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A Systems Engineering Approach to a Just-In-Time intervention system

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I am submitting herewith a thesis written by Pradeep Velur Rajashekaran entitled "A Systems Engineering Approach to a Just-In-Time intervention system." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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A Systems Engineering Approach to a Just-In-Time intervention system

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Pradeep Velur Rajashekaran
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I dedicate this degree to my Mom for all the sacrifices she has made, my Grand mom without whom I wouldn't have survived the hard times and finally to my Dad who was a great teacher and a role model.

To all the Gurus(teachers) who gave me the knowledge and strength to pursue this degree.

எனக்கு ஊக்கமும் ஆற்றலும் கொடுத்த எனது தாய் தந்தை மற்றும் எனது பாட்டிக்கு இப்பட்டதை சமர்ப்பிக்கிறேன்.

மேலும் எனக்கு அறிவாற்றலையும், நல்லொழுக்குதையும் கற்று கொடுத்த ஆசிரிய பெருமக்களுக்கும் சமர்ப்பிக்கிறேன்.

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ABSTRACT

Systems Engineering, a diverse engineering field provides tools and processes to develop efficient systems across different domains. Design thinking, and Agile methodologies are some of the commonly used tools in system design. A mobile health solution using Systems Engineering principle is proposed in managing one of the costliest and common chronic diseases, Asthma. Out of many chronic diseases, Asthma is chosen to be studied, since it has shown a multi-fold increase in the last thirty years. Also, one in nine children in the United States is affected by Asthma. There is no cure for this chronic disease, but it can be controlled by proper medication and symptom tracking. The Just-in-Time Asthma Self-Management and Intervention (JASMIN) is a hybrid mobile application that provides efficient ways for patients to track the asthma symptoms, to learn and get educated about Asthma and their allergens, to communicate and get the necessary support from the care team in the long-term asthma control. JASMIN system is built on a Bio-Behavioral model which encourages and enables the use of system including parents, peers, school personnel and health care providers. JASMIN sends text message interventions to the entire care team when the child fails to track the symptom, ensuring the regularity in symptom adherence. The action plan which is rarely used when written in a physical journal has been given a digital form in JASMIN enabling the provider or parent to update it whenever the need arises. JASMIN is proposed to be used in a pilot study at East Tennessee Children Hospital recruiting 60 children who are between 7-17 years old and their parents and the providers treating their asthma.

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Chapter 1: Introduction

1.1 mHealth

Mobile Health, or mHealth, is defined by the World Health Organization (WHO) as “any electronic device such as mobile phones, patient monitoring devices, personal digital assistants that support medical and public health” (WHO, 2011). mHealth is a subset of electronic health that includes mobile computing, medical sensors, and communication technologies related to healthcare. mHealth has recently shown potential in reshaping the existing healthcare service trends (Ghani *et al.*, 2018). Mobile phone use is nearly ubiquitous across all ages and communities. Research shows that the use of smart phones has seen a steady increase of about 33% since 2011. By 2011, about 35% of the American adults were using smart phones, which dramatically increased to about 68% in the year 2015 and has continued to increase in recent years (Anderson, 2015). By the end of 2022 it is estimated that the population of users using smartphone will be about 270 million which is a 65% increase from the total smartphone users from 2011(Statista, 2018b). The three main components of mobile computing are mobile computers, wireless networks, and mobile applications. Tablets, pocket computers, palmtops, and wearable computers are all considered to be mobile computers. Networks such as Personal Area Networks, Local Area Networks, and Wide Area Networks are wireless and have sufficient bandwidth for use with mHealth applications (which can be accessed during the physical movement). Mobile applications (apps) are software that provide context rich information to the user and can be installed onto any smart phone or used as a stand-alone application that runs in the web browser (Rebolj, Menzel and Menzel, 2004). Like mobile computing, mHealth has three main components: mobile devices, software platforms, and mHealth applications. Personal Digital assistants (PDA) and mobile phones are both considered mobile devices. The former had seen a steady increase from 1990 to 2000; however, the use of PDAs became relatively obsolete after the year 2000. Mobile phone use saw a steep increase after the year 2000 and now is preferred over the use of PDAs (Guerri

et al., 2009). The six major software platforms are Android by Google, Symbian OS by Nokia, iOS by Apple, Windows by Microsoft, Blackberry by Research in Motion (RIM), and Linux Mobile Operating System by the LiMo Foundation (Holzer and Ondrus, 2011). According to the Gartner Report, Android, iOS, and Symbian are the highest rated and most preferred mobile operating systems (Egham, 2010).After fourth quarter in 2012, Microsoft has replace Symbian (Statista, 2018c). Healthcare-related mobile applications are growing at an exponential rate (Silva et al., 2015). In the Apple store alone, there are approximately 47,000 healthcare apps referencing cardiology, smoking cessation, obesity, or asthma (Free *et al.*, 2013; Statista, 2018a). It is also interesting to note that the number of mobile health apps on the Android platform is greater than the number of health apps in the Apple store. Between 2016 and 2017 ,Android has seen a 50% increase in mobile health apps while Apple's iOS has seen just a 20% (Reearch2guidance, 2017). The six broad categories in which mHealth finds its application currently are Emergency care, Chronic Condition Care, Information and Self-Help, Public Health Research and System Efficiency Improvement.

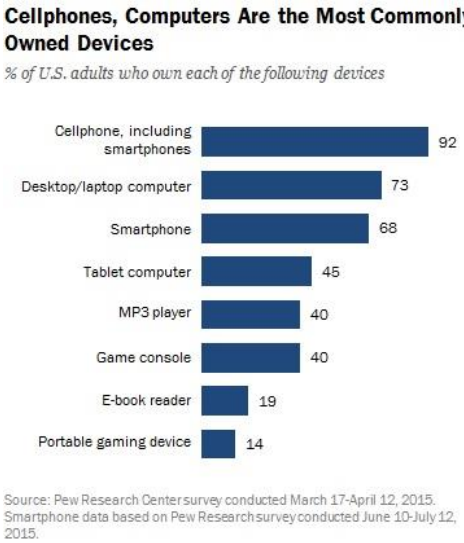

Figure 1: Mobile device usage (Adapted from (Anderson, 2015)).

1.2 Chronic Disease and Asthma

The WHO reports that the United States has higher per capita healthcare expenditures than any other country in the world. Additionally, it states that about 50% of the total health care expenditure is utilized by just 5% of the population (Russo and Andrews, 2006; WHO, 2012). The top seven causes of death in the United States are caused by chronic health conditions (Center for Health Statistics, 2015). Asthma is a chronic condition where the air that flows in and out of the lungs is inhibited by constriction and inflammation in the airways (American Academy of Allergy Asthma & Immunology, 2017). According to the National Heart, Lung, and Blood Institute (NHLBI), inflamed and narrowed air passages to the lungs can cause wheezing and shortness of breath. Asthma is considered a subcategory of general allergic disease. Overall, those affected by asthma had increased from 7.3% of the USA population to 8.4% by 2010, which included seven million children between 0-17 years of age (Akinbami *et al.*, 2012). Figure 2 displays the asthma prevalence percentage by age, gender, and ethnicity in the United states as of 2016. It shows that asthma is equally prevalent between children and adults, but more prevalent in females than it is in males, as well as more prevalent in blacks than in whites or Hispanics.

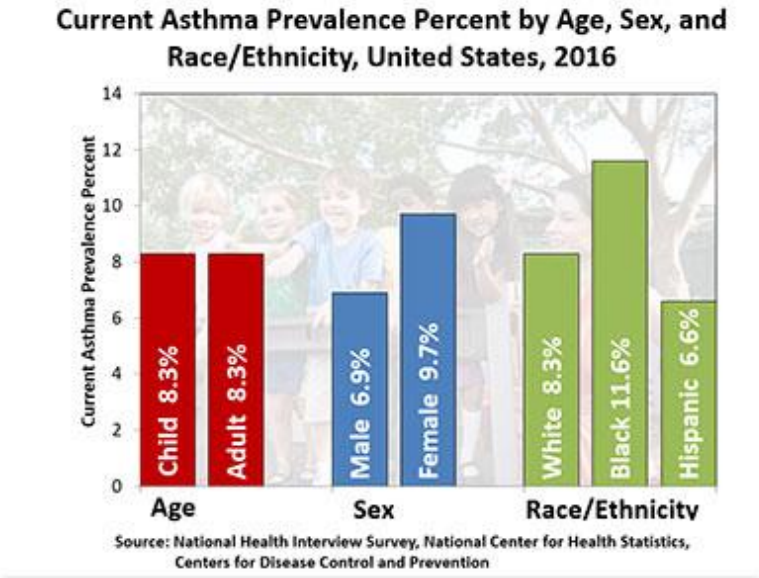

Figure 2: Asthma spread in US (Centers for Disease Control and Prevention, 2017).

Children are often diagnosed with this disease at a young age and often have continued symptoms into adulthood (Martin *et al.*, 1980). Boys tend to be affected by asthma more than girls and this holds true across age and demographics (Gergen, Mullally and Ill, 1988). The WHO reports that about 235 million people around the world are affected by this chronic disease (World Health Organization, 2017). Worldwide, asthma is the number one chronic limiter of disability-adjusted life expectancy among children (Asher and Pearce, 2014). As of 2016, one in twelve children in the US was diagnosed with asthma and one in two children had asthma attack, which demonstrates the severity of the problem affecting not only the children, but also their families and the community.

There are multiple triggers that can elicit an asthma attack. Thunderstorm asthma is a name given to the asthma attacks that are caused by thunderstorm activity. The rupture of the pollen grains due to rain and the distribution of these allergens due to heavy winds can cause increased asthma attacks during rainfall (D'Amato, Liccardi and Frenguelli, 2007). Changes in the climate, including rain or increased humidity, cause hydration and fragmentation of pollen grains, which are emitted into the atmosphere. During the summer, there seems to be a correlation between lightning strikes and asthma attacks. Falls in air-pressure, increased humidity, and drops in maximum air temperatures are also associated with asthma exacerbations. Rises in the concentration of atmospheric sulphur dioxide, used as a preservative in dried fruits, and nitrogen dioxide, a by-product of hydrocarbon combustion and industrial wastes, tends to increase rates of asthma attacks (Celenza *et al.*, 1996). Environmental Tobacco Smoke (ETS) is one of the primary indoor air pollutants that increase asthma prevalence and morbidity (Wang *et al.*, 1994). Additional causes include mold-spores, cockroaches, dust mites, rats, and mice (Delfino *et al.*, 1996; Mitchell et al., 1997) .

1.3 mHealth in Health Management

Mobile health applications are designed for improving the management and control of chronic diseases while others can also be fitness and nutrition related (Free *et al.*, 2013).

mHealth provides cost-effective ways to help manage chronic diseases and improve overall health outcomes. mHealth improves the decision-making process by providing the right amount of information at the right time. Remote data collection and subsequent remote patient monitoring using mHealth applications can eventually result in the improvement of the health and living standard of patients (Vital Wave Consulting, 2009). Just-In-Time Adaptive Interventions (JITAI) aim to deliver the required support to patients at the moment when it is needed, meaning providing the right type of support neither too late nor too early (Hulshof and de Jong, 2006). Mobile health applications deliver JITIAs with right the amount of information at the right time, regardless of the geographical locations and time zones of the users.

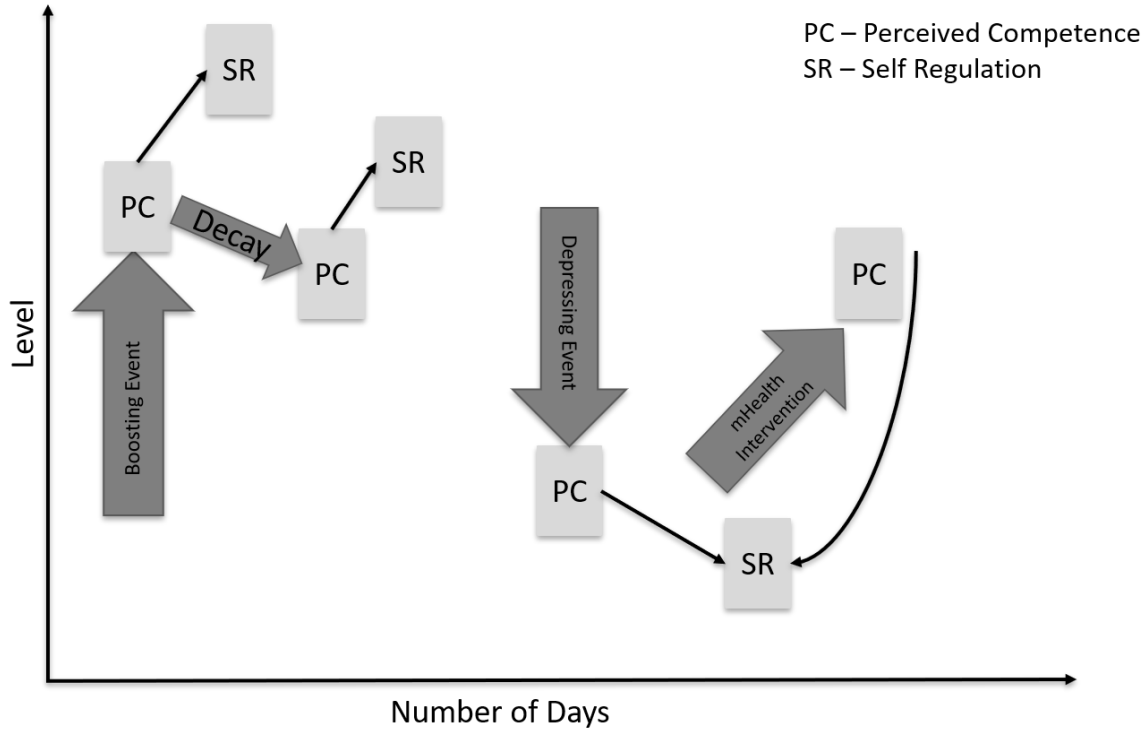

Figure 3: Just in time interventions using mHealth Applications.

Numerous features available in mobile applications, such as educational text, videos, flashcards, and easily-accessible symptom monitoring components, play a vital role not only

in improving the individual's quality of life, but also in minimizing the use of societal healthcare resources.

Of these features, a Short Message Service (SMS) is one of the most important elements and is considered a type of Ecological Momentary Assessment (EMA) (Nahum-Shani *et al.*, 2014). This type of active assessment involves the user receiving interventions in the form of text messages that prompts the user to perform a certain action or reminds them of a self-management task that needs to be completed. Sending text reminders to patients with chronic diseases has been linked to improved medication-regimen adherence. With respect to process improvement, mHeath's SMS feature has shown correlation to improved health management and fewer missed medical appointments (Ugburo, 2015). In China, researchers using SMS features reported improved appointment attendance by about 7% as well as overall improvements in chronic health conditions (Chen *et al.*, 2008). In Malaysia, a randomized control trial revealed an approximately 40% increase in appointment attendance for patients enrolled in the SMS-feature experimental group (Liew *et al.*, 2009). These SMS features can also be used to make sure the patient is following the medication routine and for monitoring other beneficial health assessment measures.

