for a Platform-as-a-Service (PaaS) architecture.
- The system was developed as a web application using the Microsoft ASP.Net MVC 3 technology in C#, as this allowed for a fully object-orientated and RESTful web architecture. The Model-View-Controller design of MVC allows for testable code and a cleaner separation of concerns between the different facets of the application.
- The code structure is loosely coupled and the use of the ADO.Net Azure data-access libraries allowed for the fast creation of a reliable data-access software layer.
- A Rich Internet Application (RIA) design was used, using JQuery as the basis for a rich UI.

4.3.1 Reasons for using the Cloud

The decision was made to host the application in the cloud because it provides a level of reliability that cannot be got with more traditional technologies, without prohibitive cost. It also allows the application to easily scale out as needed. For example, for the initial testing period, one web role server, along with one (more powerful) SQL Azure server was sufficient. As more diabetics and hospitals are added to the system, this can be scaled out quite easily.

In deciding on a platform to use between Azure, EC2 and AppEngine, the following comparison was considered.

Table 1:Cloud Platform Comparison

Feature	App Engine	EC2	Azure
Vendor Lock-in	Very much so. You are tied to Google's APIs and can use only Python or Java. Moving to another platform requires significant re-development.	Not really. EC2 basically gives you a Vanilla server hosting either Windows or Linux. Any application can be built in any language, just as if it was a traditional on-site application.	Somewhat. Code is developed in .Net and will use Azure features but support for other languages and features like Python and node.js are available
Pricing	Free for applications up to certain (restrictive) limits.	Not free but does now offer 'micro-instances'. These are single, low-powered servers that are available to new EC2 users for up to one year.	Not free. Microsoft does offer certain 'offers' of free basic usage periodically to promote Azure and MSDN subscribers can also get offers. A MSDN Universal subscription was used in testing the application
Scaling	Relatively easy, as most of the work is handled by the platform.	Harder, as the developer must design this into the application.	Relatively easy, as Azure will scale as needed with minimum administrator intervention.
Data storage	Non-relational data store which can have high failure rates.	SimpleDB and S3 offerings but can also host a vendor relational database if needed	Azure Local Storage for temporary storage. Windows Azure Storage for persistent data and SQL Azure for a relational structure that can be backed up locally. Storage is highly reliable.

Services	SimpleDB, S3 Cloudfront, SQS	Users, MemCache, BlobStore, Task Queues, URL Fetch	Azure, a scalable, 'cloud based' Operating System, SQL Azure, AppFabric.

Windows Azure was ultimately chosen for iDiabetesCare, for the following reasons:

- It provides the most comprehensive cloud-enabled platform on the market. EC2 provides an Infrastructure-as-a-Service model which is not optimized for Microsoft applications. AppEngine has not been proven yet as a platform (hence the lack of any substantial applications running on it). It has a restricted programming model that does not easily allow for such features as communicating with an on-premises database. It is also harder to find technical resources skilled in its usage.
- Microsoft .Net skills are readily available, making it easier to find developer/technical resources. As the .Net platform is long established, this situation should continue into the future. This would be a consideration for a commercial implementation of the application.
- The use of Table storage allows for a relatively cheap form of scalable data storage.
- The use of SQL Azure (in the prototype) allows for the database to be easily migrated to an on-premises database in a commercial version of the application.
- Microsoft are readily pushing Azure and are willing to provide continuous help to anyone developing on the platform. There is also a wide community off online technical resources available.

4.3.2 Azure and Data Privacy

iDiabetesCare stores medical records and it is advisable to store such privileged data within national borders. In order to meet Irish data protection legislation, the production application would be owned by a registered company and that would be registered with the Data Protection Commissioner as a holder of private medical data. Additionally, as part of registration, users would need to accept a declaration that they consent for their data to be stored by the site. A clear explanation of what will be stored will be given. (Data Protection Rules, 2011)

Microsoft Azure allows the option to ensure stored data is kept within a data centre in a specific region. As Microsoft's Western European Azure data centre is actually located in Dublin, this will ensure that the records of Irish diabetics do not leave the Irish national borders.

Concerns have been raised over the privacy of data stored in Microsoft data centres in light of the US Patriot Act.(Finn, 2010) Personally identifiable data is stored off the cloud in an on-premises SQL Server database. Only non-identifiable data is stored in the Azure table storage. During registration, each new user is assigned a Globally Unique Identifier as a User identifier. This is used to link a user in the on-premises user database with their record in the Azure table storage.

The HSE would be the targeted customer for iDiabetesCare. If it is decided in future by the HSE that storing any medical data in the cloud is unacceptable, the use of the Azure Platform Appliance technology would allow the option for a private, local cloud to be hosted in a private data centre. In that case, the HSE would have to source and run the data centre locally.

4.3.3 Azure Financial Costs

One of the benefits of the cloud model is that you only pay for the resources that you consume. As the author had access to a Microsoft Developer Network Universal licence, there were no costs for using Azure in a limited, prototype scenario.

An initial production implementation of the application for one hospital is estimated at having running costs of only €248.49 per month.(Microsoft, 2011) This is based on the following assumptions:

- There is one web role server of a medium compute size (2 x 1.6GHz CPU, 3.5GB RAM, 490GB Storage).
- The table storage used is a maximum of 500 GB, with no more than 1 million storage transactions per month (it would be less in reality).
- The cache size used is no more than 512 MB concurrently per month.
- The SQL database storing personally identifiable data is held on premises by the hospital or the HSE. Its implementation and running costs are handled under their regular IT budgeting.

4.4 Rich Internet Architecture

iDiabetesCare can be described as a Rich Internet Application i.e. it has a Rich Internet Architecture. This is a Web application that has many of the characteristics of desktop applications, typically delivered either by way of a site-specific browser, via a browser plug-in, independent sandboxes, or virtual machines. A RIA can also be delivered using open-source JavaScript frameworks and Asynchronous JavaScript and XML (AJAX) e.g. JQuery and ExtJS.

Adobe Flash, Java, and Microsoft Silverlight are currently the three most common platforms for 'thick-client' RIAs, with penetration rates of 95.51%, 76.35%, and 66.26% respectively (StatOwl, December 2011). Users generally need to install a software framework using the computer's operating system before launching the application, which typically downloads, updates, verifies and executes the RIA. e.g. Silverlight requires the Silverlight runtime to be installed on the client PC. This is a lightweight, sandboxed version of the .Net Framework. (Brown, 2010)

This is the main differentiator from JavaScript-based alternatives like JQuery and AJAX that use built-in browser functionality to implement comparable interfaces. Such 'thin-client' alternatives use JavaScript to manipulate HTML elements and styling to deliver a richer interface to users.

AJAX is used to provide asynchronous data access and allows for partial page updates. This is all a means to overcome the short-comings of traditional web-based applications, such as full client/server roundtrips and full page refreshes.

One of the main differentiators between a RIA and a traditional web application are the concepts of 'reach' and 'responsiveness'. Traditional web applications, using HTML are supported on virtually all platforms and all browsers. They have a wide reach. They involve server roundtrips and so the responsiveness to user input is diminished. RIAs on the other hand, reproduce the responsiveness of desktop applications e.g. Silverlight runs as executable code on the client PC and so is very responsive to user input but it is more limited in its reach. As of version 4, it only runs on the Windows platform and is only supported in the Internet Explorer, Chrome, Firefox and Safari browsers (in various configurations) (Microsoft, 2010).

4.5 RIA Technology Choice

In order to support the widest range of client platforms while still maximising responsiveness , the decision was made to implement the RIA architecture using JQuery, standard HTML (version 4.0) and AJAX. Silverlight, Flash and Java were discounted as they have a limited availability across platforms or require a client side software install. For example, Flash may have a 95.51% penetration rate but in unavailable on the Apple iOS platform. It was therefore not used as a core technology for the site but is used for generating graphs. Similarly, HTML 5 has not been ratified, is at best an emerging standard and is not yet widely supported.

The use of AJAX and partial page updates allows for an experience reminiscent of a desktop application, while the basic technologies of HTML and JavaScript are supported across all platforms and browsers.

JavaScript Object Notation (JSON) data encoding is used when sending data between the client and server, as it has a smaller payload than XML and so improves performance. It also complementary to the JavaScript client code and by its nature is a better fit with standard programming languages than XML, due to its use of arrays, structures and typed data.

4.6 Technologies Used

4.6.1 JQuery

JQuery was used to drive all the client-side JavaScript. It is a cross-browser JavaScript library designed to simplify the client-side scripting of HTML.

jQuery is free, open source software. jQuery's syntax is designed to make it easier to navigate a document, select DOM elements, create animations, handle events, and develop AJAX applications. jQuery also provides capabilities for developers to create plug-ins on top of the JavaScript library. Using these facilities, developers are able to create abstractions for low-level interaction and animation, advanced effects and high-level, theme-able widgets. This contributes to the creation of powerful and dynamic web pages.

The cross-browser nature of JQuery, along with the reusable nature of the functions it exposes made it an ideal choice to provide client-side functionality, without the need to reinvent the wheel using hand-coded JavaScript. It is also natively supported by Microsoft's ASP.Net MVC.

It should be noted that all the JavaScript in iDiabetesCare is placed in separate files that will be cached by the client browser. No in-line script is used. The script references are placed at the foot of the pages. This allow the pages to render faster in the browser while the 'blocking' behaviour occurs as the browser downloads any un-cached script files

4.6.2 JQGrid

JQGrid is an Ajax-enabled JavaScript control that provides solutions for representing and manipulating tabular data on the web. It was used for the registrations and user records grids. Since the grid is a client-side solution, loading data dynamically through AJAX call-backs, it can be integrated with any server-side technology, including PHP, ASP.Net, and Perl. JQGrid uses a JQuery Java Script Library and is written as plug-in for that package. This plug-in was chosen, as it offers a breadth of proven, client-side functionality without the need to write a lot of code.

4.6.3 JQuery UI

JQuery UI is the plug-in used to generate all the dialog windows on the site.

It is a fully featured plug-in that allows developers to easily generate multi-browser dialogs that have a wide variety of complex behaviours, such as being resizable and drag-and-drop. to quote the Jquery ui site '*jQuery UI provides a comprehensive set of core interaction plug-ins, UI widgets and visual effects that use a jQuery-style, event-driven architecture and a focus on web standards, accessibility, flexible styling, and user-friendly design. All plug-ins are tested for compatibility in IE 6.0+, Firefox 3+, Safari 3.1+, Opera 9.6+, and Google Chrome*' (JQuery UI Demos, 2010).

A proven plug-in was viewed as a preferable way to provide rich UI functionality, without the need to create a huge amount of new code.

4.6.4 XML/SWF Charts

XML/SWF Charts is a freeware tool that allows for the client-side generation of Flash-based graphs using data represented as XML. It is used to generate graphs of blood-sugar data on the main user screen on demand.

XML/SWF Charts requires a XML file on the web server to be created and used as a source for the client-side script that generates the graph. When the user selects the option of generating a graph, the data is retrieved from the server as XML via an AJAX call and is saved on the server under the unique user Identifier, to prevent file clashes between users. The file is then used as a source with which to generate a graph in a JQuery UI dialog.

4.6.5 Rules Engine

The rules engine is implemented as a stub with code to simulate the logic of an intelligent system. For demonstration purposes, it includes hard-coded logic to return a message indicating the user should adjust their insulin levels, if an average of their previous readings falls outside of the range 4-7 mmol/L.