Chapter 2: Literature Review

A thorough literature review was conducted to gain insight and understanding of the current discussion about mobile health applications on chronic disease management, and successful interventions for asthma. These topics are closely related and are discussed through this section. Search terms included mobile health, asthma, mHealth, self-management applications, and childhood asthma interventions.

2.1 Asthma management models

Self-management of asthma, which has been a primary concern of CDC's "Controlling Asthma in American Cities" project, can be divided into a social learning model to set an achievable goal of controlling asthma, an educational model to develop problem solving ability and to have a deep understanding of the allergens and symptoms pertaining to asthma , or cognitive behavioural models to improve the physical activity along with other components included like community support (Newman, Steed and Mulligan, 2004). Educational intervention models teach the children about the strategies pertaining to prevention of asthma attacks, managing when having acute attacks by using various strategies like educational camps, videotapes, computer assisted information to improve the social skills. Educational camps, which are part of an educational model, consist of everyday interactive education, peak flow meter recording, and relaxation exercises. Children aged between 8 -10 years have shown an improvement in the self-awareness about asthma, understanding of what it means to have an asthma attack, and managing it and proper use of inhalers during the time of emergencies (Costa *et al.*, 2008). Asthma might cause the children to miss their regular classes in school. An intervention which involved training the children about the asthma allergens, question and answer session for children and their caretakers, and eliminating the hazardous allergens in and around the school campus have shown improvement in asthma symptoms in the participants, reduced wheezing problems in schools, and reduced absence from class (Clark *et al.*, 2004). The Biobehavioural model, which involves the participation and support from parents, peers,

friends, can be implemented in addition to Educational model in self-managing asthma. Okay With Asthma, an intervention that was built with Biobehavioural model demonstrated an improved attitude and knowledge towards managing the chronic illness with support from the family, peer and health care team (Wyatt and Hauenstein, 2008). Also, the Home Based and Individualized Intervention Model has shown enhanced medication adherence in the children with Asthma (Bartlett *et al.*, 2002).

2.2 mHealth in chronic disease management

The success of the mobile application in management of chronic disease is associated with its simplicity in monitoring the symptoms, communicating with providers or family, accessing the education materials related to the disease management. In research, mHealth provides the opportunity for the participants to take part in a study at their home and at their own time of convenience rather than travelling to a distant place where the study is taking place. This has enabled the study to be completed in a shorter time frame and provides access to real-time predictive modelling. The tools that help in managing the chronic disease in mHealth can be classified into three groups namely SMS, Mobile compactable software application, and medical device or sensor connected to a mobile phone which can be either wired or wireless. These mHealth tools can be improved and scaled rapidly by trying any combination of the sensors and in different electronic mediums (Kumar *et al.*, 2013).

2.3 mHealth Short Messaging Services

In a study conducted to improve the adherence of diabetes in adults, it is proven that SMS text messages have shown an improvement in the total adherence (Mulvaney *et al.*, 2012). This was made possible because of the clear content that was provided in the SMS and the alerts that were given based on the time zones of the users using the mobile software application (Mulvaney *et al.*, 2012). In Asthma management, Action plan of each patient plays a vital role in maintaining the quality of life of patients. Design of action plan for the patients is determined by the peak flow value recorded by the patients. By advising the patients to record

the peak flow value through SMS three times a day and delivering the action plan instructions pertaining to the recorded PF value, in addition to the traditional symptom diary, has shown a significant increase in the PF value after the end of a 16 week trial period, featuring the improvement of quality of life of patients enrolled in the trial (Ostojic *et al.*, 2005). Short text messages that were sent twice a day to the patients contained the information about the usage of spirometry, preparing the action plan, handling the acute asthma attacks, medication classes showed to remove the internal barriers and increase the level of PCA in addition to an improved quality of life (Haijin *et al.*, 2012).

2.4 mHealth Mobile application

Mobile health software application is the next larger mHealth tool. Unlike SMS services, mobile software applications provide the luxury of recording the Peak expiratory value in addition to tracking the symptoms electronically and recording the usage of inhalers. In one of the studies by (Cingi *et al.*, 2015), a mobile application software that tracks the afore mentioned variables was developed and a total score to the asthma severity was given between 1-3, 1 being good and 3 being bad. The score to Peak flow values are given in percentages (1 if value is <80%, 0 otherwise, inhaler usage 1 used, 0 otherwise) and a consolidated score for four asthma symptom questions. It was found the trial group using the mobile software has shown improvement in the quality of life and good pulmonary function. The limitation of this study was a small sample size of about 89 participants, no option to communicate with the provider, and the application seemed to be difficult for the visually impaired patients to use (Liu *et al.*, 2011). One common complaint that is heard among most of these disease management mHealth tools in that they are not efficient with communicating with their providers or acquiring the necessary support from them. There has not been a significant difference between the support that is gathered from a layman versus professional tutors (Barlow *et al.*, 2002). In a study conducted by (Cingi *et al.*, 2015) which involved about 60 patients seeking immediate assistance from their providers, in addition to recording their overall health status, Asthma Control Test (ACT) and receiving the reminders about their medication based on severity,

showed a significant increase in the Asthma Control Test score. About 92% of the messages that are shared with the providers were relevant to the Asthma disease while 8% comprised of gratitude messages, appointment requests, etc. Physicians responded to the patients messages either by sharing the education materials or responding directly to urgent messages through the timeline available in the application (Cingi *et al.*, 2015). These types of interventions are not only needed to improve the asthma control score but also for the adherence of the patient in using the application regularly and adhering to the proper medication.

2.5 mHealth Web Applications

Internet based self-management poses hope in improving the lung function, quality of life of asthma patients, and reducing the overall symptom among the users. Web application features the use of sharing the reports in the form of emails to the users. In addition, charts were also made available within the application to monitor the history of the inhaler usages and the behaviour of the patients with asthma symptoms (Van Sickle *et al.*, 2013). A web application designed by (van Gaalen *et al.*, 2013) to control long term asthma has seen improved asthma control, quality of life, and asthma symptoms by the end of a 12 month trial period. Web applications integrate several components like user authentication whenever the user tries to record the value, detailed symptom tracker, options to edit the user setting in sending the alerts and other reports to the user, providing extensive educational resources for assistance. The participants of this study received regular and continuous feedback from the providers/professionals notifying them of changes that should be done with the medication plan. All these features attracted participants and retained almost 85% of them throughout the study approving the use of web applications in managing asthma. Portal for Assessment and Self-management of Asthma developed by (Araújo *et al.*, 2012) recorded the peak flow value, symptoms experienced by the patients and returned the action plan designed by the providers is shared with the user. It also featured an intervention sent to both the patients and provider when the patient data is in the red zone or when the patient is scheduled for an appointment.

This study has seen an improvement in the quality of data collected from the patient and asthma quality improves every time the patient visits the hospital.

Although there is enough evidence to show that the mHealth and the tools have played an important role in improving the quality of life of asthma patients and improving the adherence to the medication and accurate symptom tracking , a comprehensive list of items suggested by (Huckvale *et al.*, 2012) is not completely present in the mHealth Apps. The items suggested by (Huckvale *et al.*, 2012) are the nature of inhaler used (maintenance or rescue), allergens resource, customizable action plan per symptom, and responding to the acute exacerbations and an effective communication among the care team

Chapter 3: Systems Engineering

Systems engineering is the application of principles from various engineering disciplines to find a solution to a multifaceted problem. The primary advantage of systems engineering is its application in the economic development of improved technological solutions (Hendrik W.Bode, 2011). Systems engineering should consider when any system is built to address a specific problem in society. It is an iterative approach that involves researching the problem, designing and developing the system, and testing and improving the system (Samaras and Horst, 2005).

Systems engineering was created by combining different engineering systems together. These systems include elements like people, machines, hardware, software, and policies. A basic system is a combination or collection of one or more of these elements combined together to form a solution for a problem (Buede, 2009). These elements are effective for solving problems in any discipline only when they are combined and are not as beneficial as individual elements. By combining these elements together, the performance, functions, properties, and characteristics of systems can be vastly improved. The interconnection of the elements between these single systems plays an important role in improving outcomes and the overall performance of the system (Maier and Rechtin, 2000). As illustrated in Figure 4, developing an effective system involves using systems management, systems engineering processes, and other systems engineering tools.

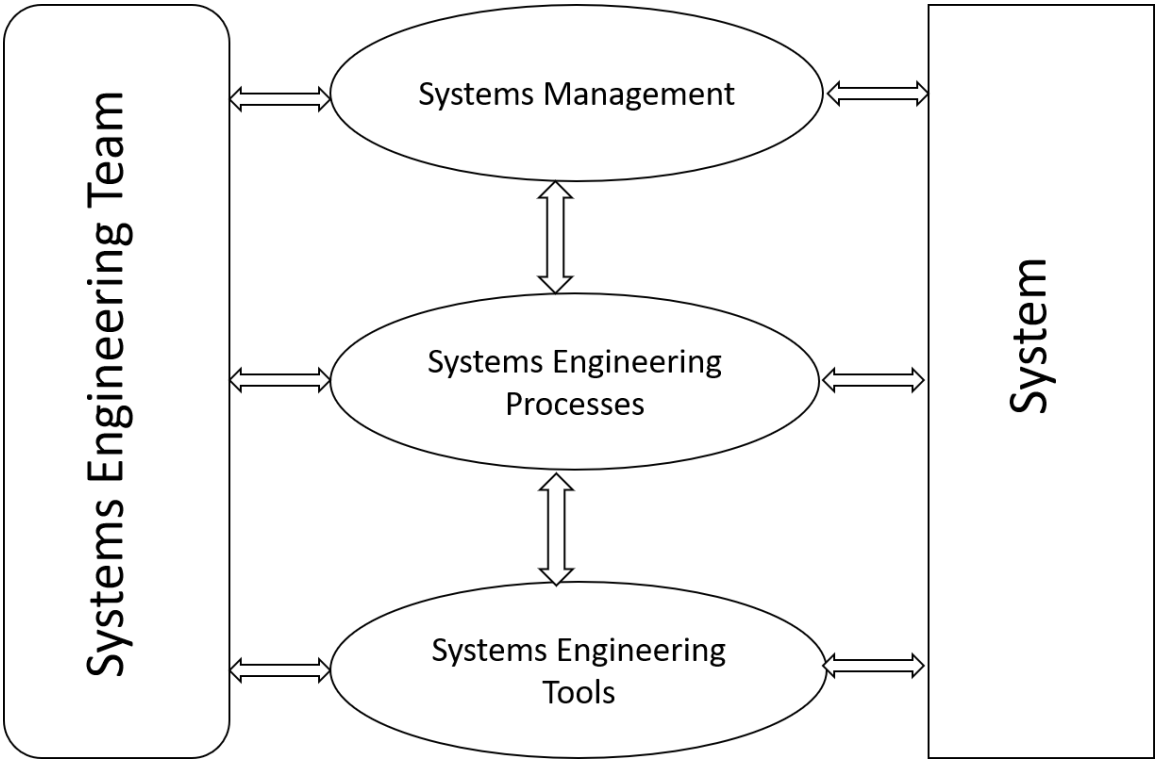

Figure 4: Systems Engineering architecture (Adapted from (Rouse and Sage, 2009)).

Studies show that systems that are software intense will be in demand until 2025. These are called Software Intense Systems (SIS). JASMIN is a SIS that can be run on a mobile or desktop environment. The following lists the primary reasons for the rapidly increasing demand for SIS: improved safety due to proper security configurations included in the system; ease of access regardless of the network; coverage of large, demographically diverse user populations; and substantial data collection at low costs (Boehm, 2006).

3.1 Systems Engineering Team

The first step in developing an effective system is the creation of the systems engineering team. This team is comprised of experts from different disciplines with the common goal of designing the system and creating an optimal solution. This is often called convergence research. Convergence research is a form of research for solving various research problems, especially those affecting an individual's daily life or broader societal issues. It involves

combining knowledge, methods, and skillsets from different domains to propose a solution for problems across any domain. Convergence research must be driven by a specific, compelling problem and must involve purposeful collaboration across disciplines (National Science Foundaiton, 2016).

3.1.1 Research Driven by a Specific Problem

Asthma is one of the most prolific chronic diseases negatively impacting health outcomes, not only in America but also globally. A system that can address this problem by assisting patients' self-management and by providing health education materials would be a greatly beneficial tool (NSF, 2016).

3.1.2 Collaboration Across Disciplines

A multidiscipline team was created with the goal of creating an effective system for this health problem. Asthma content experts from the College of Nursing, with thorough knowledge of asthma and years of experience treating patients with asthma, collaborated with experts in Industrial Engineering who have extensive knowledge of system development using systems engineering principles to address this issue. This collaboration lead to the creation of the system called Just-in-time Asthma Self-Management Intervention (JASMIN).

3.2 Systems Management

Actions involved in system management include software installation, data storage management, data security management, utilization monitoring, and creation of a user activity log (Kelly *et al.*, 1999).

The JASMIN system can be installed in any mobile operating system, from Windows to iOS. In addition to being a mobile application, JASMIN backend is hosted on a Linux server, which provides the flexibility for the system to be viewed as a standalone web application in any browser. The data collected from patients are safely stored in the MySQL database in a secure server room on the University of Tennessee's Knoxville campus. In the future, this stored data

can be mined to explore patients' medication adherence. JASMIN users' data, such as their page navigation, time spent on each page, and number of clicks on a single page, are recorded every time they log in to the system.

3.3 Systems Engineering Processes

System Engineering processes are a set of predefined steps that should be implemented while designing a system. While there are several processes involved in system engineering, the two main processes involved in developing JASMIN were SIMILAR (Bahill and Gissing, 1998), and Design Thinking.

3.3.1 SIMILAR

SIMILAR is a system engineering process and it involves a series of seven tasks that help building an ideal system. The seven tasks include stating the problem, investigating the alternatives, modelling the system, integrating the system, launching the system, assessing the system's performance, and re-evaluating the system's performance. Figure 5 shows a pictorial representation of the SIMILAR process for building an ideal and efficient system.

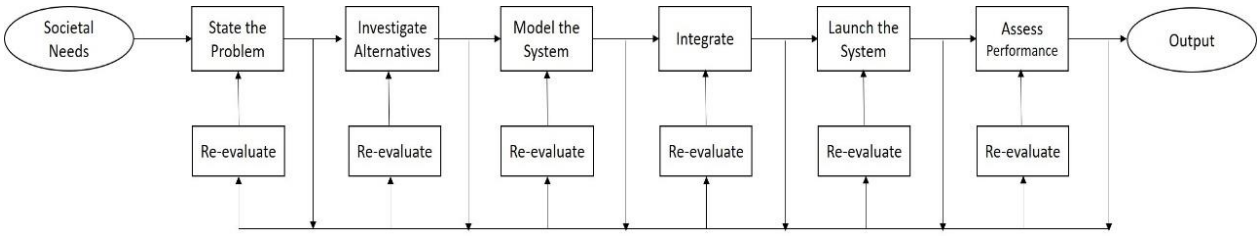

Figure 5: SIMILAR process (Adapted from (Bahill and Gissing, 1998)).