The important point is that iDiabetesCare sees this an interface and will consume any pluggable, intelligent system wrapped by that interface. The interface signature is as follows:

```
public interface IRulesEngine
{
  IList<AnalysisResult> Analyse(Guid userId, int hospitalId, DateTime startDate, DateTime endDate);
}
```

4.6.6 Microsoft Azure

Much discussion of the Azure platform has been made but what exactly is it and how does it work?

The Microsoft Azure cloud computing platform is Microsoft's offering in the cloud-computing space.

The Azure platform uses a bespoke operating system, called Windows Azure, to run its "fabric layer". This is a cluster hosted at the Microsoft data-centres that manages the computing and storage resources of the computers and provisions the resources (or a subset of them) to applications running on top of Windows Azure. The underlying virtualized servers use Windows Server 2008 and a customized version of Hyper-V (known as the Windows Azure Hypervisor) to provide the virtualization of services.

The Azure platform contains five services: Live Services, SQL Azure, AppFabric, SharePoint Services and Dynamics CRM Services. Developers can use these services to build applications that will run in the cloud. A managed code client library and associated tools are also provided for developing cloud applications in Visual Studio. Scaling and reliability are controlled by the Windows Azure Fabric Controller, so that the services and environment do not crash if one of the servers crashes within the data-centre. It also provides the management of the user's web application in areas such as memory resources and load balancing.

The Azure Services Platform runs .NET Framework applications compiled for the CLR. Applications can be developed with the ASP.NET and ASP.Net MVC application frameworks. It also supports PHP websites. Two additional SDKs have been made available for interoperability with the Azure Services Platform: The Java SDK for AppFabric and the Ruby SDK for AppFabric.

In Azure, a hosted application or service runs within a defined role. The following roles are provided by Azure:

- **Web Role** -This role can accept incoming HTTP requests and can support web applications hosted in the Internet Information Services (IIS) web server. The application is hosted within a web role.
- **Worker Role** - This role is similar to, but not quite the same as a web role. A worker role instance is not hosted in IIS. They are executable in their own right and are typically used to host background processes. The application does not use worker roles.
- **VM Role** - This role differs from a web role and a worker role in that the focus is on running an application within an operating system that is managed by Windows Azure. In a VM role, the developer provides a preconfigured operating system image. The application does not use VM roles.

As all roles instances are held on virtual machines, new instances can be spun up and added on demand, ensuring an elastic response to resourcing. Any application hosted on Azure needs to take account of the fact that it may be run on multiple, disconnected instances and this must be reflected in the application design. In the application, the use of a RIA design ensures that application state is managed on the client and is therefore unaffected by the fact that it may be run on multiple servers. This ensures that any web role instance can serve a client request.

Azure provides the following means of data storage in the cloud. All are accessible via a RESTful API.

Table Storage Service

This is a non-structured form of data storage that store data as collections of entities. Entities are analogous to rows. Entities have a primary key and a set of properties. A property is a name, typed-value pair, similar to a column. In the application, table storage is used to store all patient record data (blood-sugars, exercise, food and insulin).

Tables are partitioned to support load balancing across storage nodes. All of a table's entities are organized by partition and a partition is a consecutive range of entities possessing the same partition key value. In the application, all data uses the hospital Id to keep data for patients in a particular hospital in the same partition. This helps maximise query efficiency ,while still allowing the data to scale out. (Haridas et al, 2009)

A primary benefit of the Table service is that it does not enforce any schema for tables, so two entities in the same table may have different sets of properties and a table may contain any number of entities. In the application, the schema is enforced by the application itself and is invisible to the underlying table. This ensures that any future version of the application that is designed to support other chronic illnesses, can be accommodated within the same underlying tables.

Blob Storage Service

Blob Storage is used to store text and binary data as binary files. Blobs are stored within containers which provide a way to organize sets of blobs. There are two types of blobs:

Block blobs, which are optimized for streaming, and Page blobs, which are optimized for random read/write operations and which provide the ability to write to a range of bytes in a blob.

The application does not use blob storage.

Queue Service

The Queue Service is used for storing messages and provides a reliable messaging system between role instances.

The application does not use queue storage.

SQL Azure

SQL Azure uses a customised version of Microsoft SQL Server as a backend. It provides high availability by storing multiple copies of databases, elastic scale and rapid provisioning. It does expose a subset of the full SQL Server functionality and only a subset of the regular data types. There is also an XML-based format used for data transfer. T-SQL is used as the query language and Tabular Data Stream (TDS) as the protocol to access the service over the internet. Unlike the other forms of storage, it does not provide a REST-based API to access the service via HTTP.

A production version of the application would not use SQL Azure as a store for the relational data as this data is personally identifiable and it was believed that storing it in a Microsoft data-centre would not guarantee confidentiality. Instead, the intent is that this data would be stored in a SQL Server database under the control of, for example, the HSE. The application would then access this data via a secured web service. The larger data i.e. the patient records is stored using Table storage in a Microsoft data centre. This was considered acceptable as it contains no personally identifiable information.

For testing purposes, data was stored in SQL Azure as it was no feasible to set up a local SQL server database with a web service. As all personally identifiable user data was actually mocked up, this was considered to be acceptable.

4.7 Code Design

The application consists of the following code libraries:

Table 2: Code Libraries

Layer	Assembly Name	Purpose
Presentation	IDiabetesCare.WebRole	The actual website. It contains the following: All the static resources: • JavaScript • Images • Cascading style sheets. It also contains the following code artefacts: • Views and partial views to represent pages. • Controllers that direct The controller classes that control the flow of the application. • Repositories that allow the controllers to access the services provided by the middle layer. • The model classes that contain the view data that the views act upon.
	IDiabetesCare.Presentation.Domain	Contains the following code artefacts: • Interfaces that define the service contracts that are utilised by the application. • The factory classes that locate the services at runtime and provide them

		to the consumers.
Middle	IDiabetesCare.Implementation	Contains classes that define the following: • The Azure type and context classes that ADO.Net uses to access Azure Table Storage. • Data Access classes that are used by the web application to access data both in SQL Server and Azure. • Services used internally by the middle layer, such as security and data type mapping.
	IDiabetesCare.RulesEngine	Contains wrapper classes that provide access to rules engine functionality that represents a pluggable intelligent system.
Data	IDiabetesCare.Database	The User database that stores the following personally identifiable data: • Users • Registrations • Hospitals

A core part of the application structure is that the web site makes use of application resources without having direct knowledge of them. The web site is only aware of interfaces that represent contracts implemented by the resource classes. For example, when the user request a list of items (blood sugar readings, food intake etc), the following occurs:

- The ItemController class makes a request to the ItemRepository.GetUserItems() method.
- When it is first instantiated, the ItemRepository class makes a request to the ItemFactory.GetItemManagementImplementation() method.
- This method will look at the web.config file to locate the assembly and class that implements the IITemManagement interface, in this case the ItemDataAccess class. This is an implementation of the Factory pattern.
- The class is dynamically loaded into memory and is passed back to the ItemRepository class.
- ItemRepository.GetUserItems() calls the ItemDataAccess.GetUserItems() method to retrieve the item records for that particular user.

This pattern is followed by all resource access in the application, as illustrated in the following sequence diagram.

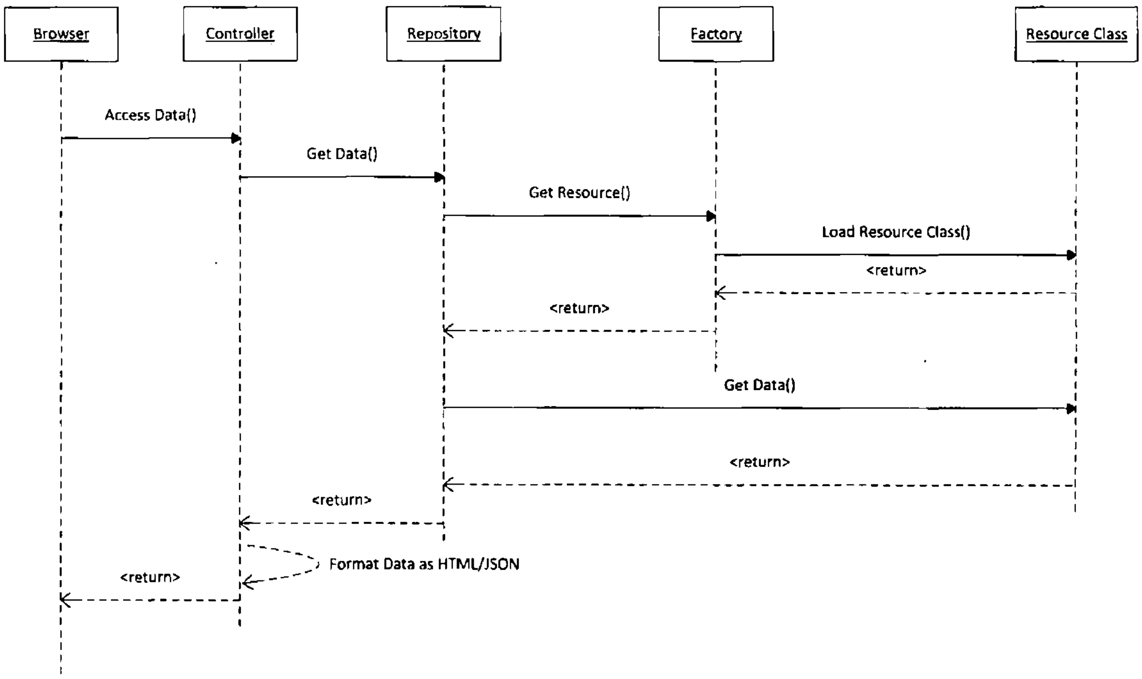

Figure 1: Generic sequence diagram showing how application resources are discovered and used

This design ensures that the web-site is fully decoupled from the application back-end. This separation of concerns means the following:

- The web site does not need direct references to the data-access or middle-layer assemblies.
- The assemblies can be easily replaced with new implementations (as long as they implement the defined contracts), by deploying the new assemblies to the web server(s) and changing the references in the Web.config file.
- The classes can be easily unit-tested as they have no direct code dependencies.
- It is easy to develop dummy data access classes that can be used by the UI developer to mock the data access layer. This allows for UI development to proceed without the need to wait for the data access layer to be developed.

4.8 iDiabetesCare Physical Topology

4.8.1 Prototype Physical Topology

The following diagram represents the physical topology for the prototype version of iDiabetesCare. As discussed previously, the identity database is held in SQL Azure.