Some of the health behaviour needs addressed by this SIMILAR process during the creation of the JASMIN app included children's struggle with asthma self-management behaviours, their limited adherence to medication regimens, and their need for social support. Paper-based journaling and action plans have traditionally been used for self-management with

supplemental visits to medical centers during acute exacerbations; however, this process was cumbersome, expensive, and not highly efficient. Using electronic journaling, instead of traditional paper-based journaling, has shown beneficial in helping self-manage chronic diseases like asthma (Palermo, Valenzuela and Stork, 2004). JASMIN was created to include multiple self-management features that provide a communication forum between users, educational resources about asthma, geographical tracking of allergens, and tracking asthma control levels. Several of the single elements like Peak Flow Meter(PFM) entry, assessment questions, educational materials, chat page, and help page are integrated together to form a single complex system called JASMIN. All the single elements can stand alone, but they are more beneficial when combined into a comprehensive system that is capable of collecting and sorting the user data for the purpose of analysing the performance of the system. JASMIN is being launched as a part of a pilot study at East Tennessee Children's Hospital where a total of 60 participants will be recruited and instructed to use the system for 30 days. JASMIN data and qualitative feedback from participants will be collected during the study phase. This data will be used to evaluate the performance of the system as well as to analyse the impact of JASMIN on the children's asthma management.

3.3.2 Design Thinking

The other system engineering process followed in the JASMIN system design is Design Thinking. It is a six-step approach in solving a problem. The six steps in design thinking are Empathize, Define, Ideate, Prototype , Test , and Implement (Dorst, 2011; Bjögvinsson, Ehn and Hillgren, 2012).

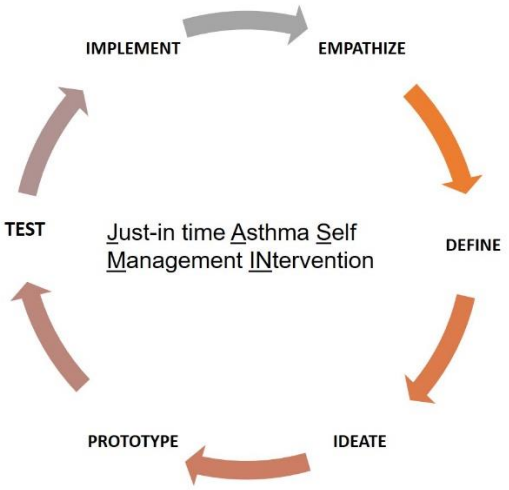

Figure 6: Design Thinking 101 (Adapted from (Dorst, 2011; Bjögvinsson, Ehn and Hillgren, 2012)).

Empathize:

JASMIN is designed for children ages 7-17 years old with asthma. As of studies done till 2010, more than 600,000 emergency room visits were made by children who are below 15 years old (American Lung Association, 2017). Advancements in technology and improved science allows researchers to address this issue in a more efficient and effective manner.

Define:

This system has been designed to help reduce the numbers of emergency room (ER) visits by children with asthma. By reducing ER visits, not only is the child's health improved but also medical expenditures are reduced. Currently, medical expenditure is a significant burden on the US economy. In 2007, the total cost to treat patients with asthma reached 56 billion dollars (Centers for Disease Control and Prevention, 2011).

Ideate:

Current asthma care often includes using a paper-based journal to record symptoms and self-management behaviours and learning about asthma on the internet. This traditional approach often leads to difficulty adhering to medication regimens, forgetting to track symptoms, or

perpetuating misinformation about asthma. The JASMIN system addresses all these issues via state-of-the-art technology features in a tool that is accessible to all patients with asthma. It not only includes a sophisticated journaling feature for tracking asthma symptoms, but it also provides the opportunity for the entire care team to communicate with each other along with asthma education resources.

Prototype:

The JASMIN prototype is developed as both a stand-alone web application and a hybrid mobile application that can run on any mobile operating system. This prototype has several components such as the dashboard, asthma action plan, medication use tracking, educational videos, and monitor for outdoor air quality.

Test:

The testing of this prototype was done at the Ideation Laboratory. Several use-cases were developed, and the app was tested against all those use-cases. A few features, like the educational video and bar charts for displaying medication usage, were added during the test phase.

Implement:

JASMIN is now being pilot tested at East Tennessee Children's Hospital. A total number of 60 participants are being recruited and will be trained to use the JASMIN system. JASMIN access will be given for a total of 30 days and feedback from the participants will be collected. The data from the pilot study will be used to build a predictive model that can be used to determine the rate of readmittance of children to the ER after using JASMIN compared to children using traditional self-management methods.

3.4 Software Engineering Tools

While there are many mathematical models used in system engineering, Agile methodology, one of the lean six sigma, was selected for developing JASMIN. This method aims to develop

a robust system, taking in continuous feedback and improving the system performance as needed without changing the entire system design. Types of agile methodologies that are followed in the mobile application development lifecycle are adaptive software development, Agile modelling, Crystal family, dynamic systems development method, eXtreme Programming (XP), feature-driven development, internet-speed development, pragmatic programming, and Scrum (Abrahamsson *et al.*, 2003). XP, one of the afore mentioned agile methodologies, was followed during the development of JASMIN. XP adapts a number of sprints involving constant coordination with the business and development team, continuous testing, integration, and mini-releases once every two weeks. Extreme programming was a good fit for developing the JASMIN system because, instead of focusing on the long-term results and consuming time and money in planning, analysing, and optimizing the resources, releases were quick and the feedback instant, which reduced the planning time and cost associated with the software development (Beck, 1999; Beck and Kent, 2000).

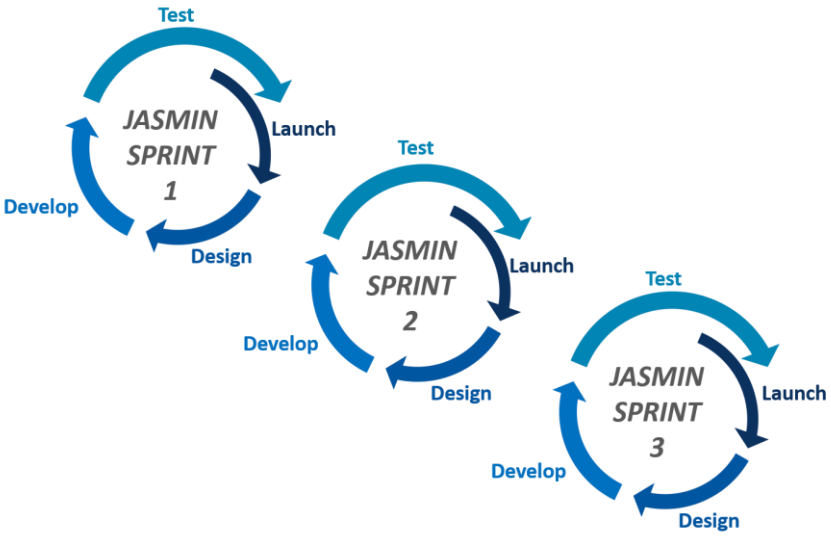

Figure 7: Agile - Extreme Programming (XP).

3.4.1 Extreme Programming in JASMIN

First Sprint: The initial version of JASMIN consisted of the features that enabled the basic data capturing pages including the assessments, chat option, and the educational resources. This made JASMIN a functioning resource for basic asthma self-management.

Second Sprint: Once the first sprint of the JASMIN was successfully launched, a couple of pages, including the badges and help page, were developed and tested. After testing, the next version of JASMIN was released. A bug preventing a parent with three children from viewing the third child's action plan was detected after the launch of the system.

Third Sprint: In the third sprint, the bug involving the action plan was fixed and bar charts were added for the assessments and the inhaler usage page. These charts capture the user inputs and display the user data with the time in the X-axis against the value selected on the Y-axis. These features underwent rigorous testing and the third version of the application was launched. After user testing, it was proposed that physicians should be able to opt out of receiving text alerts.

Fourth Sprint: The most recent version of JASMIN includes the option for the providers to opt out of the SMS notifications, which improved provider satisfaction. Further educational resources from the National Health Institute were added to the resources page alongside the information about asthma that was already provided.

Chapter 4: System Architecture

JASMIN consists of both a frontend and backend for data collection and data manipulation, which contributes to the system's smooth functioning. The frontend of JASMIN is built on the Quasar framework while the backend is built on Laravel's framework.

4.1 Frontend

The frontend of an application is the part which the user accesses to enter data or see any requested output from the system. The Quasar framework was chosen to build the frontend of JASMIN. Quasar is a free, open source MIT licensed framework that can be used to build powerful hybrid mobile applications. The mobile applications that are built using this framework are compatable with any web browser. Quasar framework is built on top of Vue.JS and it offers options to build hybrid mobile applications which can run on any mobile operating environment. HTML5 and CSS3 are the programming languages which can be used to develop a mobile application in the Quasar framework.

The frontend of JASMIN allows the users to view the application's output and to input their peak flow values and medication use and edit their user profile information. JASMIN has a Dashboard, Profile tab, Message Center, Chat Feature, Assessment tab, Asthma Action Plan Feature, Inhaler Usage Tracker, Badge Feature, and Educational Resource tab that were built using the Quasar framework.

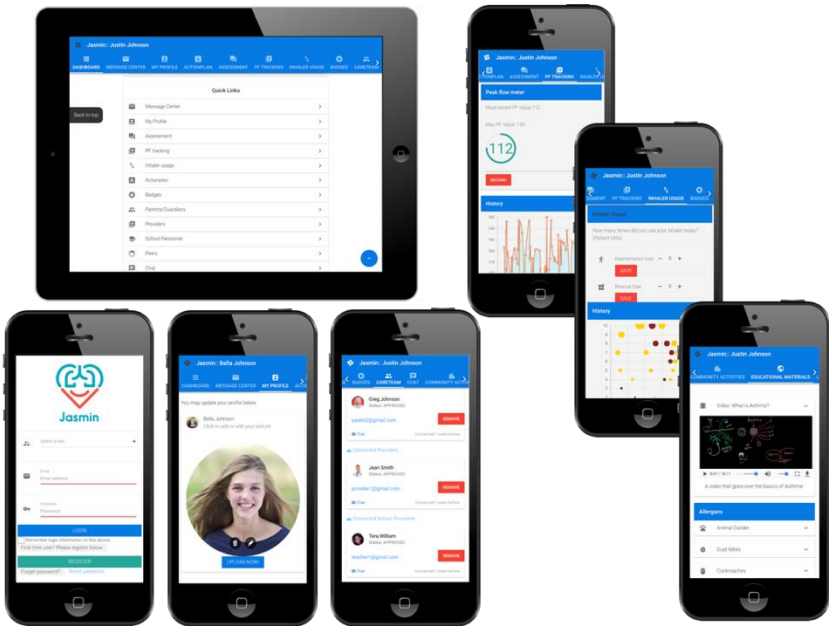

Figure 8: JASMIN and its User interaction pages.

4.2 Backend

The backend of the JASMIN system is built using the Laravel framework. Laravel is an open sourced MIT licensed framework that is built using the Model-View-Controller (MVC) architecture. MVC is a powerful framework for designing any system because the model page controls the flow, the view page controls the design aspects of the system, and the controller acts as the brain of the entire system. Also, Laravel comes with two virtual environments -- Homestead and Valet. Homestead is the system used for Windows and Valet can be used for Mac operating systems. The main use of these virtual environments is the presence of preinstalled PHP (Hypertext Pre-processor), an Apache web server, and for all other necessary components that are used to run any mobile/web application. These features are built-in, which means the user is not required to install this application onto the machine. The scripting language that is used to contact the database, retrieve the data, and post the data to the frontend is written in PHP.

Web services are used to address problems that are caused by the heterogeneity of networks, access technology and other actuation devices, and to host clients. In addition to solving these

challenges, web services can also be used to develop interoperable applications (Parra *et al.*, 2014). Representational State Transfer (REST) is a light and clean technology that is used as an alternative to Simple Object Access Protocol (SOAP) based services, which are heavy and suffer performance degradation (reference). REST is a stateless framework with protocols that are designed to be independent and transparent for building large-scale distributed systems. The architecture of the REST framework is based on Resource Identification through Uniform Resource Identifiers (URI), uniform interface, self-descriptive messages, and stateful interactions through hyperlinks.

URIs provide a global addressing space for resource and service discovery and are used to identify any resource that is present in the system (Croll *et al.*, 2007).

The interface in the system built with the REST service is uniform. This is achieved by using Create, Read, Update, Delete (CRUD) operations with PUT, GET, POST, and DELETE commands, which manipulate the resources uniformly. Below are the uses for the commands:

- PUT: Responsible for creating a new resource.
- GET: Retrieves the current state of the source, which includes all the input from the client through the HTTP request.
- POST: Submits any form of data that has to be processed to the database.
- Delete: Deletes any new resources that were created after using the PUT command

The resources are decoupled, which makes it simple to access HTML, XML, plain text or any other format based on user needs. Authentication or detecting transmission errors can be performed with the available metadata resource. Since the interactions are happening through hyperlinks, all the interaction with the resources remain stateless, which makes REST stateless. Chrome or Internet Explorer can be used to host the client due to the lightweight infrastructure of REST's service (Pautasso, Zimmermann and Leymann, 2008).

The frontend and the backend of JASMIN communicates using RESTful API, one of the most powerful modern application programming interfaces. RESTful API conducts the GET and POST functions that occur between the client and the server side of the application.

JASMIN has several security features included within the application.

4.2.1 HIPAA Compliance

According to the Privacy Rights Clearinghouse report (2018), over 23 million data breaches involving healthcare data have occurred to date. The primary cause of these data breaches is due to design flaws committed during the initial stages of the system design. These security breaches involve releasing user's private demographic and health-related information to third-party vendors. There are two types of risks that are involved with these kinds of security breaches – identity theft and privacy risk. Of the two, identity theft is considered to be the most dangerous and is one of the fastest growing types of theft in the United States (Schneier, 2005).

To protect against these types of healthcare data breaches, the Health Information Interoperability and Accountability Act (HIPAA) of 1996 was passed. The primary aim of HIPAA is to protect user's data while providing users with high-quality care at a reduced cost. The privacy components of HIPAA regulations were created in April of 2003 and further security regulations were added in April of 2005. Since the passing of this legislation, it has been mandatory for any healthcare agencies, hospitals, or insurance providers to adhere to HIPPA privacy and security mandates while building healthcare operating systems or handling patient information (Appari *et al.*, 2009).

The JASMIN system is HIPAA compliant. All the security and privacy regulations that are listed in HIPAA were duly followed while developing JASMIN. The main server area, where the data records are stored, is closely monitored and only authorized personnel can enter the server room. Some of the following IT features were included in the JASMIN system to make it more secure and to protect against a data breach.

4.2.2 HASHING

Password hashing was introduced to Information Technology in 1970 and it prevents passwords from being stored as plaintexts in a notepad or WordPad file. This addresses the risk of storing passwords in a simple notepad or WordPad file that would be easily accessible to hackers and risk the exploitation of data. Several password hashing algorithms have been introduced and *bcrypt* is one of these hashing algorithms (Provos, Mazières and Mazi, 1999). *bcrypt* is an adaptive hashing function based on the Blowfish cryptographic algorithm. It is a slow hashing algorithm compared to other algorithms like SHA-2. The benefit of a slow hashing algorithm is that it creates a better output hashing for the passwords, which provides more resistance against hackers attempting to break into the system (Malvoni and Knezovic, 2014).

The backend system of JASMIN, which runs on the PHP server, has this *bcrypt* hashing algorithm implemented. This increases the security level of the user's passwords that are being stored in the database.

4.2.3 JSON Web token

JSON Web Token (JWT) plays an integral role in providing security during the authentication and use of any system application. JWT is a JSON Object which is in RFC7519, which creates a safe means of a facilitating data transfer between two parties. JWT encodes and signs the data rather than encrypting the data. The structure of data is transformed during the transfer of the data by encoding it. The authenticity of the data that is being transferred can be ensured by adding the Sign component to the transferred data. Header, Payload, and Signature are the three most important parts of JSON Web Token. The two most common places where JSON Web Token can be used are for Authentication and Information Exchange. During the authentication, each subsequent request that is sent to the user after the initial login will include a JWT, which makes it more secure. Furthermore, the JSON Web Tokens usually

require a secured HTTPS connection for maintaining the lightweight infrastructure rather than an unsecured HTTP environment (Jones & Bradley, 2015).

The authentication feature of JASMIN is executed using this JSON Web Token. When the user first logs into the system, a JWT is created and is used for each subsequent action performed by the user in the system such as navigating to different pages or updating user information. The typical authentication architecture of the JSON Web token is illustrated in Figure 8.

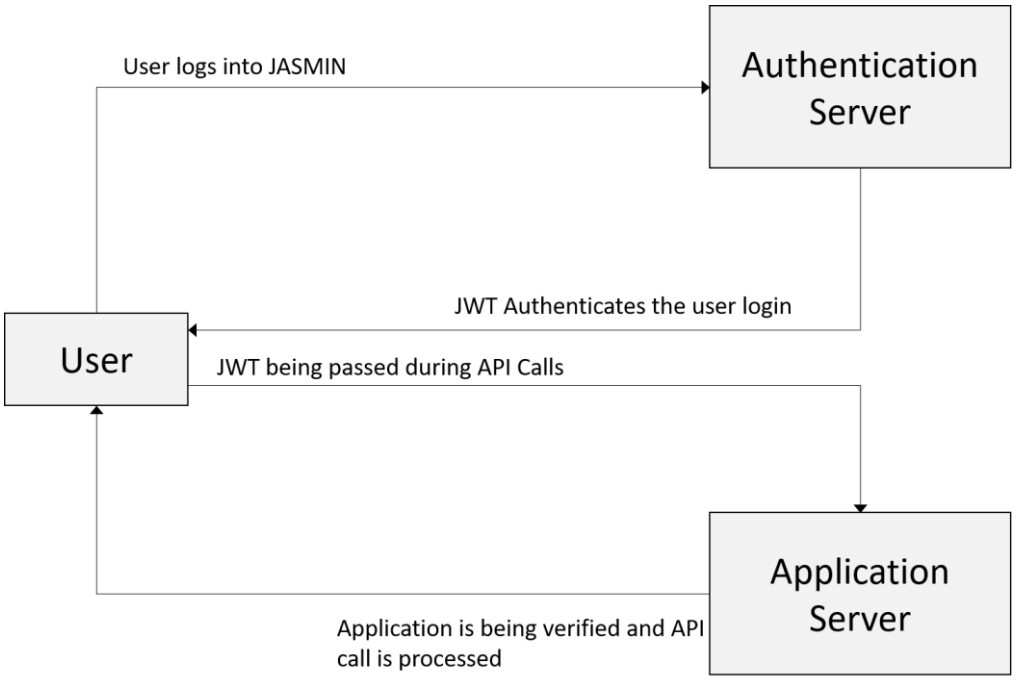

Figure 9: Illustration of a JSON Web Token

4.2.4 SELinux

Security-Enhanced Linux or SELinux is a Mandatory Access Control (MAC) system (National Security Agency, 2000). SELinux protects the system from malicious software programs or any other programs that might harm the system and its performance. The two fundamental properties of SELinux systems are Discretionary Access Controls (DAC) and Type Enforcements. The DAC component of SELinux provides the administrator with control over all the file systems, directories, files, sockets, messages, and the network interface. Type

enforcement is important for maintaining the performance of the system because it categorizes every object in the system into specific domains and labels. Additionally, SELinux has Role-Based Access Control (RBAC), which gives privileges to the users based on their designated role. For example, a Super User ID (SUID) might have full access to add a record, update an existing record, or delete the record, whereas a User ID (UID) might have more limited access to these features. This RBAC reduces the complexity when a new user needs to be added or removed (Croll *et al.*, 2007).

This part of SELinux is beneficial to the JASMIN system as the backend Apache Web Server and Laravel and the MySQL database Server are run on top of SELinux.

Chapter 5: JASMIN Features

This section explains the purpose and use of the JASMIN system features. JASMIN contains the following features: a login/registration page, application overview page or dashboard, personal profile creation page, asthma-control assessment questions and tracker, PFM value tracker, inhaler usage records, a personalized action plan, chat feature, community page, reward badges, help page, and logout page.

Effective asthma management depends on patients' understanding of their symptoms based on regular self-assessments, the following of their prescribed action plan and their adherence to their medication regimen. Self-management and adherence to prescribed treatment plans can prove difficult for a young child. Barriers to self-management that have been reported in previous studies include a lack of support from parents, insufficient resources in the schools, and an inability to control the environmental triggers (Forbis *et al.*, 2006; Laster *et al.*, 2009; Liberatos *et al.*, 2013). Children often struggle to understand their medication regimen or to identify symptoms of asthma exacerbations (Friend and Morrison, 2015). JASMIN was created to help support these children with their asthma self-management and it uses a biobehavioural community model framework as its theoretical basis. The biobehavioural community model relies heavily on the child's parents, school personnel, healthcare providers, and community. This model is inspired by Bronfenbrenner's model which includes numerous societal components that affect health management such as the child, the child's family, peers, and the child's broader community (Naar-King *et al.*, 2009). The use of this model as a guide for asthma management interventions has been shown to be effective in previous studies and is a logical foundation for this asthma tool (Friend and Morrison, 2015). JASMIN provides a platform for social interaction between the child, parents, school personnel, and healthcare providers while simultaneously supplying information about asthma support communities, reporting geographical air quality measures, and providing basic education about asthma and asthma triggers.

Figure 10: Bio-Behavioral Asthma Management Model Design (Adapted from (Naar-King et al., 2009)).

5.1 Login Page

The login page is the first feature in the JASMIN system. This page allows the user patient to either log in with existing credentials or create an account within the system. Before entering the credentials, the user must choose a role from the following choices: child, parent, provider, peer or school personnel. The username and password credentials will be matched with the user role within the database and, upon successful login, the user will be able to use the app with the specific features that are approved for each type of user.

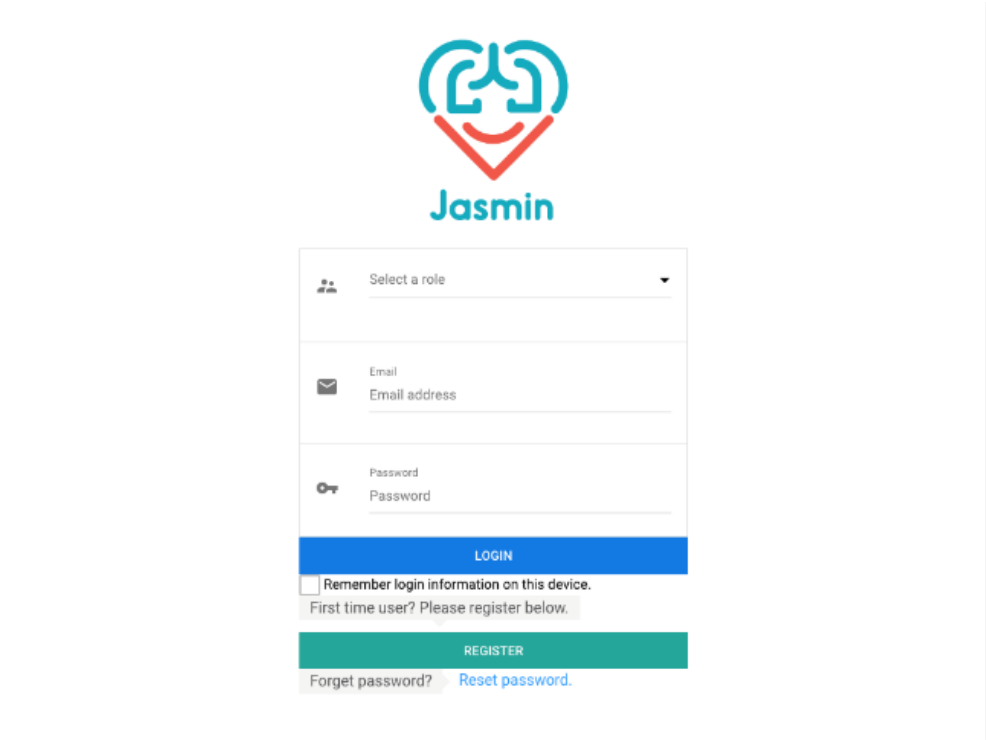

Figure 11: Login Page in JASMIN

5.2 Dashboard

On this page, the user can see their “JASMIN code”. This is a special code that the user can share with any of their care team and allows the members of the care team to connect their profiles to the primary users’ account. This page also has features that show air quality readings based on global positioning system (GPS) data, the local weather report, upcoming self-management tasks, and unread messages from other JASMIN users. This page will also show the entire care team whether the child is in the green (asthma under control), yellow (asthma symptoms are getting worse) or red zone (needs immediate medical attention) based on the information entered by the child into JASMIN. From this page, the user navigates to any other page either by using the quick links at the bottom of the page, the tabs on the top of the page, or by clicking the rotating icon in the top left corner.

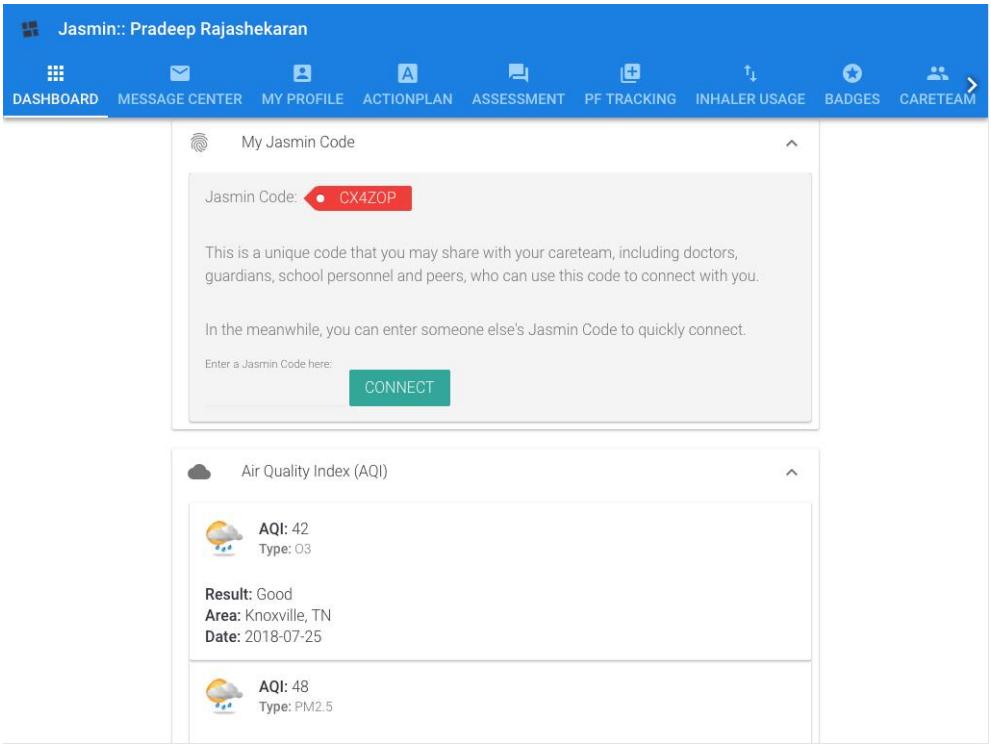

Figure 12: Dashboard Page in JASMIN.

5.3 Message Center

The third element in the JASMIN system is the Message Center. This page displays messages from any care team members as well as requests by other JASMIN members to connect with the user. The user can navigate to the ‘Care Team’ tab to confirm these connection requests.

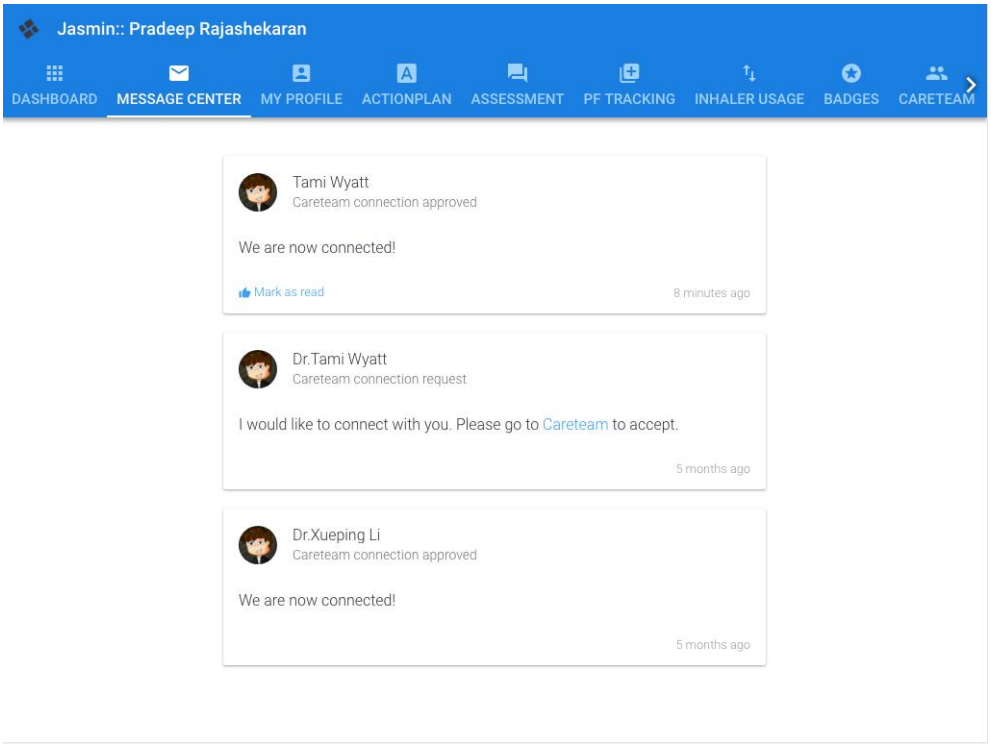

Figure 13: Message center Page in JASMIN.