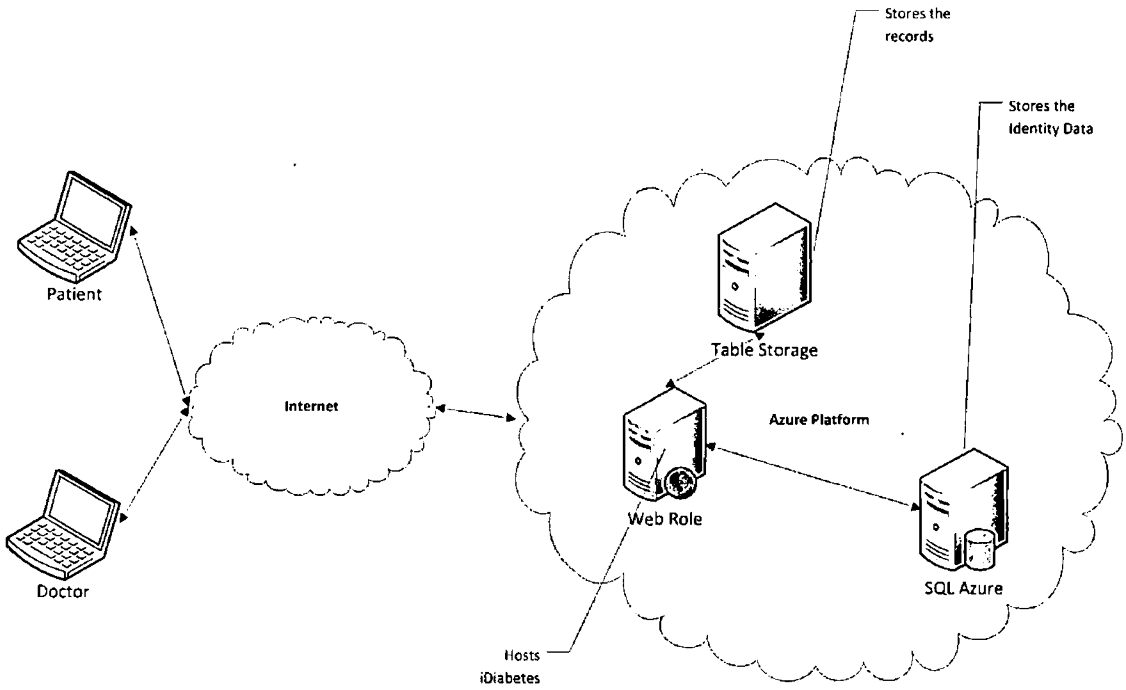

Figure 2: Physical topology of the prototype version of iDiabetesCare

4.8.2 Production Physical Topology

The following diagram represents a proposed physical topology for a production version of iDiabetesCare. The identity database is held in a private data centre, under the control of the HSE. It is accessed by the cloud-based website via a secure web-service.

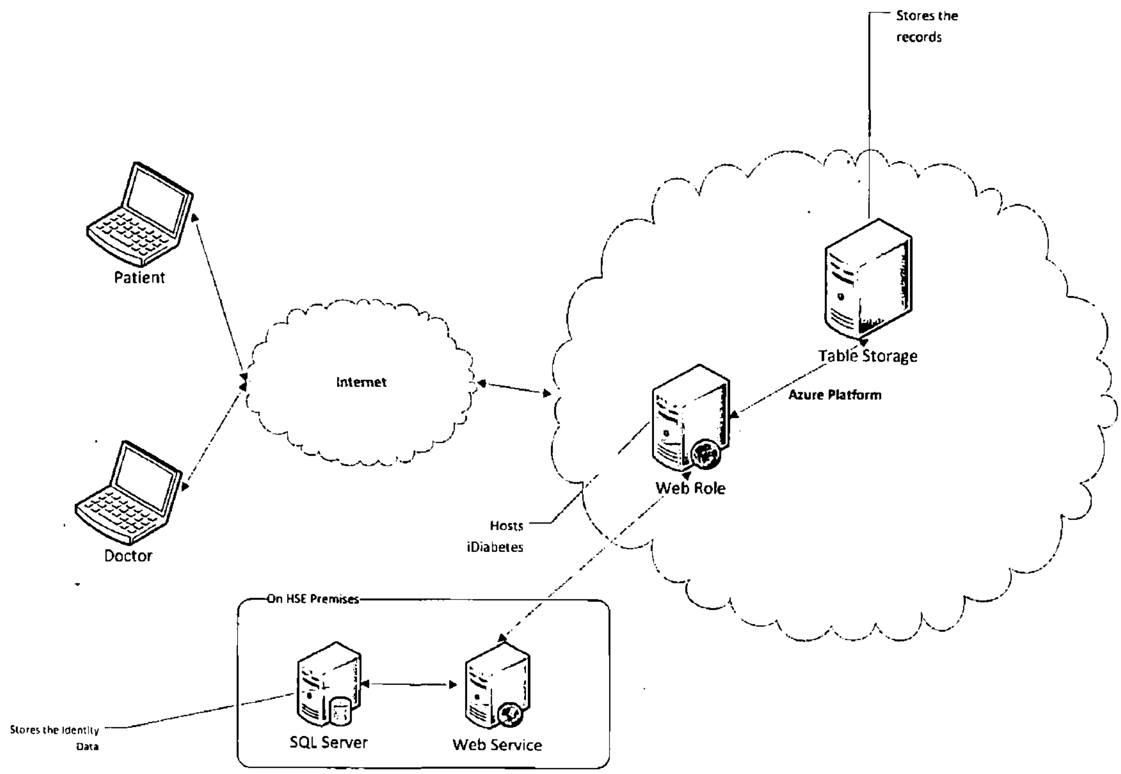

Figure 3: Physical topology of the production version of iDiabetesCare

4.9 Data Structure

The following is the data schema for the iDiabetesCare user identification database:

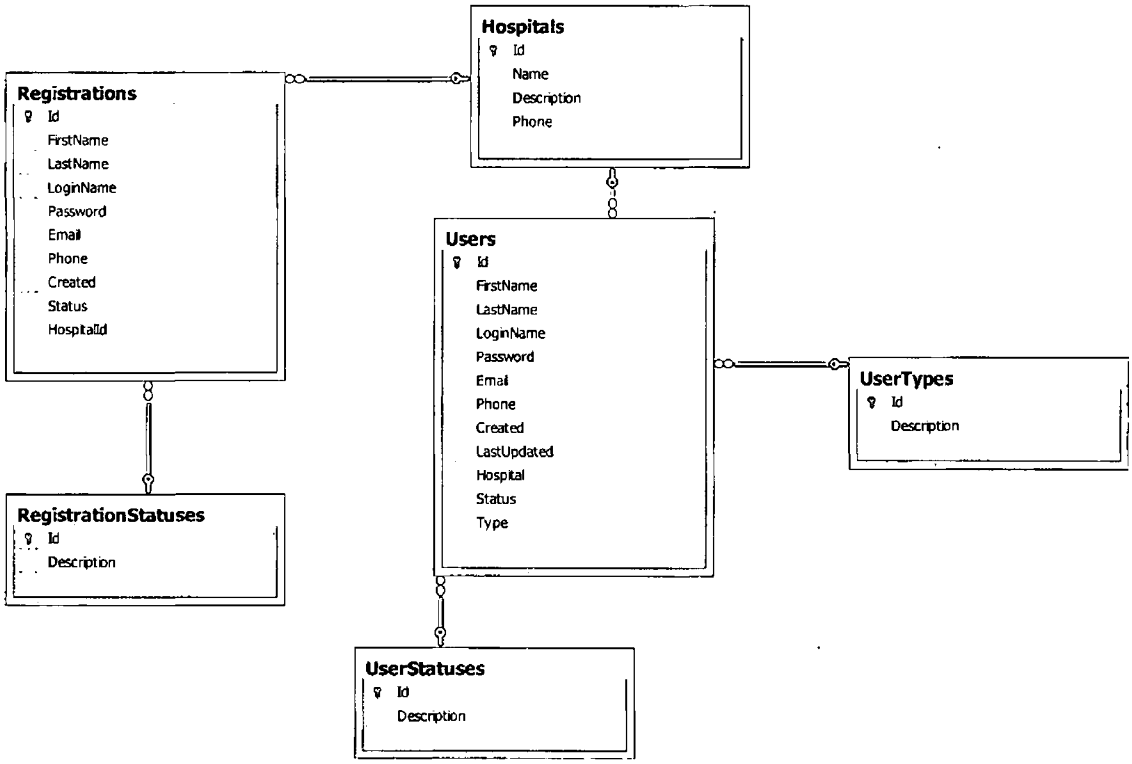

Figure 4: iDiabetesCare user identification database schema

The following is the data structure for the Items table in Azure Table Storage. Note, as Table Storage has no schema, this table can easily store data of a different structure. The table structure is intended to be able to store data other than diabetes records.

Items	
PK	<u>PartitionKey</u>
PK	<u>RowKey</u>
	TimeStamp
	Comment
	ItemDate
	Value
	Type

Figure 5: iDiabetesCare Items table in Azure Table Storage

4.10 Security

The Web site uses ASP.Net Forms authentication to protect the restricted sections of the site, utilising user name and password. This is validated against the on-premises SQL Server database . It was decided not to use Microsoft's ASP.Net Application Services for authentication, as this would force use of a fixed and complex database schema.

The site allows the user to link to the Irish Diabetics group on Facebook. It was decided not to use the Facebook authentication mechanism to allow users to automatically log into Facebook, as its design insists on replacing a participating site's authentication mechanism. In effect, Facebook would then act as the store for all authentication data and this would mean storing patient data within the Facebook store. This would be unacceptable for the following reasons:

- Personally-identifiable Patient data would be stored by a third-party company over which the site administrators have no control.
- Patient data would be stored in locations outside of the Irish jurisdiction.
- Facebook has a questionable history with privacy of user data. (SecurityNews Daily, 2011) (RTE News, 2001)

In a production scenario, the Web site would use SSL to protect the connection between the site and clients as this is an industry standard that can also benefit from acceleration at the hardware level.

4.10.1 Security and the Cloud

Security in the off-premises model presented by the utilisation of the public cloud (as Azure is) is a constant question. There are a number of potential areas that are of most concern:

4.8.1.1 Insecure Interfaces and APIs

Cloud Computing providers expose a set of APIs that customers use to manage and interact with cloud services. Provisioning, management, orchestration, and monitoring are all performed using these interfaces. The security and availability of general cloud services is dependent upon the security of these basic APIs.

Azure uses the standard .Net Framework implementation which is a proven quantity in API security and its use of managed programming languages reduces the chance of memory manipulation exploits.

4.8.1.2 Malicious Insiders

The threat of a malicious insider is well-known to most organizations. This threat is amplified for consumers of cloud services by the convergence of IT services and customers under a single management domain, combined with a general lack of transparency into provider process and procedure.

Microsoft claims that it performs stringent background checks on employees who administer the Azure data centres and follows the principle of least privilege in assigning them access rights to the system. (Kaufman and Venkatapathy, 2010) (Microsoft, 2011) Ultimately this is a question of the trust that a user of Azure will have of Microsoft's diligence in the application of employee checks. It should be noted that the data that the application stores in Azure is not personally identifiable and it would be possible in a production version of the application to encrypt this data before storing it in the Azure table storage.

4.8.1.3 Shared Technology Issues

In a virtualized infrastructure such as Azure uses, a virtualization hypervisor mediates access between guest operating systems and the physical compute resources. Even hypervisors have exhibited flaws that have enabled guest operating systems to gain inappropriate levels of control or influence on the underlying platform.

Dynamic virtual machines remove the traditional security of hardware segregation. A poorly designed image can cause security vulnerabilities to be copied across instances. All virtual machines in Microsoft data centres are guaranteed to have all the latest security patched. It should be noted, that the security issues associated with virtual machines are not specific to cloud computing but to all the many organisations (including medical ones) that have implemented server-virtualisation programs in recent years (Sengupta et al, 2011)

Azure uses a hypervisor specifically constructed for the cloud that it claims is fully tested for such issues. (Kaufman and Venkatapathy, 2010).