5.4 My Profile

This feature collects basic demographic information from the user. This page lists options to upload or change the user's profile picture, update the password, edit the username, or update the user's mobile phone number. Mobile numbers must belong to smart phones for the JASMIN system to send text reminders to the mobile device from the application. On this page, providers have the option to enable or disable text and email remainders that are sent to them from the system. Providers might get overwhelmed when they are too many reminders about all the children who are taking part in the study and affect their daily work.

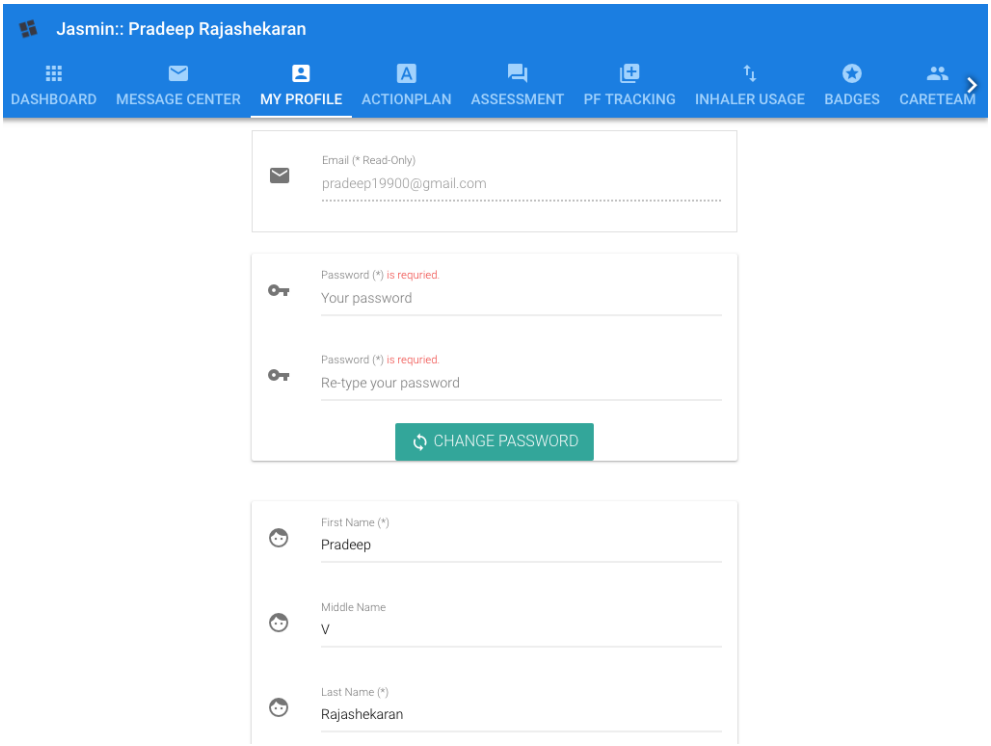

Figure 14: My Profile Page in JASMIN.

5.5 Action Plan

This feature of JASMIN provides a digital asthma action plan based on the National Heart, Lung, and Blood Institute (NHLBI) guidelines (National Heart, Lung, and Blood Institue [NHLBI], 2007). Traditionally, a written questionnaire was given to patients prior to healthcare visits in order to identify the patient's current level of asthma control (Dinakar, Van Osdol and Wible, 2004). JASMIN incorporated this same assessment and action plan in a digital format. The action plan includes a prescribed medication plan for three different control zones based on patient symptoms and current peak flow meter value. Patients in the Green Zone are labeled as 'Doing Well' and are advised to continue with their normal medication use. Those in the Yellow Zone have worsening asthma and additional medication used is advised per their provider's instruction. When the patient falls in the Red Zone, it's considered a 'Medical Alert' and patients are instructed to find the nearest hospital for emergency treatment. Parents or providers can edit the action plan, including medication names, dosage, and target peak flow

scores as well as provide any special instructions for the child at the bottom of this page. Children using JASMIN do not have the ability to edit their action plans.

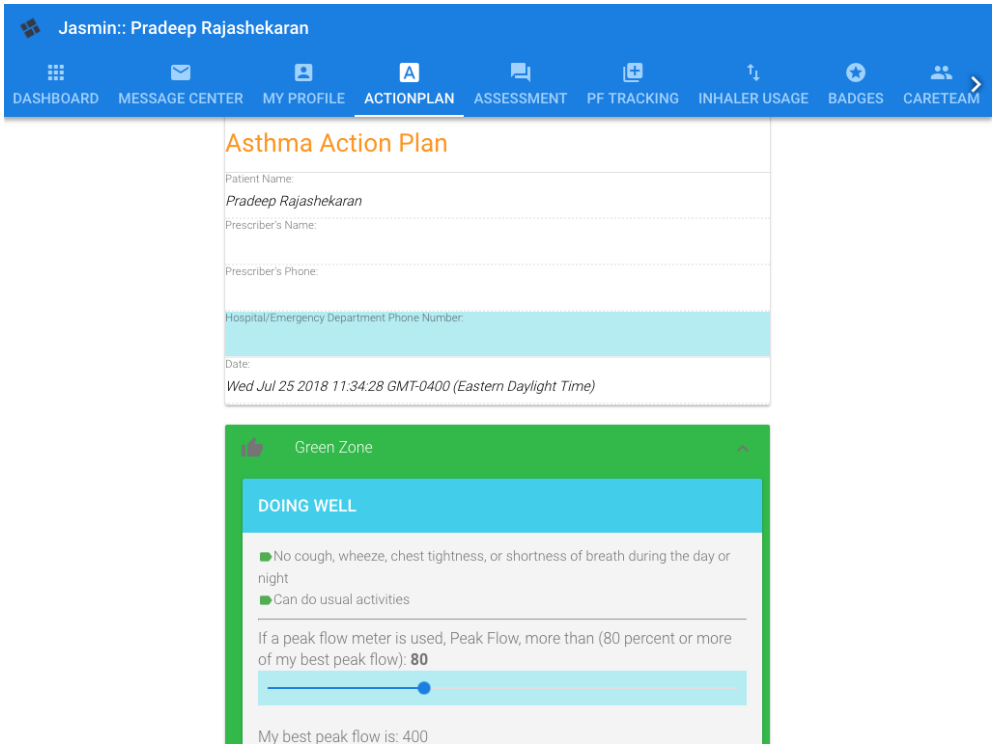

Figure 15: Action Plan Page in JASMIN.

5.6 Assessment

This part of the system includes Classifying Asthma Severity Test (CAST) assessment questions. Past studies have created asthma severity scores based on the patient's chest retractions and wheezing (Gorelick *et al.*, 2004). Building on the success of these previous studies conducted with children between 5-17 years old, this CAST score has been formulated with additional and more detailed questions that aim to help better reveal asthma symptom severity and place the patient in the correct asthma action plan zone. (Smith, Baty and Hodge, 2002). The CAST section consists of four different assessment questions. When completing the assessment, the user chooses one of four answers to each question. The answer to each question is ranked from zero to three, with zero being the best score and three being the worst. The final score for the assessment is out of twelve potential points. This final control

assessment score places the patient into the green, yellow, or red zone (Odom and Christenbery, 2016). Once all four questions have been answered, the zone classification is revealed. CAST scores and corresponding zone classifications are also listed in a chart on this page under the assessment questions. If the user fails to complete this assessment, daily text and email reminders will be sent to the entire care team.

Table 1: Asthma zone classification

CAST Score	Zone Classification
0-1	Green
2-9	Yellow
10-12	Red

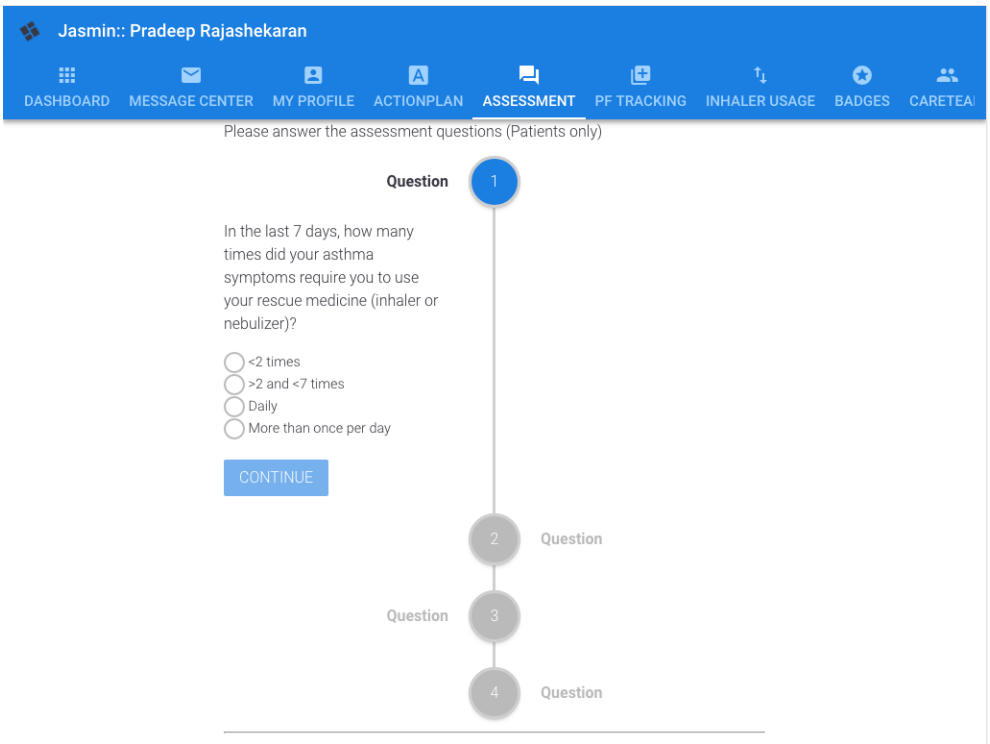

Figure 16: Assessment Page in JASMIN.

5.7 Peak Flow Tracking

Peak Expiratory Flow (known as PEF, Peak Flow, or PFs), describes the amount of air that comes out of the lungs when the patient exhales with full force and is measured in liters per minute. The device that measures PEF is called a Peak Flow Meter. This is one of the cheapest and easiest ways to measure asthma severity and levels of asthma symptom control (Wensley and Silverman, 2004). PEF readings have also been shown to be useful and reliable when evaluating changes in asthma severity (Zhang, 2005). In JASMIN, the child can manually enter his or her PEF value. To record the score, the child must enter the value and click “Save.” After the value is entered, the parent or provider will be able to review this value and compare it to the set values in the child’s asthma action plan. The set values in the action plans are based on the child’s personal best PEF scores. The green zone encompasses PEF values within 80 - 100% of the child’s best baseline PEF value, the yellow zone includes PEF values between 80-50% of the baseline value, and the red zone includes all scores below 50% of the baseline value (Nhlbi, 2007). These zones correspond to the asthma action plan and actions to take based on the PEF scores are outlined in the action plan (Adeniyi and Erhabor, 2011). A graphical representation of the daily or weekly-entered PEF trends can also be viewed on this page.

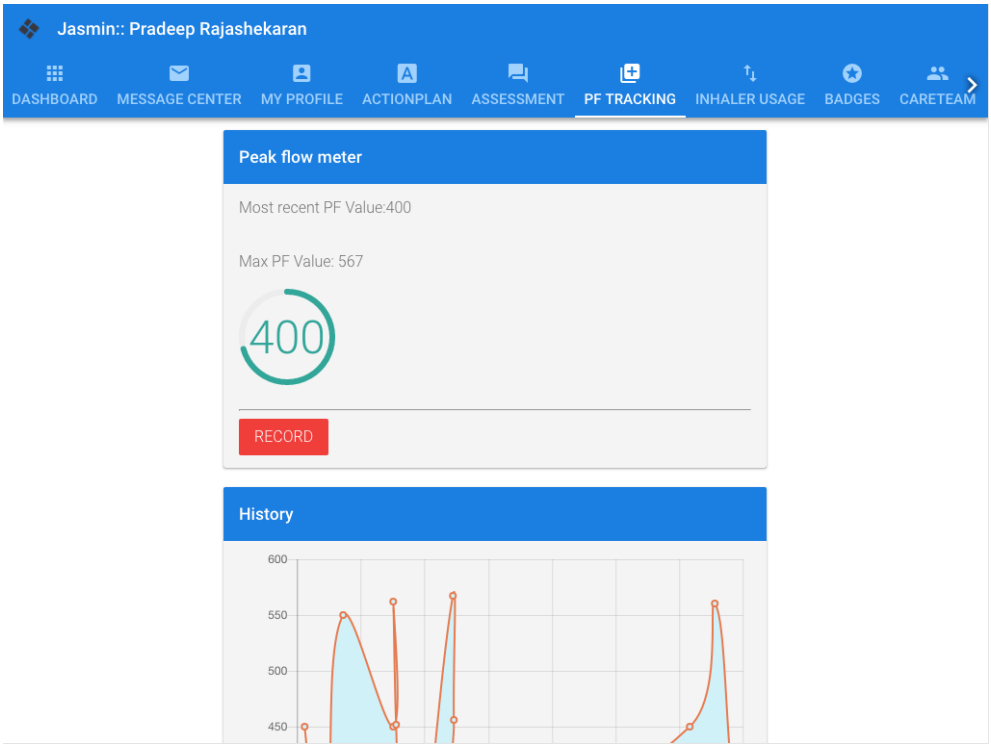

Figure 17: PF Tracking Page in JASMIN.

5.8 Inhaler Usage

Daily inhaler use is another indicator of asthma control. There are two types of medication inhalers commonly used by patients with asthma – maintenance medications and rescue medications (Byer and Myers, 2000). Children with asthma are prescribed maintenance medications for daily use and rescue inhalers for acute asthma exacerbations (Allen *et al.*, 2012). In JASMIN, the user is required to submit data regarding how many times maintenance and rescue inhalers were used that day. Similarly, to other JASMIN tabs, this feature is accompanied by a chart representing the pattern of both the maintenance and rescue medication use. High levels of rescue medication use is a sign that the child's asthma is not under control and his or her treatment plan should be revisited.