4.8.1.4 Data Loss or Leakage

The threat of data compromise increases in the cloud, due to the number of and interactions between risks and challenges. Examples include insufficient authentication, authorization, and audit controls; inconsistent use of encryption and software keys; jurisdictional and political issues.

Azure uses cryptographically generated storage account keys for all internal authentication and authorization and developer and administrator access is handled using Windows Live Ids. All internal communication between the various parts of the platform, and hence any applications running on that platform, is done via SSL. While all such certificates are self-signed, any connections that extend outside of the Azure network are signed using certificates signed by a Microsoft Certificate Authority (CA) that in turn chains back to a trusted root CA. (Kaufman and Venkatapathy, 2010).

A standard countermeasure is to ensure data is backed up at other data centres and if this is unacceptable for jurisdictional reasons, backups to storage outside the data centre should be made (Tanimoto et al, 2011).

As discussed previously, all application data stored in Azure will be kept within the Dublin-based data centre.

4.8.1.5 Account or Service Hijacking

If an attacker gains access to account credentials, they can eavesdrop on activities and transactions, manipulate data, return falsified information, and redirect application users to illegitimate sites.

It is important that any authentication mechanisms employed follow both best practice and are legally compliant (Ramgovind et al, 2010). While Azure does have the ability to provide identity federation, it is envisioned that the standard and proven .Net Forms authentication mechanism will be used to authenticate users. There will be no need to integrate the authentication with a 3rd party system.

As discussed, Live Ids are used for developer and administrator access and Windows Forms authentication is used to secure the application. In Azure, Digital Certificates and their private keys are not exposed even to the application developers and administrators as they are stored in Azure as PKCS12 files and are installed via a separate mechanism to the code that uses them. (Kaufman and Venkatapathy, 2010).

4.8.1.6 Unknown Risk Profile

One of the tenets of Cloud Computing is the reduction of hardware and software ownership and maintenance to allow companies to focus on their core business strengths. Cloud deployments are driven by anticipated benefits by groups who may lose track of the security ramifications.

The published information indicates that Azure provides a low risk profile to those implementing applications on its infrastructure, for the following reasons:

- The Azure Fabric Controller service uses encrypted credentials to authenticate itself to various hardware resources under its control. At no time are these exposed to developers or administrators using the system. (Kaufman and Venkatapathy, 2010).
- Data isolation is achieved via the following mechanisms:
    - The Isolation of Hypervisor, Root Operating Systems, and Guest Virtual Machines.
    - The isolation of Fabric Controllers.
    - Packet Filtering. As Guest Virtual Machines are not fully trusted, all their packets are filtered by the Azure infrastructure. As Kaufmand and Venkatapathy say '*The hypervisor and the root OS provide network packet filters that assure that the untrusted VMs cannot generate spoofed traffic, cannot receive traffic not addressed to them, cannot direct traffic to protected infrastructure endpoints, and cannot send or receive inappropriate broadcast traffic* '. (Kaufman and Venkatapathy, 2010).
- Virtual Local Area Networks (VLANs) are used to isolate the Fabric Controllers and other devices. VLANs will partition a network in such a way that no communication is possible between VLANs without passing through a router. This will prevent a compromised node from faking traffic from outside its VLAN.

4.11 GUI Design

In designing the GUI, attention was paid to the six principles of RIA design. (Scott and Neil, 2009)

4.11.1 Make it Direct

At all times feedback is given back immediately to the user. If he fails to log in, a message is immediately shown. Lists of items are clickable and the length of user/system interaction is kept as short as possible.

4.11.2 Keep it Lightweight

Adding a record or changing its state are a one-step process. This minimizes the number of actions needed to work.

4.11.3 Stay on the Page

The user is kept on the page as much as possible to improve performance. e.g. adding a record is performed by buttons on the same page. Generating a graph of blood-sugar records is shown in a dialog on the same page.

4.11.4 Provide an Invitation

This involves leading a user through an interaction. As the current version of iDiabetesCare has reasonably basic functionality, there is no need for prompts or wizards to lead a user through a complex interaction. Enhancements to the site may cause this need to change. That being said, the site will direct the user to where they are most likely to need to go. e.g. when a medical professional logs in, they will be shown the list of user registrations first, as approving/rejecting these is the action an medical professional will be doing most often on the site.

4.11.5 Use Transitions

As the GUI is relatively simple, there is currently no real need for indications of which part of a page to focus on e.g. the Light Box effect pattern. However, the collapsible comment section and the use of dialogs are good examples of preserving screen real-estate.

4.11.6 React Immediately

All user actions respond with a quick change of screen state. There are no long running processes here as the actions are lightweight. An overlong delay due to technical reasons, will result in an error being shown to the user.

The use of AJAX and partial screen updates is an implementation of the 'Asynchronous Particle Update' design pattern.

4.12 Page Design

Site functionality is divided into two main areas:

- Patient functionality consisting of the following:
    - Registering as a user
    - Adding an item (blood sugar reading, exercise, food or insulin intake) manually
    - Uploading data in bulk from a CSV file
    - Locating the hospital on Google maps.
    - Contacting the hospital using Skype
    - Browsing stored items
    - Generating rules-based advice from the stored data
    - Generating a chart of blood sugar readings
- Health professional functionality consisting of the following
    - Approving/Rejecting a new user registration
    - Viewing data for patients in a hospital
    - Downloading patient data as a CSV file

There are only five pages needed to provide this functionality:

- Logon page, incorporating a new registration screen.
- Items screen, incorporating adding and browsing items, as well as generating advice and graphs. This also includes uploading data as a file, locating and contacting the hospital.
- Pending registrations screen, incorporating approving/rejecting pending registrations.

- Processed registrations screen.
- Browse user data screen (incorporates downloading data)

The use of rich internet controls allows these five pages to provide functionality that would traditionally require up to fifteen separate pages.

The pages use a minimalist design to avoid distracting the user from the task at hand. A simple colour palette of brown, black and cream is augmented with more primary colours to draw attention to important items such as warnings or feedback.

Pages listing multiple records use a table format, with the data items primary key as a link to allow the user to view a distinct record. Pages will move from the general level of detail to specific. The JQGrid plug-in from Trirand is used to implement the grids. It uses AJAX and JSON to communicate with the server and all activity is rendered on the client.

Figure 6: diabetes records screen

When the user selects a record, it is displayed in a window with an overlay over the hosting page that makes the window modal. This is a dialog control that ensures the user stays on the same page and will display the data along with controls to highlight the actions most required by the user. For example, in the add new item dialog, the activities available are displayed as a grouping of green buttons below the record detail. The use of modal dialogs allows for various different forms of functionality while preserving screen real-estate.

Figure 7: diabetes add records dialog

Patients will be brought to where they most likely need to go on the site. e.g. when a user logs in, they are shown the list of items for that patient. Working on items is what a user will be primarily doing.

For Health Professionals, Tabs listing the primary screens are shown in the top right hand-side of the screen. These are the pending registrations, processed registrations and user records.

Figure 8: Pending registrations screen

The primary actions on a screen are displayed on the left-hand side as large buttons. These represent the primary actions the user will take on that page. e.g. On the browse the patient records page, the health professional will see a 'Download User Records' button as the primary action.

Figure 9: Patient Records screen

Regular users will work on items and so are only shown one screen. All activity takes place on this screen via dialogs and JQGrid and so implements the 'Stay on the Page' principle.

The currently logged-in user login name and the log out button are shown in the top right of the screen at all times. This allows the user to know what login they are currently using and allows him to quickly exit the application when he is finished.

The 'Immediate Feedback' principle is followed when the controls give immediate results of actions back to users. e.g. when a user generates a blood-sugar graph, the dialog window is refreshed with server data to show the graph. The main screen itself does not refresh. If errors are detected when a user is initially registering, the dialog is updated with those errors.

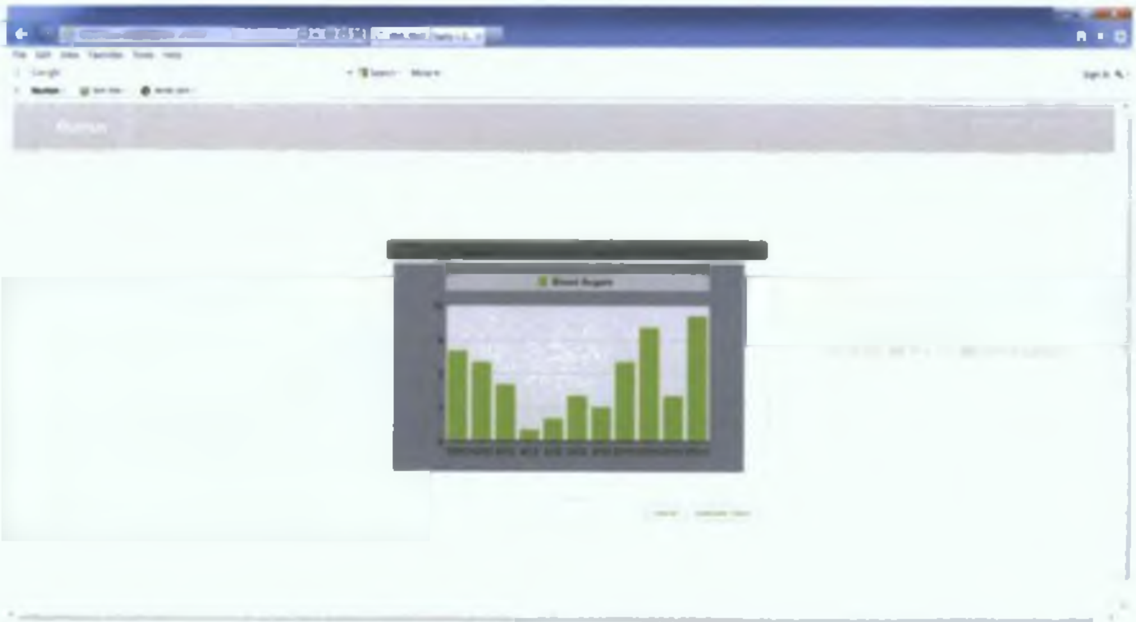

Figure 10: Blood Sugar analysis dialog

5 Cost and Commercial Potential

One of the criteria for success of this research is how cost effective producing iDiabetesCare has been and what, if any, commercial potential it has.

5.1 Cost

Development costs for iDiabetesCare were relatively low, as there was only one developer involved and it was a prototype site. The estimate is that a commercial-grade site could be produced with 3 developers over 4 months, at €350 per day. There would also be the need for one Quality Assurance resource for a 3 month period, running concurrently with months 2-4 of the development, at €300 per day. These are at current market rates. The User Acceptance testing would be performed by the HSE, to whom the application would be sold, and they would absorb this cost.

The other costs involve the software and hardware involved. These are as follows:

- The .Net Framework is available for nothing.
- JQuery is available for nothing.
- JQuery UI is available for nothing.
- JQGrid has a once-off commercial licence of €235 per developer
- XML/SWF charts (http://www.maani.us/xml_charts/) has a free version which provides all the functionality used in the sites. If product support was needed by the development team, a bulk licence is available for a once-off charge of €390.
- The identity database would be hosted by the HSE and this would be absorbed into their own IT costs.
- The Azure platform cost is based on a usage model. Using the Azure pricing calculator (https://www.windowsazure.com/en-us/pricing/calculator/advanced/), the cost is estimated at €249 per month. This is based on the following criteria (per month) and will increase as the system expands:
    - 1 Medium Compute instance, (2 X 1.6GHZ CPU, 3.5GB RAM)
    - 550 GB Table Storage
    - 1 Million Transactions
    - 20 GB bandwidth

It is clear that the costs involved are low and the use of Windows Azure provides a cost-effective, consumption based model.

5.2 Commercial Potential

The increase in Type 2 diabetes in Ireland has already been discussed. It is the responsibility of the HSE to provide healthcare to these individuals and to do it at a time of unprecedented levels of budget and staff cuts, due to the current economic circumstances. This all means that the HSE is challenged with meeting increased demand with reduced resources.

There is therefore the need for a solution that can enable and streamline the provision of this care without an increase in cost. In fact, a technological solution such as iDiabetesCare will allow HSE staffing resources to be freed up while at the same time allowing increased contact with diabetics who are not living near a diabetes centre.

5.2.1 Competitors

The systems detailed in the literature review are either bespoke systems for research purposes or are not available outside of the US. If iDiabetesCare is to have commercial potential, it is necessary to examine the potential competitors in this area.

Microsoft HealthVault

Microsoft HealthVault is a Personal Health Record (PHR) system used to store and maintain health and fitness information.

An individual interacts with their HealthVault record through the HealthVault site, or, more typically, through an application that talks to the HealthVault platform. HealthVault is free for use to individuals. HealthVault is intended as a complete electronic Personal Health Record (PHR) system. It is not intended specifically for use by Diabetics. Microsoft HealthVault is internationally available but currently the only European countries it is available in are Germany and the UK. (Microsoft Europe PR Announcements, 2010) No concrete information is available as to whether it will be released in Ireland.

LifeScan OneTouch

LifeScan OneTouch is a service provided by LifeScan Ltd and is available in Ireland. LifeScan is a manufacturer of a range of blood sugar readers and the OneTouch service is an online service meant to compliment their products. It allows diabetics to upload their readings from LifeScan readers and acts as a web-based store of blood sugar readings. (LifeScan, 2011)

It is a free service for patient use only and does not offer any functionality to healthcare professionals. The system is intended for users of LifeScan's products only. During the research, this author spoke with the Technology Officer of the Irish Diabetes Federation. It was indicated that there have been legal issues with storing Irish patient data in the UK and periodic unavailability of the UK hosted LifeScan website.

Best 4 Diabetes

Best 4 Diabetes is a web based software solution that allows users of Blood-Sugar readers to upload glucose information to the website. There is also the option to record records of food intake, medicines being taken and exercise levels. It contains preset reports based on blood-sugar levels and food intake which can be emailed to health-care professionals.

Best 4 Diabetes is a free service intended for patient use only and does not provide any services to health-care professionals. (Best 4 Diabetes, 2011) It is only for use by US residents.

Body Sigma

Body Sigma is a Canadian web based software solution that allows users to track their diabetes by uploading data from their meters Users can create graphs and charts once the blood sugar data has been uploaded. The graphs and charts are customizable. It is only available to US of Canadian residents. (BodySigma, 2011)

It is clear to see that there are currently no viable competitors to iDiabetesCare in the Irish marketplace.

6 Evaluation Method

6.1 Sample

The target demographic was previously established during the requirements survey i.e. Type 2 diabetics in the 20-40 age range who regularly use the internet. The challenge in establishing the sample of users was that the project requires individuals meeting very specific criteria. As discussed, the sample group was established via contacts in the Diabetic clinic in St James Hospital, Dublin. Another challenge was that, for confidentiality reasons, it was not possible for the author to make direct contact with the group and all communication was therefore handled through an intermediary. The author also had to rely on the intermediary to gather the sample group.

The sample group was initially established as 10 individuals but only 7 of these ultimately took part. While a group of 7 is certainly below the ideal size hoped for (40-50 would have been preferable), it was enough to gather results that are at least indicative.

The group (n=7), met the following criteria, as these were established as criteria for the individuals to take part in the first place:

- Diabetics, predominately with Type 2
- In the 20-40 age group
- Have had diabetes between 3-10 years
- Are technology literate to at least an intermediate level

Criteria such as gender, background and employment were disregarded as they were seen as having little relevance to the research i.e. these criteria may determine why an individual has technology literacy but it is only important that they do.

In order to be able to establish the external validity of results it is important for the sampling strategy to be randomized. As the intermediary was responsible for selecting the sampling group based on the aforementioned criteria, the selection was based on who was willing to participate, as opposed to choosing randomly from a pre-established group. It should be said that as the intermediary was a much more disinterested party than the author, the sampling group was not 'contaminated' by this author choosing individuals that he would judge most likely to give preconceived, desired results.

6.2 Procedure

The evaluation procedure for iDiabetesCare was as follows:

- All users were supplied with a (brief) description of the system and how to use it.
- As it was not possible to get a medical professional to take part in the system, the users were advised that the data that they stored in the system would not be reviewed by their doctors. They were advised to keep recording their blood-sugar readings in their usual fashion, as well as storing this in the system.
- The system was made available on the web for all users for a 3 week period.
- Each individual in the sample group was assigned a 'dummy' identity to use in the system (this was to avoid storing privileged, personally identifiable data in the system. The users registered on the system using these dummy identities. The doctor identity on the system were also a dummy but the hospital contact details were genuine.
- The users then used the system functionality for the trial period.

The mechanism used to evaluate the system was as follows:

- At the conclusion of the testing period, all the users filled out an online, 24 item survey.

This is available in the appendices.

6.3 Measurement

The survey was mainly in the Likert scaling format. By rating various key aspects of the system in a 6-pount range from 'very satisfied' to 'very dissatisfied', a picture of how useful a marriage of internet technologies could be to helping in the management of Type 2 diabetes. As the literature review and background research had established what the useful criteria were, it was hoped that the survey could measure the success of the application of the theoretical concepts.

7 Results

The questions asked evaluated the users impressions of the features offered by the site.

Based on the gathered results, the profile of the user sample was as follows:

Table 3: User Profiles

Gender	Age	Years with diabetes	Frequency (per day) of testing blood sugar	Recording Method
Male	25	6	3	Diary
Female	32	8	3	Diary
Male	25	5	2	Diary and Device
Male	29	7	4	Diary
Female	36	9	5	Diary and Device
Male	33	6	2	Device
Female	26	4	4	Diary and Device

As can be seen, most participants use a written diary to record their blood sugar readings, while some also use their electronic blood sugar readers. While the blood sugar meters will automatically store data, they will only do so for up to 30 days.

The following are the results of the evaluation questions:

7.1 How useful did you find the ability to upload and store blood sugar readings?

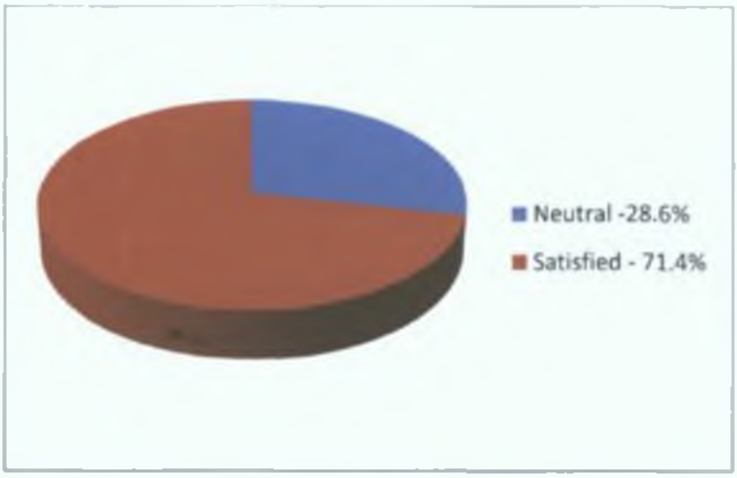

Figure 11: Uploading and storing blood sugar evaluation results

The reason for this question was that frequent testing of blood sugars is or primary importance in good diabetes management. Automating the manual process of recording blood sugar readings would save a lot of time for diabetics and would potentially encourage them to test their blood sugars more frequently. It was important to find if the target audience would find this feature worthwhile.

7.2 How useful did you find the ability to record your diet details?

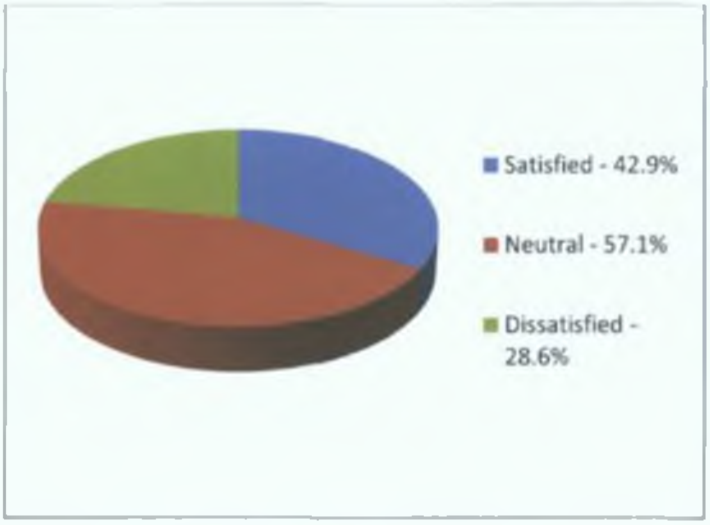

Figure 12: Recording diet details evaluation results

The purpose of this question is that carbohydrate intake has a direct effect on the levels of blood sugars (by increasing them). It was important to see if users would find this useful.

7.3 How useful did you find the ability to record your exercise regimen?

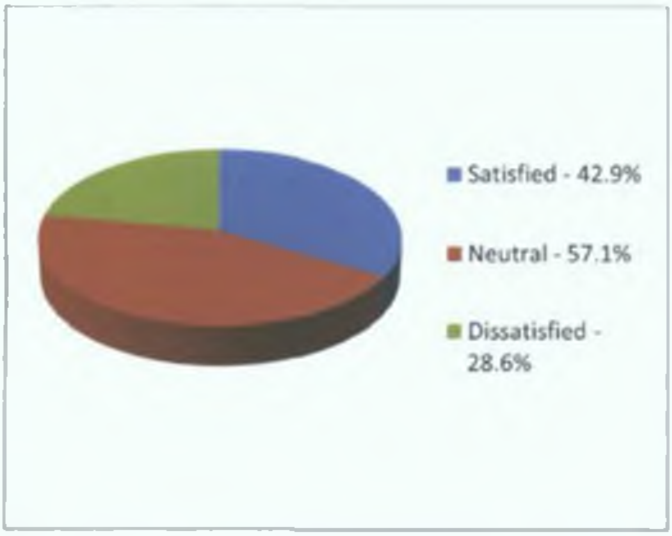

Figure 13: Recording exercise details evaluation results

Exercise will reduce blood sugar levels. It was necessary to see if users would find this feature useful based on this criterion.