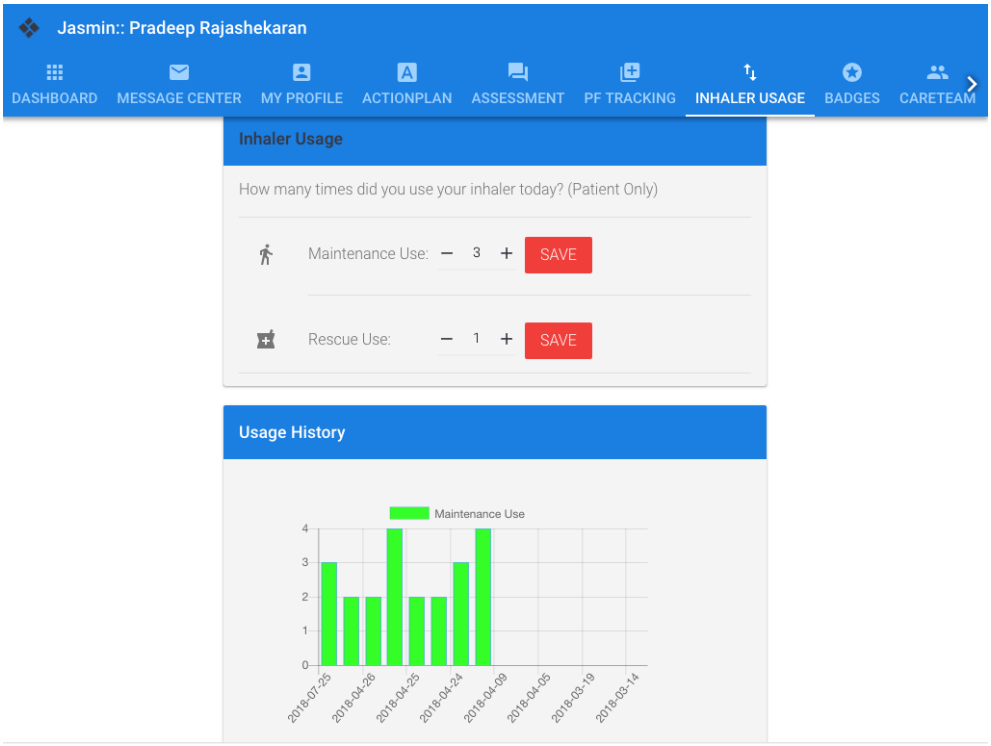

Figure 18: Inhaler Usage Page in JASMIN.

5.9 Badges

Psychological studies suggest that children tend to positively modify their behavior when their efforts are properly recognized and rewarded (Zhao et al., 2017). In an effort to recognize children's use of this app, reward badges will be made available and will be awarded to the children after a seven-day use streak, a fifteen day use streak, a 30 day use streak and so on for each consecutive fifteen days of use. This element of the JASMIN system is still under construction. The feedback from the ongoing pilot usability study will be used to modify this feature. The below image portrays the badges page that is built in the JASMIN system.

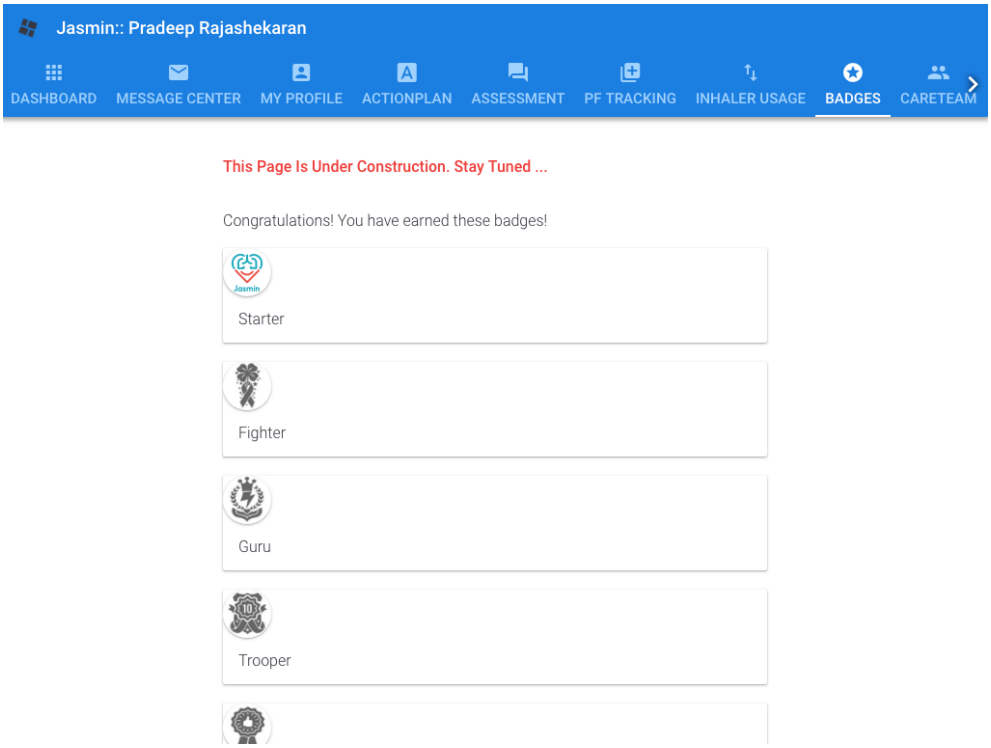

Figure 19: Badges Page in JASMIN.

5.10 Care Team

For any patient with a chronic illness, the social support provided by a care team is greatly beneficial and this is especially true when the patient is a child. Children with a chronic illness often struggle to identify exacerbation symptoms or they may struggle to adhere to their prescribed treatment plan. Care team members who understand the child's treatment plan and can help the child self-manage his or her asthma between provider visits are a crucial aspect of chronic disease care (Bodenheimer, Wagner and Grumbach, 2002). The child's care team should ideally be comprised of the child's family, friends, school personnel, and his or her healthcare provider. This helps create a supportive environment for the child while he or she learns to self-manage his or her asthma (Lemieux-Charles and McGuire, 2006). The care team is strongest when it is multidisciplinary, interdisciplinary, and transdisciplinary because the members are able to share their domain knowledge while speaking a common language of care (Dinakar, Van Osdol and Wible, 2004). This page of JASMIN allows the primary user

to connect with his or her team by entering the team member's JASMIN code and clicking on the "connect" button. A request will then be sent to team member's account. Once the connection request is accepted, the team member can see the child's account and connect through JASMIN. Similarly, the child can be sent a connection request by a team member and can accept these requests by clicking the green "accept" button on this page. There is also an option to remove care-team members by clicking the red "remove" button. Once users are connected to other accounts, they can chat or send emails to anyone on the care team.

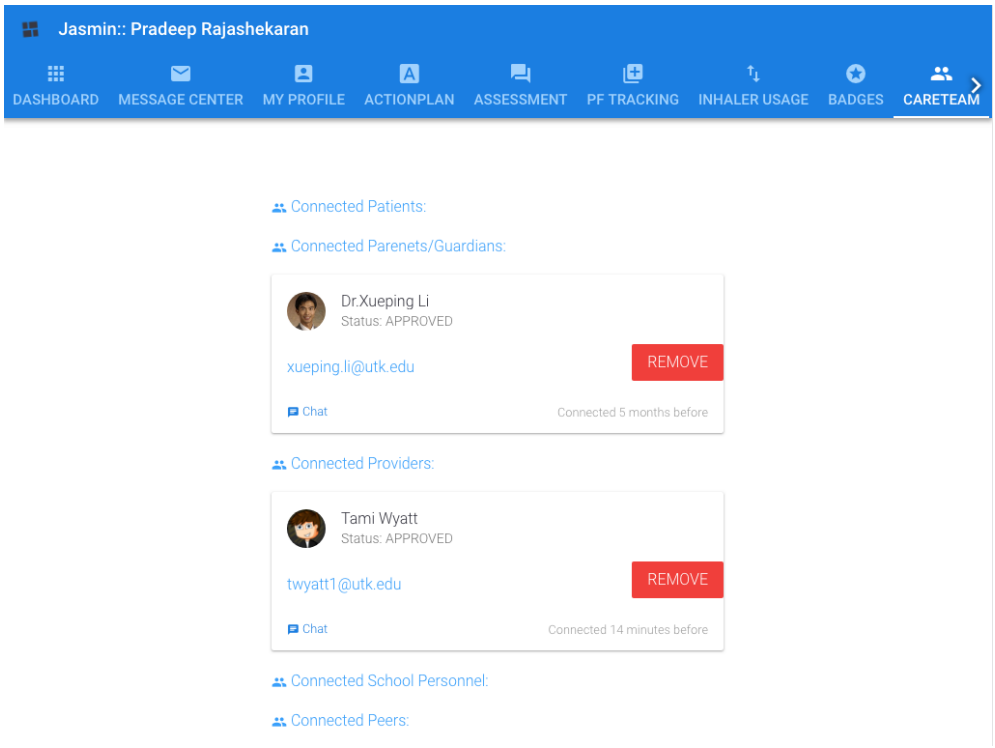

Figure 20: Care Team Page in JASMIN.

5.11 Chat

During self-management of any chronic illness, the interaction between the patient and provider is essential and can involve communication through e-messages or chats. Patients feel more motivated when they are able to communicate with their provider electronically whenever they feel ill or confused about their plan of care (de Jong, Ros and Schrijvers, 2014). JASMIN allows children and parents to communicate with the child's provider or with other

members of the care team instantly through the chat feature. Interestingly, this chat feature allows for group chat and can include everyone in the care team at the same time. A child can be at school, the provider might be at the clinic, and the parents might be at home, and all these team members can receive a digital message simultaneously and respond accordingly. Anyone who is connected to the account will be able to see these chat messages and take part in the chat discussion.

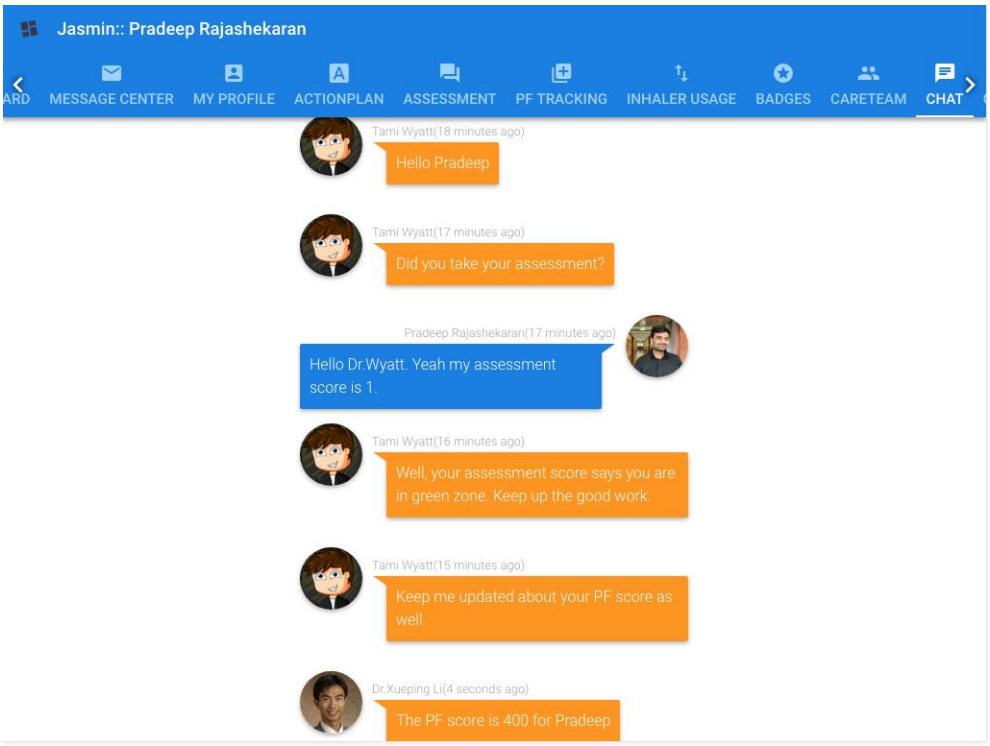

Figure 21: Chat Page in JASMIN.

5.12 Education and Community Activity

Community educational programs are often highly effective for teaching patients about asthma self-management (Fisher *et al.*, 1994; Garrett *et al.*, 1994). However, these program implementations can sometimes prove difficult due to their complex and diverse nature. JASMIN seeks to provide a simplified avenue for users to learn about asthma. The most effective way for users to learn is for educators to create the opportunity for users to learn at their own pace and convenience (Partridge and Hill, 2000). JASMIN's community feature

allows users to post any activity that is taking place in their community and send an open invitation for others to participate. Ideally, this will create opportunities for health-related social connections among JASMIN users. Everyone who uses JASMIN can post about activities or events that are happening in and around their community and can invite others to join the activity. Also, users can send JASMIN-wide notifications about air quality alerts in their area. To add any asthma trigger spot, users can select “add an asthma trigger spot” and then hit the “save” button. JASMIN also includes an educational material page. Reading through these materials and watching the accompanying videos can help users learn facts about asthma and learn how to better self-manage this chronic condition.

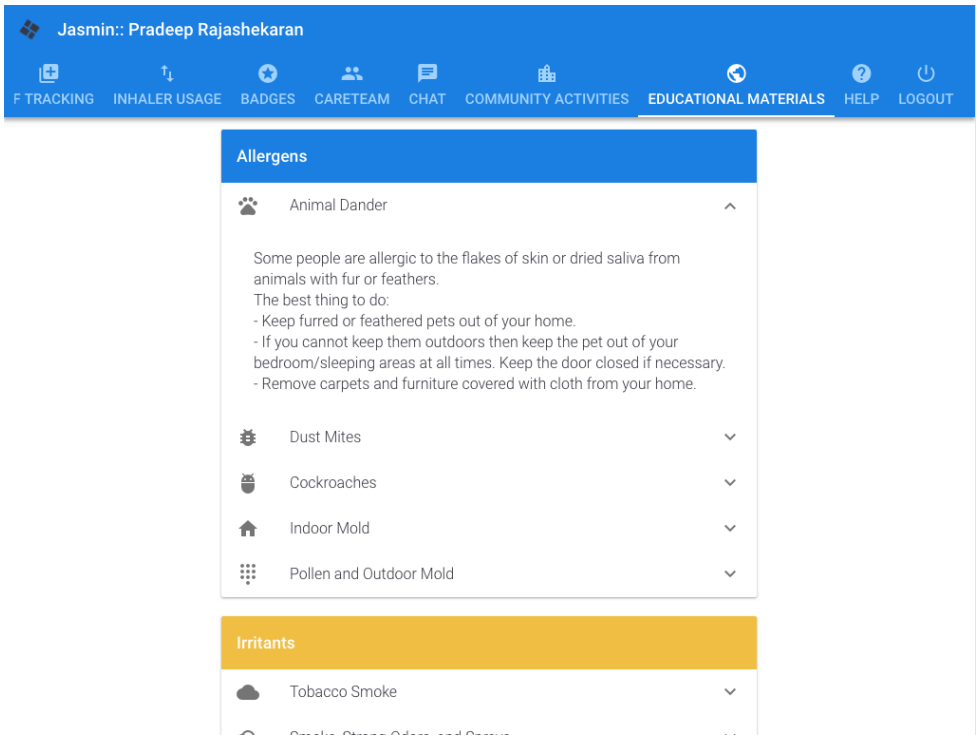

Figure 22: Educational materials Page in JASMIN.

5.13 Logout

This is the final feature of the JASMIN system. Once all the assessments and other values are recorded and action plan is set, the user can sign out of the page simply by clicking the ‘Logout’ button on this page. Once the user logs out of the application, the JSON Web token that was generated during the log in session will be invalidated.