7.4 How useful did you find the ability to record the amounts of insulin/oral medications that you have taken?

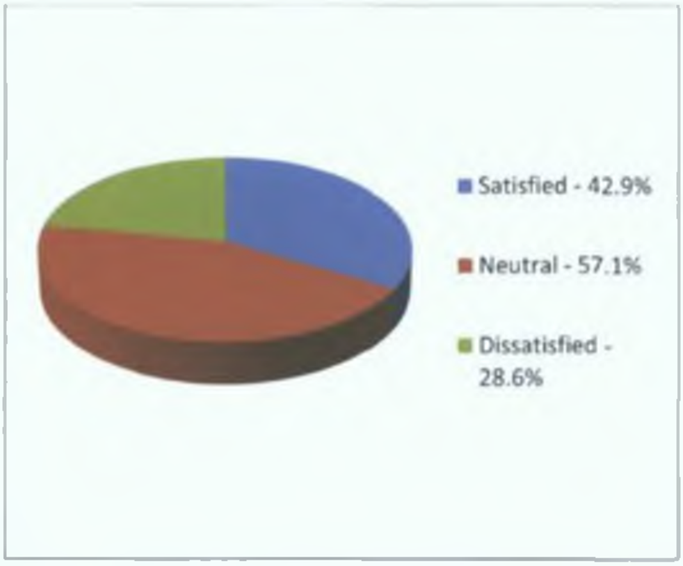

Figure 14: Recording insulin intake evaluation results

Insulin is used to control blood sugars by transforming blood sugar into fat for storage in cells. It is therefore important for this data to be recorded. The purpose of the question was to establish if the users found this to be of significance.

7.5 How useful did you find the ability for your health care professional to view the records you have recorded?

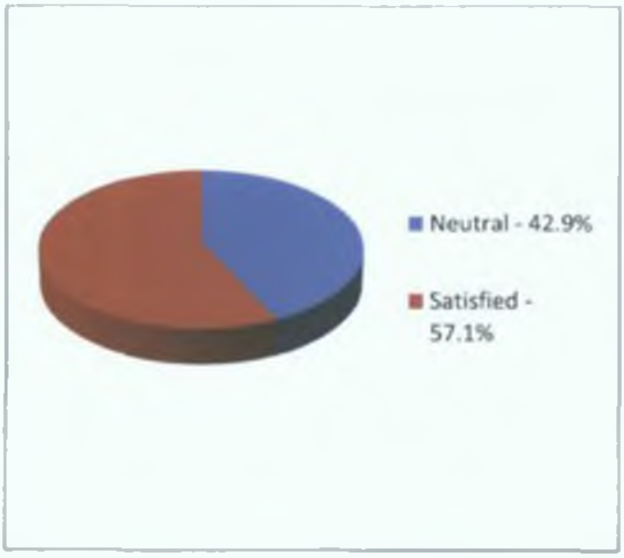

Figure 15: Health Care Professionals viewing patient records evaluation results

While it is very important for users to be able to view their own records, in order to make decisions regarding their regimen, it is equally important for the HCP to also have this ability. This allows the HCP to give timely advice as to the management of the patient's diabetes.

As discussed previously, poor diabetes management leads to serious health complications Fixing this as quickly as possible will give a lot of benefit.

Ideally, it would have been useful to get the view of a HCP on this feature but, as mentioned previously, this was not possible.

7.6 *How useful did you find the ability to generate graphs of your blood sugar readings?*

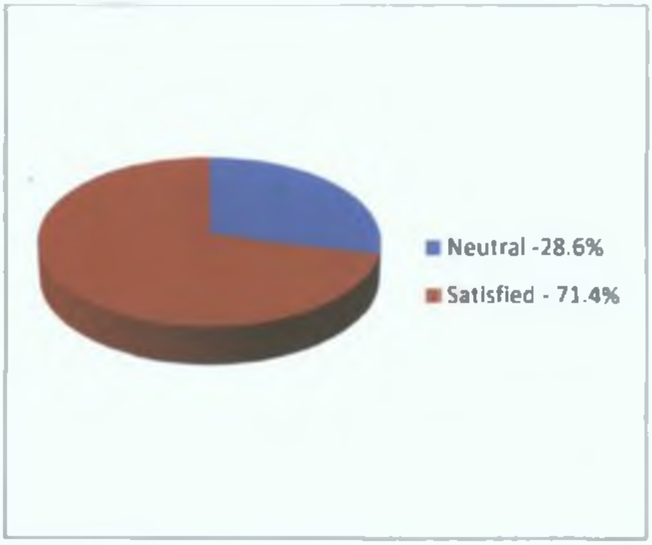

Figure 16: Generating graphs of blood sugar readings evaluation results

This feature allows the user to get a visual picture of his blood sugar readings over the previous period and allows him/her to see trends that would not be so obvious by viewing a table of figures. It was important to find out if the users would see this as a helpful feature.

7.7 How useful did you find the ability to communicate with your health care professional?

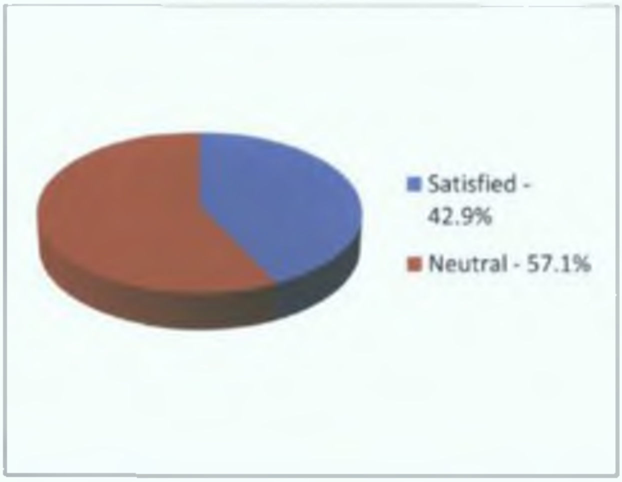

Figure 17: Communicating with Health Care Professionals evaluation results

The system needed to provide a feature to allow the user to contact their HCP to ask questions of get advice. It was important to get the users' view on this.

7.8 How useful did you find the site making suggestions about improving your diabetes management, based on records that you have previously entered?

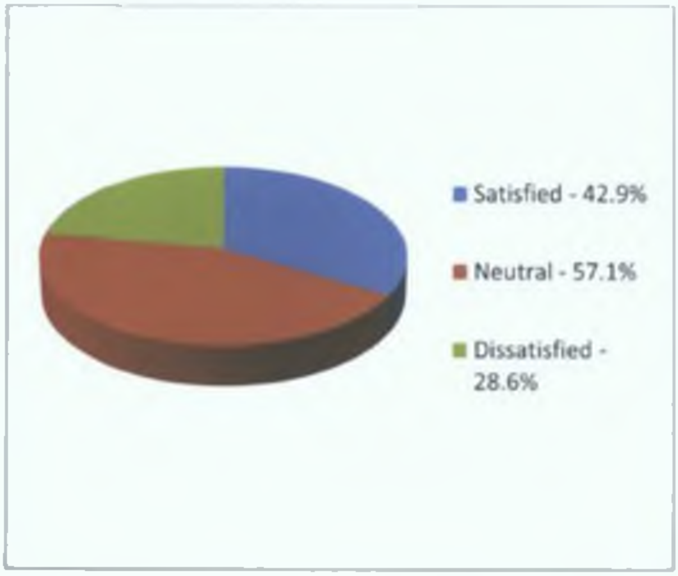

Figure 18: Automated site suggestions evaluation results

Suggestions to the user derived from a rules-based analysis of the data that the user has entered, would be an important feature to allow the user to get advice without having to constantly rely on direct contact with the HCP. It may not be possible to contact the HCP out of surgery hours and it is time consuming for the HCP to be continually answering questions. This is especially the case with newly diagnosed diabetics. It was therefore important to see if users were receptive to the idea.

7.9 How useful did you find the ability to socially network with other diabetics?

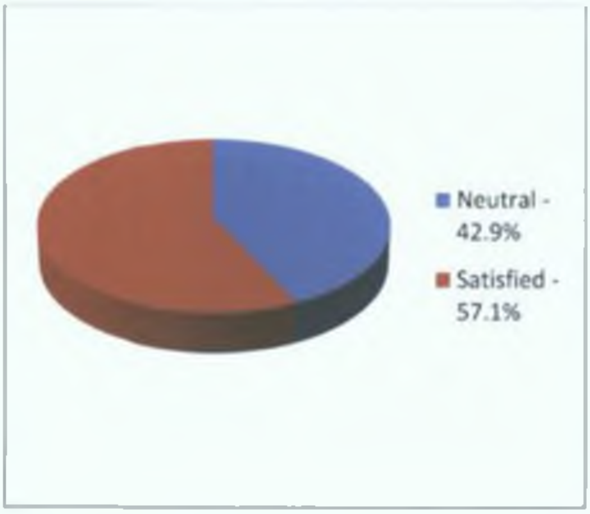

Figure 19: Social Networking evaluation results

The diagnosis of a serious, chronic illness as an adult can be quite traumatic for an individual and requires a complete lifestyle change. This can cause isolation and even depression. The role to be played by community support of fellow diabetics, who have encountered a similar experience should not be understated. Such support may not be fully available to individuals who do not have direct access to Diabetes clinics or support groups. There is a role here for social media and the purpose of this question was to establish the participants reaction to this feature.

7.10 This site would encourage me to place closer attention to the management of my diabetes.

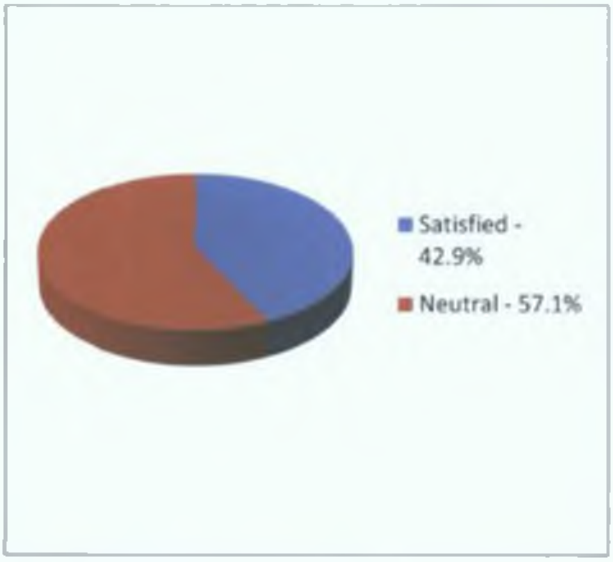

Figure 20: The site encourages the patient to pay closer attention to diabetes management evaluation results

The purpose of this project is to see how internet technologies can help in the management of diabetes from the patient point of view. A hoped for long-term result of this would be that patients become more expert and conscientious in the management of their condition, if they have a tool that helps to eliminate a lot of the associated manual work. It was important to get the participants view on this

8 Discussion

It should be born in mind that a sample size of 7 users is too small to lend itself to a detailed statistical analysis, as the opinions of one atypical individual will have a very significant effect on the outcomes. Therefore, the results cannot be considered to be conclusive but indicative. That being said, the results do give some insight into how successful the system is in meeting its purpose.

The site features for recording blood sugar, diet, exercise and insulin data are interrelated. Diet, exercise and carbohydrate levels all have a direct effect on blood sugar levels.

The blood sugar recording feature has proven to be welcomed by the testers. This was to be expected, as it is one of the primary features of the system.

In the initial research survey, 25% of respondents tested their blood sugars 3 times or less per day. One respondent gave the following comment as to why he/she did not test more frequently: '*Lazy and Forget*'. Of the 28.6% of the testers that were neutral in their evaluation of the blood sugar recording feature, one commented as follows: '*Don't need this. I store readings on my reader.*' This tester appears to be unaware of the time limit on data storage of the blood sugar meters.

The features for recording diet, exercise and insulin proved to be less popular, with only 42.9% approval and 28.6% being actively against it. The survey results show that it is the same users that gave the same answers to these 3 questions. Recorded comments included '*What is the point of this?*' and '*Do not see the relevance*'. This is somewhat at odds with the result from the initial research survey that shows that 75% of users would welcome the ability to record diet details, exercise and insulin intake.

A possible explanation can be found in the requirements survey which showed that 33% of those diabetics surveyed rated their understanding of their condition and its mechanics as average, at best. Taking into account the subjective nature of such a self-rating and the fact that individuals will tend to rate their abilities as better than they are, it can be assumed that the real figure is much higher. This would offer an explanation as to why the ability to record details other than blood sugars may not be as welcome. Of course, why then would the group of diabetics surveyed approve of these features more than those tested? Two possible explanations come into play here. One is that those surveyed are not necessarily the same as those who tested the system (both surveys were anonymous). The second is that diabetics are used to manually recording their blood sugars and, to a certain extent their insulin intake. Carbohydrate and exercise recordings are new to them and it is easier for those taking the requirements survey to approve of this, as they are not necessarily the ones that will be asked to do it, as part of an evaluation process. Of course, the low number of participants means individual behaviours also have a large bearing on the results. For instance, when asked to comment on why one user was indifferent to recording exercise, the answer was '*Don't take much exercise*'.

Many diabetics would not fully understand the relevance of food/exercise/insulin on their blood sugar control. The results point to a need for more education on the part of diabetes patients. It should also be noted that in this prototype application, there is no help section available that would be included in a full production version. This would help alleviate some lack of understanding on the user's part.

The feature to allow a HCP to view a patient's recorded data was welcomed by 57.1% of the users. This fits in with the 83.3% of users that were in favour of this in the requirements survey. In fact, the recorded comment of one user who approved of this feature was '*Saves me reading out my readings over the phone when talking to the doctor*'.

It is believed that the results in favour would be closer to the results of the requirements survey in a full version of the system. The users were briefed in advance that no HSP would be taking part in the project. They had to 'imagine' how useful this feature would be if there were receiving direct feedback from their doctor, on the data that they had entered.

The feature to allow users to generate graphs of blood sugar readings was welcomed by 71.4% of those surveyed and this is the same as the results for those who are in favour of the feature allowing the storage of blood sugar records in the system.

The functionality allowed in the prototype system is limited and it is believed that even more users would find this feature useful if it was enhanced e.g. graphs to allow comparisons between blood sugar readings and the effects of recorded exercise, diet and insulin intake.

The feature to allow communication with the HCP was somewhat less popular but is in line with the results of the requirements survey in that 50% were in favour of such a feature, 41.7% were neutral and 8.3% were against. The site allows the user to launch communication via Skype but the fact that no HSP was partaking in the project would negatively impact the users view of this feature. It is believed that in a full version of the system, this feature would prove to be more popular.

In the requirements survey, 66.6% of participants were in favour of the site making suggestions as to how users manages their diabetes . The question is why has it proven less popular in its implementation..A probable answer is that the features implemented in the prototype are quite basic. This is coupled with the fact that users were warned that this feature was for demonstration purposes only and that the advice was not a substitute for proper medical analysis. It is reasonable to assume that users viewed this as not a compelling feature for this reason. As one user commented; '*Advice is too general*'. It should be noted that the testers were not professional Quality Assurance Analysts and would not be used to evaluating a system in a purely objective frame of mind.

In a production version of the application, the system would use a rules engine containing rules devised by medical experts and would be of much greater use to the patients. This is a feature that would then be strongly pushed as a selling point.

The results for the social networking aspect of the site were favourable, like those of the requirements survey which showed 75% of respondents in favour of this feature. They were not however, exact matches. One user commented '*Why do I have to log in twice*?', referring to the fact that the system does not automatically authenticate against Facebook. As discussed previously, the Facebook API insists on a consumer site using the Facebook authentication mechanism and this is unacceptable to a site storing medical data. Another fact to consider is that a closer integration with Facebook functionality would be implemented in a production application, as long as it does not pose a privacy risk. The conclusion to be drawn here is that this feature is seen as useful by the users but it needs to be matured.

Asking if the site would encourage the user to pay closer attention to the management of their diabetes is perhaps the most subjective question asked here. This certainly needs to be taken into account in the results, along with the restricted nature of the prototype site. The fact that 42.9% of respondents agree and the rest are no worse than neutral in their opinion, can be viewed in a positive light. Of course, further development and research would be needed to reach a more conclusive finding.

9 Conclusion

In answering the question, 'Can an effective diabetes management system for type 2 diabetics be produced using a 'mash-up' of existing technologies and services?', a detailed review of the current state of the application of Internet technology to diabetes management was performed. This revealed that the application of such technologies was beneficial overall, but that there was a need for a system that could be constructed out or pre-existing technologies.

A detailed user survey and secondary research was performed to confirm this need and to establish what such a system should contain. A cloud-based prototype system, iDiabetesCare, was constructed in order to evaluate the technologies. It provided the means to record and analyse the daily data associated with Diabetes, such as blood sugar, exercise and food and insulin intake. This was coupled with functionality that demonstrated the ability to plug in an intelligent system to provide automated advice to patients and to network with other diabetics via facebook.

To evaluate iDiabetesCare, a selected group of diabetics used the system and reported their findings in a user survey. The results demonstrate that the response to the system was positive overall. There was a somewhat more muted response to the ability to record data other than blood sugars as well as to the demonstration rules engine.

It was not possible to get the participation of a medical professional in the project, the benefits of iDiabetesCare to the medical community can only be predicated based on the evidence of similar studies, providing similar functionality using bespoke systems.

As stated previously, it should be born in mind that the user testing group was unavoidably small and so the results of the analysis can be considered indicative rather than conclusive. Despite this, it is reasonable to conclude that the results show that such a system can provide worthwhile benefit to Type 2 Diabetes management and the author believes that a larger study would only confirm this.

10 Future Perspectives

Some future possibilities for research and development for iDiabetesCare are as follows:

- A study could be performed to evaluate the financial savings that iDiabetesCare could provide when applied in a clinical environment. The system could be provided in one diabetes clinic over a 12-24 month period and the running costs could be recorded. A similar cost record could be kept in a similar clinic, with a similar patient population that is not using iDiabetesCare. A cost comparison would then show the possible savings that iDiabetesCare could provide.

- Another study could be performed to see if using iDiabetesCare would help improve the long-term health of Type 2 diabetics. This would involve continuous monitoring of two diabetic groups over a long-term period, maybe 5-10 years. One group would use iDiabetesCare, the other would not. An evaluation of the state of their health, as well as the resulting understanding of their condition and their confidence with its management, would show what benefit iDiabetesCare could provide.

- The decoupling of the patients' readings data from their personally identifiable data provides an added safeguard to storing this data in the cloud. To add additional security, this data could also be encrypted. For instance, the use of session keys to encrypt the data and public/private keys to digitally sign it would ensure that patient data could only be accessed by the patient and his/her health service provider. The loosely-coupled structure of the application would facilitate plugging in such technology.

- iDiabetesCare could be applied to the management of chronic illnesses other than Diabetes. Heart disease, Haemophilia and Epilepsy are conditions that could also be managed with the system. The important thing to note is that all diabetes-specific functionality is built into the front-end of iDiabetesCare. The data storage is generic and non-specific. For instance, the readings data is stored in Azure table storage which does not have a schema. The multi-tenancy nature of Azure means that it would be easy to add new versions of the web site targeted at specific conditions that could operate concurrently with iDiabetesCare.

- Future advances in blood-glucose monitors, e.g. the addition of Bluetooth capabilities would allow the connectivity between these devices and mobile devices. This would allow a mobile version of iDiabetesCare to be provided that would give the full capabilities of the PC based site.

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Appendices

Appendix A: Surveys

A.1 Requirements Survey

- What gender are you?
- Which age group are you in?
- How long have you had diabetes?
- Which type of diabetes do you have?
- How would you rate your control of your diabetes?
    - Poor
    - Below Average
    - Average
    - Good
    - Very Good
- How many times per day do you test your blood sugar?
- If you do not test your blood sugar, please say why.
- If you test your blood sugar, how do you record your readings?
    - A written diary
    - An electronic meter
    - Other
- How many times per year do you see a medical diabetes specialist?
- Do you adjust your intake of insulin/oral medications based on your own decisions or medical advice?
    - Own decisions
    - Medical Advice
    - Both
- How would you rate your understanding of the relationship between insulin/oral medications, exercise and food intake?
    - Poor
    - Below Average
    - Average
    - Good
    - Very Good
- How many hours per day would you use the internet?
- Which device(s) do you use to access the internet?
    - PC
    - Net-Book
    - Tablet
    - Mobile
    - Games Console
    - Other
- Do you use the internet to seek information on your diabetes?
- How reliable a source of information (on diabetes) would you consider the internet?
    - Totally unreliable
    - Somewhat unreliable

  - Neither reliable or unreliable
  - Somewhat reliable
  - Totally reliable
- Do you use social networking sites?
- If you use social networking sites, which ones do you use?
  - Facebook
  - Twitter
  - Google+
  - Tumblr
  - Other
- Do you take part in social networking groups concerning diabetes?
- Do you believe that a new web site that would help you to manage your diabetes would be useful to you?
- Please elaborate on your previous answer.
- The site should allow me to upload and store my blood sugar readings.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should allow me to record my diet details.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should allow me to record my exercise regimen.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should allow me to record the amounts of insulin/oral medications that I have taken.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should allow my health care professional to view the records I have recorded e.g. my blood sugar readings, my diet.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree

- The site should allow me to communicate with my health care professional. e.g. to get suggestions on how to improve the management of my diabetes.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should automatically make suggestions about improving my diabetes management, based on the records that I have previously entered.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should be able to send me suggestions about improving my diabetes management via media such as SMS or email.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree
- The site should allow me to socially network with other diabetics.
  - Strongly disagree
  - Disagree
  - Neither agree nor disagree
  - Agree
  - Strongly agree

A.2 Assessment Survey

- What gender are you?
- How old are you?
- For how many years have you had diabetes?
- How many times per day do you test your blood sugar?
- How useful did you find the ability to upload and store blood sugar readings?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the ability to record your diet details?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied

- Please comment on your previous answer.
- How useful did you find the ability to record your exercise regimen?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the ability to record the amounts of insulin/oral medications that you have taken?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the ability for your health care professional to view the records you have recorded?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the ability to generate graphs of your blood sugar readings?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the ability to communicate with your health care professional?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.
- How useful did you find the site making suggestions about improving your diabetes management, based on records that you have previously entered?
  - Very satisfied
  - Satisfied
  - Neutral
  - Dissatisfied
  - Very dissatisfied
- Please comment on your previous answer.

- How useful did you find the ability to socially network with other diabetics?
    - Very satisfied
    - Satisfied
    - Neutral
    - Dissatisfied
    - Very dissatisfied
- Please comment on your previous answer.
- This site would encourage me to place closer attention to the management of my diabetes.
    - Very satisfied
    - Satisfied
    - Neutral
    - Dissatisfied
    - Very dissatisfied
- Please comment on your previous answer.