Chapter 6: Pilot Study

JASMIN 1.2 is currently in the testing phase. This version of the mobile application is a hybrid, meaning that JASMIN can be installed on any mobile operating system including iOS, Android and Windows. JASMIN can also be accessed online using the URL *https://jasmin.engr.utk.edu*. This system is currently being used in a pilot study following its approval by the University Institutional Review Board (IRB).

The proposed pilot study has three main aims:

1. To compare the validity of CAST scores by comparing the scores to peak flow meter readings. Peak flow data and asthma assessment questions (CAST questions) in JASMIN will be compared and analyzed to determine the face, concurrent, and content validity of the four asthma assessment questions. The proposed hypothesis is that the four assessment questions in JASMIN are directly correlated to peak flow meter readings. Therefore, the scores from the CAST questions should be able to predict asthma severity without requiring the patient to complete peak flow assessments. Although the National Asthma Education Prevention Program recommends the use of peak flow meters as a diagnostic and management tool for asthma severity, patients do not regularly use peak flow meters. Hopefully, these CAST questions will help address this gap in patient self-management.
2. To test the usability and functionality of JASMIN across multiple devices. All usability and feasibility data from the system will be gathered, evaluated, and analyzed using Nielsen's usability heuristics and evaluation methods. Aspects that need refinement will be identified by the research team and an enhanced version of the JASMIN system (version 1.3) will be released for the final stage of the study.
3. To determine the JASMIN users' emergency room readmission rates over a one-month period compared to patients receiving usual care, East Tennessee Children's

Hospital's (ETCH) emergency room records will be reviewed to determine readmission data.

6.1 Recruitment of participants of the study

This pilot study is being conducted at the East Tennessee Children's Hospital in Knoxville, Tennessee. A total of 180 participants will be recruited to test the JASMIN system. The 180 participants are separated into the following groups: children with asthma, parents of children with asthma, providers of children with asthma, and children in the control study group. There is no cost involved for the participants taking part in this study. A gift card worth 15 dollars will be given to each patient and parent who agree to participate in the pilot study. Providers will also be awarded a gift card worth 15 dollars for each of their patients who are taking part in the study.

6.2 Criteria for selection of participants to the study

Selection criteria has been outlined for all three participant groups. Children must be between seven and seventeen years old, have at least a third-grade reading level, be treated for asthma in the ETCH emergency room, have access to an internet capable device, be seen by a health provider participating in the study, and be English-speaking. Parents or caretakers must have a child participating in the study, must have access to an internet capable device, and be English speaking. Physicians must provide care for children with asthma in the ETCH emergency room and be English speaking.

6.3 Procedure for Carrying out the study

The initial recruitment for the pilot study starts with the providers. Emergency Room providers who treat children with asthma at ETCH will be identified. Each provider will be given a consent form that clearly states the aim of this pilot study, their role in the study, and the risk factors associated with the study. The consenting providers' information will be added to a brochure detailing the study procedures. This brochure will be placed in ER patient rooms and in nurses'

stations. The nurses will be responsible for distributing brochures to patients admitted to the ER with asthma exacerbations. Families who are willing to participate in the study will then contact the Principle Investigators (PIs) through phone or email. The PI's contact information and study details will be clearly mentioned in the brochure. If the participants meet the eligibility criteria, the research team will set up a meeting with the participants at a public location. Once consent and assent forms are signed, a Graduate Research Assistant from the College of Nursing will explain the JASMIN system and will download the mobile application to the family's mobile device. This training includes providing participants with a 'JASMIN How-To' manual and corresponding video that will be made available through the JASMIN web application. The participants will be required to use the JASMIN system for a month, but they are encouraged to continue using the system following completion of the study.

JASMIN will be accessible online at *https://jasmin.engr.utk.edu* and through a mobile application package that can be downloaded on a mobile device. User information and the password details will be entered on the registration page of the mobile application by each participant. A unique JASMIN code will be created for each user of the system. The child can connect to the rest of the team by using this code as a connection request. Children are advised to enter their peak flow values (PFV) at least once daily and the CAST assessment questions should be answered once a week. A text message and email will be sent to the entire care team if the child does not enter a PFV for three days or does not answer the CAST assessment questions for seven days. Parents and providers may opt out of receiving these SMS notifications. At the end of the 30-day period, the participants will be interviewed regarding the ease of use of the app, the features that were most useful, and features they would like to see in future versions of JASMIN.

To measure the effectiveness of the JASMIN system, the number of ER readmissions for the JASMIN group will be compared against a control group for one month. After the 60th participant of the JASMIN study group has completed the 30-day trial, the data from the ETCH

ER records will be retrieved and a retrospective chart review will be done to compare the ER visits made by the JASMIN group and the control group.

6.4 Data Analysis

6.4.1 Correlation Analysis

A Pearson Correlation analysis will be used to check the correlation of the CAST assessment score to the PF meter readings. Using this method, the data that we obtain from the PF meter and the data from the CAST questions are assumed to be normally distributed. These plotted data should be represented by a bell-shaped curve. Using this correlation method, we will be able to compute an *r*-value, which will represent the degree of correlation between these two variables. The Pearson correlation coefficient is written as

$$r=(n(\sum xy)-(\sum x)(\sum y)) / (\sqrt{[n\sum x\text{^}2 - [(\sum x)\text{^}2][n\sum y\text{^}2 - [(\sum y)\text{^}2]})$$

where,

r = Pearson correlation coefficient

n = number of observations

$\sum x$ = sum of x scores

$\sum y$ = sum of y scores.

An *r*-value greater than 0.70 indicates a positive correlation between the two variables, which would indicate that CAST assessment scores could be used as a metric for the calculation of asthma severity in children. An *r*-value of 0 indicates that there is no correlation between the two variables and CAST scores should not be used to measure the severity of asthma. Finally, an *r*-value less than -0.70 indicates a negative correlation between the two measured variables.

6.4.2 Heuristic Evaluation

A heuristic evaluation method will be used to evaluate the usability of the mobile application. The evaluation will be based on ten major factors namely error prevention, control and freedom for users, consistency and standard, design and aesthetics, help and documentation, recognition of system working, flexibility, understandable error messages, simple and real-world messages, and system status (Nielsen, Molich and Bitnet Denmark, 1990). Error prevention involves preventing all possible errors in the application. When a user can navigate within the app without restriction or without encountering glitches within the app, it demonstrates the user's control over the application. Icons used to represent an object or task should remain consistent throughout the application. This ensures consistency within the application. Aesthetic consideration is accomplished by maintaining only the required information and removing all unnecessary icons or features from the application. Help features, and documentation of all resources needed for the smooth functioning of the app should be easily accessible. Error messages should be easily understandable to the users and should not be a system-generated message. Instructions for app use should be clear and easily accessible. The application should be flexible to ensure that it can fit any screen size and easy-to-use so that all users can use the application with minimal assistance from external sources. The language that is used in the application should be native to the application users. The users should not struggle to understand the application and should be able to understand how to navigate the app features (Nielsen, Molich and Bitnet Denmark, 1990).

JASMIN feasibility testing will be carried out using this heuristic method. An evaluator will gather qualitative data by interviewing the participants about their experience using the application. Themes will be created by grouping the most commonly reported errors and a continuous severity score ranging from 1-5 will be assigned to these errors. Once all the interviewing is completed, the severity scores will be aggregated, and the problems will be addressed in order of severity. This helps ensure the system is intact and the users can enter information with minimal difficulty.

Table 2: Sample Use case questions

S. No	Sample Test Case	Severity Score	User Comment
1	Easy Navigation	5	
2	Minimalist Deign	4	
3	Clear labels for navigation	4	
4	Buttons with concise text explaining the action	3	
5	System status feedback to the user	5	
6	Number of buttons is reasonable	2	
7	Readable color throughout application	2	
8	No ambiguous icon	2	
9	Readable font sizes throughout application.	5	
10	‘Save’ button that updates the changes.	5	
11	Log in with proper credentials.	5	
12	Registration of new user going through.	5	
13	Concise messages to understand the errors.	3	
14	Confirmation before logging off from the app.	5	
15	Easy retrieval of instructions regarding app usage.	3	

6.4.3 Factor Analysis

Factor analysis can be performed to determine the linearity among the observed variables and the unobserved factors. It identifies correlations among variables to bind them into one underlaying composite factor driving the values.

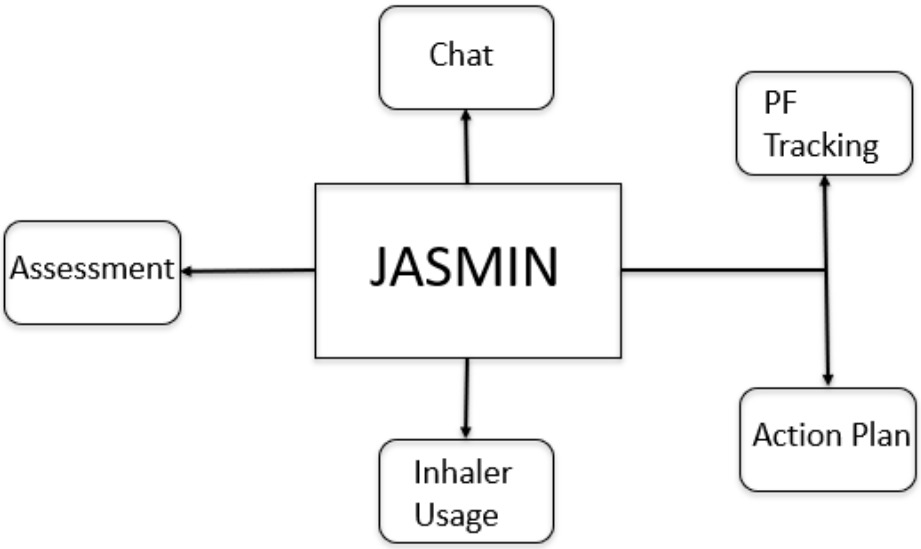

Figure 23: JASMIN Specific Components

In JASMIN system factor analysis can be implemented to study the correlation between the five components that pertains to asthma control and support. For the study purpose, the total time spent by patients on each page and the total number of clicks/taps made on each component can be considered.

x_1 - Mean time spent by a user in Assessment.

x_2- Mean number of clicks in Assessment.

x_3 - Mean time spent by a user in Inhaler Usage.

x_4 - Mean number of clicks in Inhaler Usage.

x_5 - Mean time spent by a user in Action Plan.

x_6 - Mean number of clicks in Action Plan.

x_7 - Mean time spent by a user in PF Tracking.

x_8 - Mean number of clicks in PF Tracking.

x_9 - Mean time spent by a user in Chat.

x_{10} - Mean number of clicks in Chat.

Running a factor analysis test will provide with a component matrix that explains the correlation among the ten variables that are derived from the five components. The scree plot is a plot that plots variables against the Eigen value and helps to determine the number of factors that should be retained in the factor analysis. A plot with a random dataset is illustrated in the below figure.

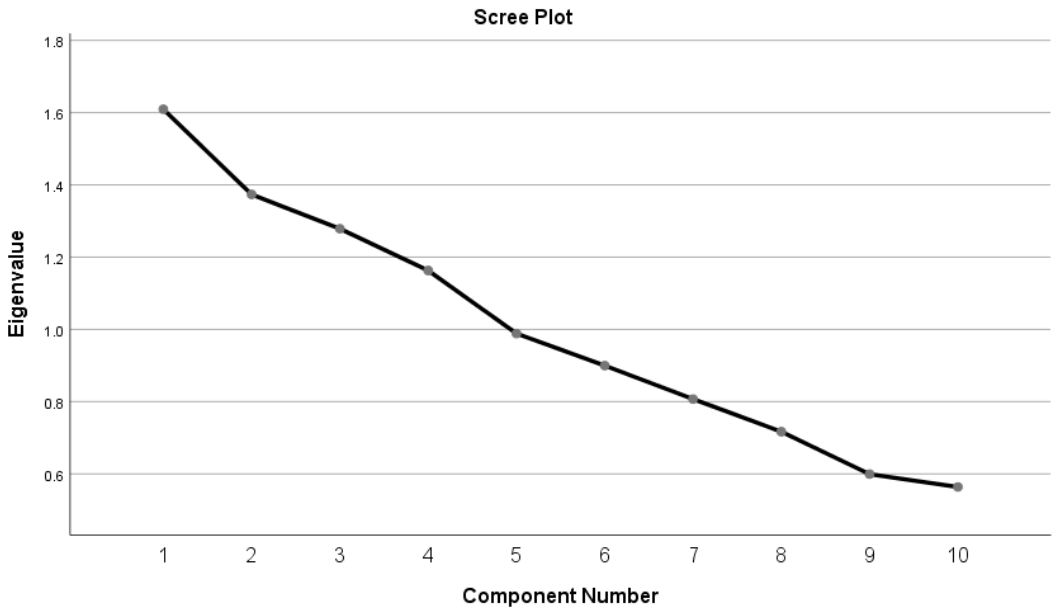

Figure 24: Scree plot for demo data.

Eigen value to run this analysis was arbitrarily set to 1 and out of ten components, the components that have the eigen value more than arbitrary value will be considered for analysis. Here we have four components and the correlation matrix for these four factors without any applying any rotation will be further discussed. In general, a varimax rotation can be applied to reduce 50 variables to 10 composite factors. Hierarchical agglomerative clustering technique can also be used to cluster the patient group for further analysis. The variables that are considered for the analysis can be written in the form of components as,

$$y_i = \beta_{ij} + \beta_{ij}F_i + B_{ij}F_i + \beta_{ij}F_i + e_i \quad \begin{cases} i = 0,1,2, \dots n \\ j = 1,2,3 \dots n \end{cases}$$

And the generalized component matrix shown as,

Variable, y_i	$\beta_{i1}F_1$	$\beta_{i2}F_2$
y_1	+	0
y_2	0	+
y_3	0	+

The matrix describes the variable 1 has the most influenced from component 1 whereas the variable 2 and 3 constitute for the second component. The component matrix generated for the test data using SPSS is,

Component Matrix[a]

	Component			
	1	2	3	4
x1	.206	.601	.317	-.313
x2	.725	.078	-.122	-.160
x3	.331	-.206	.533	.491
x4	.362	.332	-.036	.309
x5	-.200	.757	.219	.135
x6	.470	.112	.163	-.558
x7	.268	.314	-.267	.604
x8	-.548	.350	-.315	-.086
x9	.351	-.162	-.344	-.024
x10	-.213	-.146	.717	.022

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Figure 25: Correlation matrix with test data.

From the component matrix the variables x2 and x6 have strong factor loading from the component 1 and they can be chosen for the optimal variables during interpretation. However, this is a matrix that is generated with random data set, further studies and more data points may be needed for component selection in future.