Appendix B: Personas

B.1 Frank

Age: 35

Frank was diagnosed with Type 2 diabetes 7 years ago. He treats it with injections of insulin 3 times per day and takes Glyset tablets before each meal (Glyset is an Alpha-glucosidase inhibitor that slows the breakdown of starches in the intestine, blunting the excessive rise in blood glucose that occurs after eating). His doctor has estimated that he is technically obese and that this is the main contributing factor to developing Type 2 diabetes. He has attempted to lose weight but has found that both his lifestyle and the management of his diabetes makes this quite difficult. He has been advised to watch his food intake and to keep a food diary to help with this.

Frank rates his knowledge of his diabetes as intermediate and tends to suffer from high blood sugars first thing in the morning. He tests his blood sugar 2-3 times per day using an electronic reader and records the readings in a hand-written diary.

Frank attends the (public) diabetic clinic in St James Hospital in Dublin every 4 months. There he will meet with the diabetes consultant, who will review his blood sugar readings and insulin intake over the previous 4 months and will advise on where improvements can be made. Frank will sometimes skip his appointments at the clinic because he has to wait on average 3 hours to be seen and cannot afford to take the time off work.

Frank use the internet as part of his work and will spend on average 2 hours per evening online when at home. He does not use the internet to research information on his diabetes, as he has found that some information available online was not actually accurate when he checked it with his doctor. He uses Facebook for social networking and has recently become a member of the diabetes Ireland Facebook group.

Daily Activities:

- At 7:30, Frank will test his blood sugar. He will then take his breakfast, as well as his insulin and Glyset.
- At 13:00, Frank will take his lunch , as well as his insulin and Glyset. He does not test his blood sugar, as he does not like to do this at this place of work.
- At 19:00, Frank will take his evening meal , as well as his insulin and Glyset. Prior to this, he will once again test his blood sugar.
- At 22:00, Frank will go to bed. He will only test his blood sugar if he is feeling unwell or dizzy.

Goals

- To make his life easier.
- Minimize the time spent on the daily activities enforced by his diabetes.
- To be able to get advice about his diabetes management without having to queue for 3 or more hours in a hospital.
- To avoid long-term health complications.

B.2 Linda

Age: 27

Linda was diagnosed with Type 2 diabetes 4 years ago. She treats it with injections of insulin 3 times per day. While Linda keeps a careful control of her weight, she has a family history of Type 2 diabetes, with both her Mother and Grandmother suffering from it.

Linda rates her knowledge of diabetes as poor and tends to suffer from high blood sugars, as she will occasionally forget to take an injection of insulin. She tests her blood sugar (at most) once per day using an electronic reader and relies on the reader to record the readings.

Linda attends her local GP every 6 months, who will review her blood sugar readings and insulin intake over the previous period and will advise on where improvements can be made. Linda understands that her GP does not have the level of specialist knowledge that a diabetes consultant would but the nearest diabetes clinic is a 2-hour car journey from her home. She has been criticised by her GP for not testing her blood sugar more often.

Linda is currently pregnant with her first child and is quite worried, as she knows that high blood sugars during pregnancy can increase the risk of birth defects. Her Obstetrician/Gynaecologist advised her to seek more specialist advice for managing her diabetes during her pregnancy.

Linda will spend on average 3 hours per evening online and will use the internet to research information on her diabetes and pregnancy. She is an avid user of Facebook for social networking and is a member of 3 groups focusing on pregnancy.

Daily Activities:

- At 8:00, Linda will take her breakfast and insulin.
- At 12:30, Linda will take lunch, if she is not too busy. She will also take insulin but has found that when busy she may occasionally forget
- At 18:30, Linda will take an evening meal and her insulin. If she remembers, she will also test her blood sugar

Goals

- To reduce risks to her child by managing her diabetes better.
- To find a way to get access to better medical advice when it is not locally available.
- To avoid long-term health complications.

B.3 Terry

Age: 39

Terry was diagnosed with Type 1 diabetes 30 years ago. He treats using insulin delivered via and insulin pump that he wears on his person 24 hours a day.

Terry rates his knowledge of his diabetes as advanced and his HbA1c readings indicate that this control of his blood sugars is very good. He tends to use a larger than average amount of insulin and this has led to some weight gain over the years. However, he cannot yet be classified as obese. Terry tests his blood sugar 4 times per day using an electronic reader and records the readings in a hand-written diary. Despite having diabetes for an extended period of time, Terry has not developed any complications and attributes this to his good control.

Frank attends the (private) Diabetic clinic in St James Hospital in Dublin every 6 months. There he will meet with the diabetes consultant, who will review his blood sugar readings and insulin intake over the previous 3 months and will advise on where improvements can be made. Frank will also see the nurse specialist who advises on insulin pump therapy and a nutritionist who advises him on diet.

Terry uses the internet as part of his work and will spend on average 3 hours per evening online when at home. He does use the internet to research information on his diabetes, as he believes that he has the knowledge to distinguish between reliable and unreliable sources. However, he has found that the information online is not always trustworthy. He does not use Facebook for social networking but is willing to do so if he can make contact with fellow diabetics to discuss issues that they may share.

Daily Activities:

- At 8:00, Terry will test his blood sugar. He will then take his breakfast, as well as his insulin.
- At 12:00, Terry will take his lunch , as well as his insulin. He will also test his blood sugar.
- At 19:30, Terry will take his evening meal , as well as his insulin. Prior to this, he will once again test his blood sugar.
- At 22:00, Terry will eat a snack. He will take insulin and will test his blood sugar again.

Goals

- To reduce the administrative overhead in managing his diabetes.
- To make contact with fellow diabetics
- To gain information on the latest research in the area of diabetes.

Appendix C: Use Cases

C.1 Register a new patient

Scope

A new patient registers on the system to obtain login credentials.

Flow Description

- The new patient goes to the site.
- He selects the link to the registration page.
- The patient will register by providing a new patient name, password, full name, email address and phone number. The patient will also select which hospital that they are a member of.
- The patient submits the data.
- A confirmation message appears.

Preconditions

The patient requires to register.

Activation

This use case starts when the patient creates a new registration.

Exception Flow

E1 : The system is in error

- The login name already exists
- The patient is informed that the login name already exists.
- The patient is prompted to select a different login name

E2 : The system is in error

- The error details are displayed to the patient.

Termination

The registration is created.

C.2 Patient Logs on

Scope

A patient logs onto the system to identify themselves.

Flow Description

- The patient goes to the site.
- The patient provides a valid patient name and password.
- The patient is brought to the records screen.

Preconditions

The patient has a valid login.

Activation

The Use case starts when a patient goes to the login screen.

Exception Flow

E1 : The system is in error

- The login or password name is invalid.
- The patient is informed that the login credentials are invalid.
- The patient is prompted to enter different credentials.

E2 : The system is in error

- error details are displayed to the patient.

Termination

The patient logs in.

C.3 Health Service Professional (HSP) Approves a new Registration

Description

A HSP approves a new patient registration

Flow Description

- The HSP logs in.
- The HSP will select an existing pending registration .
- The HSP clicks the approve button.
- A confirmation message is displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the HSP.

Termination

The registration is approved.

C.4 Health Service Professional (HSP) rejects a new Registration

Description

A HSP rejects a new patient registration

Flow Description

- The HSP logs in.
- The HSP will select an existing pending registration .
- The HSP clicks the reject button.
- A confirmation message is displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the HSP.

Termination

The registration is rejected.

C.5 The Patient adds a new record manually

Description

The patient adds a new record. This can be of type blood sugar, exercise, food or insulin intake.

Flow Description

- The patient logs in.
- The patient select the add new record button.
- The patient enters the new record details.
- A confirmation message is displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the HSP.

Termination

The record is added.

C.6 A Patient adds new blood sugar records via upload

Description

The patient adds new blood sugar record via an upload from a file created from a download from the blood sugar reader.

Flow Description

- The patient downloads a file from the blood sugar reader.
- The patient goes to the site.
- The patient logs in.
- The patient select the upload records button.

- The patient selects the downloaded file
- The records upload. If any of the records are already there, they are handled in an idempotent fashion.
- A confirmation message is displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the patient.

Termination

The records are added.

C.7 A Patient Views existing Records

Description

The patient views existing records on the site..

Flow Description

- The patient goes to the site.
- The patient logs in.
- The patient is brought to the records page
- The patient views existing records.

Exception Flow

E1 : The system is in error

- The error details are displayed to the patient.

Termination

The records are viewed.

C.8 The Patient gets advice on their regimen from the site

Description

The patient is given advice on their regimen based on data inputted on the site

Flow Description

- The patient goes to the site.
- The patient logs in.
- The patient select the analyze records button.
- The system analyses previously entered records.
- An advice message is displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the patient.

Termination

The analysis is displayed.

C.9 The HSP views a patient's records

Description

The HSP views records entered by a particular patient on the site.

Flow Description

- The HSP goes to the site.
- The HSP logs in.
- The HSP selects a patient registered for the HSP's hospital
- The patient's records are displayed.

Exception Flow

E1 : The system is in error

- The error details are displayed to the HSP.

Termination

The records are viewed.

C.10 The HSP downloads a patient's records

Description

The HSP downloads records entered by a particular patient on the site.

Flow Description

- The HSP goes to the site.
- The HSP logs in.
- The HSP selects a patient registered for the HSP's hospital
- The patient's records are displayed.
- The HSP selects the download records button.
- The system prompts for a location where to save the file.
- The file is saved locally.

Exception Flow

E1 : The system is in error

- The error details are displayed to the HSP.

Termination

The records are downloaded as a file.

C.11 The patient communicates with their HSP via Skype

Description

The patient communicates with their HSP via Skype, launched from the site.

Flow Description

- The patient goes to the site.
- The patient logs in.
- The patient clicks on the hospital phone number which has been highlighted as a Skype number
- Skype opens on the client machine.
- The patient opens a Skype call or Internet Messaging session with their HSP.

Exception Flow

E1 : The system is in error

- The error details are displayed to the patient.

E2 : The patient does not have the Skype browser client installed

- The patient does not have the Skype browser client installed
    - The hospital phone number is not clickable.

Termination

The patient opens a Skype session with the HSP.

C.12 The patient uses Facebook to communicate with other diabetics

Description

The patient communicates with other diabetics via Facebook, launched from the site.

Flow Description

- The patient goes to the site.
- The patient logs in.
- The patient clicks on the Facebook link.
- Facebook opens on the client machine, in a new browser window or tab.
- If the patient is not already logged into Facebook, they are prompted for their Facebook login credentials.
- The patient is brought to the Diabetes Ireland group.

Exception Flow

E1 : The system is in error

- The error details are displayed to the patient.

E2 : The patient does not have a Facebook login

- The patient does not have a Facebook login
    - The patient may not partake in the Facebook group.

Termination

The patient logs into the Diabetes Ireland group.

C.13 The HSP uses Facebook to disseminate articles and article links to the patients

Description

The HSP uses Facebook to disseminate articles and links to articles to the patients

Flow Description

- The HSP goes to Facebook.
- The HSP logs in.

- The HSP goes to the Diabetes Ireland group.
- The HSP posts an article or link to an article to the group (this article has been previously vetted by the HSP).
- The article is available to the patients next time they log onto Facebook.

Exception Flow

E1 : Facebook is in error
- The error details are displayed to the HSP.

E2 : The patient does not have a Facebook login
- The patient does not have a Facebook login
  - The patient may not partake in the Facebook group.

Termination

The article or link is added to Facebook.