6.4.4 Measuring Effectiveness of variables in the mobile application

A multiple logistic regression can be applied to the mobile application usage data. The hypothesis for this assumption would be spending time in all components of the mobile application accounts for the reduction in the readmission of the children in the ER room. A multiple logistic regression can be defined by,

$\ln[y\ /\ (1-y)] = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8$ where

x_1 – Session Length _ Dashboard,

x_2 – Session Length_ Action plan,

x_3 – Session Length_ Assessment,

x_4 – Session Length_ PF Tracking,

x_5 – Session Length_ Chat,

x_6 – Session Length_ Community Activity,

x_7 – Session Length_ Education material,

x_8 – Session Length_ Inhaler usage.

a – intercept of the best fitting line,

b_i - slope.

The response / dependent variable (y) for this would be the re-admission to the ER department.

The variables with the positive slopes indicates increasing the variable usage will further make the variable to be significant in reducing the readmission, whereas the negative slopes will mark the inverse relation.

6.4.4.1 Standardization Techniques

Variables from the mobile phone statistics usage might be measured at different scales and hence they would not contribute equally to the analysis. So, a data standardization should be carried out to equalize the range and data variability.

0-1 scaling: In this method each of the variables in the data set is formulated as (V - min V)/ (max V - min V), where V represents the value of the variable in the original data set.

Dividing each value by the range: recalculates each variable as V / (max V - min V). In this case, ranges of the variable will be similar but the mean, and variance will be different.

Z-score scaling: All the variables in the data set will have a zero mean and normal standard deviation with different ranges, since variables are calculated as (V - mean of V)/s

Dividing each value by the standard deviation: The variables will be transformed with variances of 1, and with different means and ranges.

6.4.5 Measuring Effectiveness of Communication

An analysis that could be done to measure the effectiveness of communication among the care team and the efficiency of the system is by checking the zone classification of the child at the end of the study. For the purpose of this analysis the demographic of the child including the age, gender in addition to several other factors like chat messages exchanged among the care team, the size of the care team, average length of each session in the mobile application, frequency of taking assessments and recording the PF value. K-Means clustering can be performed on the collected demographic data and the app usage statistic data. K-Means clustering helps in identifying the group of variables/objects which can explain a certain behavior. K-Means might have problems if there are too many outliers in the dataset, hence it is better to remove the outlier data or standardize the outliers before it is being implemented. The following variables can be defined to run the K-Means clustering,

x_1 – Age,

x_2 – Gender (Categorical variable),

x_3 – Care team size,

x_4 – Number of messages exchanged among the care team,

x_5 – Session Length_ Chat,

x_6 – Session Length_ Community Activity,

x_7 – Session Length_ Education material,

x_8 – Session Length_ Inhaler usage,

x_9 – Session Length_ Action plan.

The asthma zone would be the measured category.

The below figure shows the different clusters obtained from k-means clustering analysis. It can be used to identify the variables affecting different clusters in the observed group.

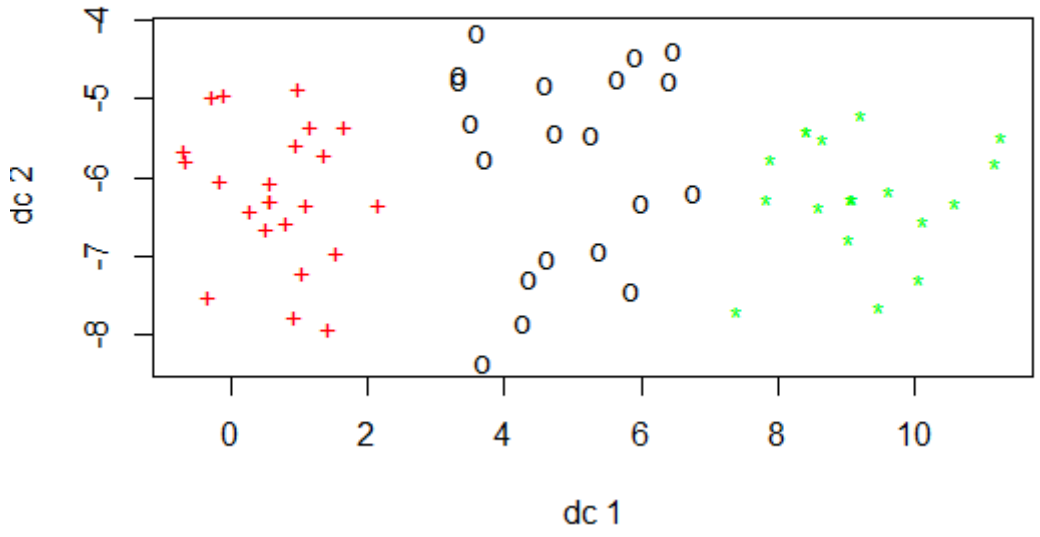

Figure 26: K-Means cluster analysis

Chapter 7: Discussion

A Just-in-time Asthma Self-Management Intervention (JASMIN) system that helps in the improved medication adherence, asthma symptoms tracking, and reduction in the ER readmission was successfully developed and deployed for real time testing. Current version of JASMIN has the components to deliver the information about air quality, record the PF value manually, track the asthma symptoms, edit the asthma action plan based on personal behavior and communicate with the care team through chat. A SMS intervention that reminds the child to take assessment and alerts the care team if the child misses the same for about a week is facilitated.

The GPS component in the system collects information about the surrounding environment and the associated weather conditions. Pollens and molds are some of the major causes of asthma attacks in children (Delfino *et al.*, 1996). Also, during thunderstorms, pollen grains burst into smaller fragments due to the absorption of moisture in the air and can be easily spread through the wind (Celenza *et al.*, 1996). Therefore, thunderstorms create the possibility of higher asthma attack rates in children with asthma. JASMIN can be used to detect environmental changes using the GPS feature and can send automated messages to users warning about upcoming thunderstorms. This automatic, passive intervention can alert the user to prepare for an asthma exacerbation before the patient begins experiencing symptoms.

Smart spirometers are spirometers that are connected to a mobile application through Bluetooth. When the user blows through these spirometers, the Peak Flow Value is entered directly into the app without requiring the user to manually type in the value. This option can be added to JASMIN.

Feature Selection by Backward Elimination – The JASMIN system has about fifteen components built in to the software. It comes with a log function that checks and logs user activity whenever the user moves between tabs in the app. Using the backward elimination technique, researchers will be able to identify the features that contribute most strongly to

the reduction of emergency department readmission rates. When performing this feature selection, all the features that have a significance level above 0.05 (alpha) will be removed, which will help move the adjusted r square value closer to one. Following these statistical evaluations, the remaining variables will be considered for future model building.

References

1. Abrahamsson, P. *et al.* (2003) ‘New Directions on Agile Methods: A Comparative Analysis’. Available at: http://eljabiri1.tripod.com/sitebuildercontent/sitebuilderfiles/2003_icse03_new_directions_on_agile_methods.pdf (Accessed: 13 June 2018).
2. Adeniyi, B. O. and Erhabor, G. E. (2011) ‘The peak flow meter and its use in clinical practice’, *African Journal of Respiratory Medicine*, 5. Available at: http://africanjournalofrespiratorymedicine.com/articles/march_2011/Peak flow meter.pdf (Accessed: 19 June 2018).
3. Akinbami, L. J. *et al.* (2012) ‘Trends in asthma prevalence, health care use, and mortality in the United States, 2001-2010.’, *NCHS data brief*, (94), pp. 1–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22617340 (Accessed: 21 June 2018).
4. Allen, K. *et al.* (2012) ‘Potential Life-Threatening Events in Schools Involving Rescue Inhalers, Epinephrine Autoinjectors, and Glucagon Delivery Devices: Reports From School Nurses’, *The Journal of School Nursing*, 28(1), pp. 47–55. doi: 10.1177/1059840511420726.
5. American Academy of Allergy Asthma & Immunology (2017) *Asthma*. Available at: https://www.aaaai.org/conditions-and-treatments/asthma (Accessed: 21 June 2018).
6. American Lung Association (no date) *Asthma and Children Fact Sheet | American Lung Association*. Available at: http://www.lung.org/lung-health-and-diseases/lung-disease-lookup/asthma/learn-about-asthma/asthma-children-facts-sheet.html (Accessed: 18 July 2018).
7. Appari, A. *et al.* (2009) ‘Association for Information Systems AIS Electronic Library (AISeL) HIPAA Compliance: An Institutional Theory Perspective HIPAA Compliance: An Institutional Theory Perspective’. Available at: http://aisel.aisnet.org/amcis2009 (Accessed: 8 June 2018).
8. Araújo, L. *et al.* (2012) ‘Clinical Effi cacy of Web-Based Versus Standard Asthma Self-management’, *J Investig Allergol Clin Immunol*, 22(1), pp. 28–34. Available at: www.pasma.med.up.pt (Accessed: 16 July 2018).
9. Bahill, A. T. and Gissing, B. (1998) ‘Re-evaluating systems engineering concepts using systems thinking’, *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, 28(4), pp. 516–527. doi: 10.1109/5326.725338.
10. Barlow, J. *et al.* (2002) ‘Self-management approaches for people with chronic conditions: a review’, *Patient Education and Counseling*. Elsevier, 48(2), pp. 177–187. doi: 10.1016/S0738-3991(02)00032-0.
11. Bartlett, S. J. *et al.* (2002) ‘Enhancing medication adherence among inner-city children with asthma: results from pilot studies.’, *The Journal of asthma : official*

journal of the Association for the Care of Asthma, 39(1), pp. 47–54. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11883739 (Accessed: 17 July 2018).

12. Beck, K. (1999) 'Embracing change with extreme programming', *Computer*, 32(10), pp. 70–77. doi: 10.1109/2.796139.
13. Beck, K. and Kent (2000) *Extreme programming eXplained : embrace change*. Addison-Wesley. Available at: https://dl.acm.org/citation.cfm?id=318762 (Accessed: 13 June 2018).
14. Björgvinsson, E., Ehn, P. and Hillgren, A. (2012) 'Design Things and Design Thinking: Contemporary Participatory Design Challenges', *Technology DesignIssues*, 28(3). Available at: https://www.mitpressjournals.org/doi/pdf/10.1162/DESI_a_00165 (Accessed: 13 June 2018).
15. Bodenheimer, T., Wagner, E. H. and Grumbach, K. (2002) 'Improving primary care for patients with chronic illness.', *JAMA*, 288(14), pp. 1775–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12365965 (Accessed: 19 June 2018).
16. Boehm, B. (2006) 'Some future trends and implications for systems and software engineering processes', *Systems Engineering*. Wiley-Blackwell, 9(1), pp. 1–19. doi: 10.1002/sys.20044.
17. Buede, D. M. (2009) 'THE ENGINEERING DESIGN OF SYSTEMS THE ENGINEERING DESIGN OF SYSTEMS MODELS AND METHODS Second Edition', (2), p. 3. Available at: http://www.wiley.com/go/permission. (Accessed: 11 June 2018).
18. Byer, B. and Myers, L. B. (2000) 'Psychological correlates of adherence to medication in asthma', *Psychology, Health & Medicine*. Taylor & Francis Group , 5(4), pp. 389–393. doi: 10.1080/713690213.
19. Celenza, A. *et al.* (1996) 'Thunderstorm associated asthma: a detailed analysis of environmental factors.', *BMJ (Clinical research ed.)*. British Medical Journal Publishing Group, 312(7031), pp. 604–7. doi: 10.1136/BMJ.312.7031.604.
20. Center for Health Statistics, N. (2015) 'Leading causes of death and numbers of deaths, by sex, race, and Hispanic origin: United States, 1980 and 2014', *Centers for Disease Control and Prevention*, (1), pp. 121–122. Available at: https://www.cdc.gov/nchs/data/hus/hus15.pdf#019 (Accessed: 21 June 2018).
21. Centers for Disease Control and Prevention (2011) *Asthma in the US | VitalSigns | CDC*. Available at: https://www.cdc.gov/vitalsigns/asthma/ (Accessed: 13 June 2018).
22. Centers for Disease Control and Prevention (2017) *CDC - Asthma - Data and Surveillance - Asthma Surveillance Data*. Available at: https://www.cdc.gov/asthma/asthmadata.htm (Accessed: 18 July 2018).
23. Chen, Z. *et al.* (2008) 'Comparison of an SMS text messaging and phone reminder to

improve attendance at a health promotion center: A randomized controlled trial', *Journal of Zhejiang University SCIENCE B*. Zhejiang University Press, 9(1), pp. 34–38. doi: 10.1631/jzus.B071464.

24. Cingi, C. *et al.* (2015) 'The "physician on call patient engagement trial" (POPET): measuring the impact of a mobile patient engagement application on health outcomes and quality of life in allergic rhinitis and asthma patients', *International Forum of Allergy & Rhinology*. Wiley-Blackwell, 5(6), pp. 487–497. doi: 10.1002/alr.21468.
25. Clark, N. M. *et al.* (2004) 'Effects of a Comprehensive School-Based Asthma Program on Symptoms, Parent Management, Grades, and Absenteeism', *Chest*. Elsevier, 125(5), pp. 1674–1679. doi: 10.1378/CHEST.125.5.1674.
26. Costa, M. do R. da S. R. *et al.* (2008) 'Acampamento educacional para crianças asmáticas', *Jornal Brasileiro de Pneumologia*. Sociedade Brasileira de Pneumologia e Tisiologia, 34(4), pp. 191–195. doi: 10.1590/S1806-37132008000400002.
27. Croll, P. R. *et al.* (2007) 'Utilizing SELinux to Mandate Ultra-secure Access Control of Medical Records', in *Medinfo 2007: Proceedings of the 12th World Congress on Health (Medical) Informatics; Building Sustainable Health Systems*. IOS Press, p. 498.
28. D'Amato, G., Liccardi, G. and Frenguelli, G. (2007) 'Thunderstorm-asthma and pollen allergy', *Allergy*. Wiley/Blackwell (10.1111), 62(1), pp. 11–16. doi: 10.1111/j.1398-9995.2006.01271.x.
29. Delfino, R. J. *et al.* (1996) 'Daily asthma severity in relation to personal ozone exposure and outdoor fungal spores.', *American journal of respiratory and critical care medicine*. American Public Health Association, 154(3 Pt 1), pp. 633–41. doi: 10.1164/ajrccm.154.3.8810598.
30. Dinakar, C., Van Osdol, T. J. and Wible, K. (2004) 'How Frequent Are Asthma Exacerbations in a Pediatric Primary Care Setting and Do Written Asthma Action Plans Help in Their Management?', *Journal of Asthma*. Taylor & Francis, 41(8), pp. 807–812. doi: 10.1081/JAS-200038418.
31. Dorst, K. (2011) 'The core of "design thinking" and its application', *Design Studies*. Elsevier, 32(6), pp. 521–532. doi: 10.1016/J.DESTUD.2011.07.006.
32. Egham (2010) *Gartner Says Worldwide Mobile Phone Sales Grew 35 Percent in Third Quarter 2010; Smartphone Sales Increased 96 Percent*, *Gartner*. Available at: https://www.gartner.com/newsroom/id/1466313 (Accessed: 21 June 2018).
33. Fisher, E. B. *et al.* (1994) 'Targeting high risk groups. Neighborhood organization for pediatric asthma management in the Neighborhood Asthma Coalition.', *Chest*, 106(4 Suppl), p. 248S–259S. doi: 10.1378/CHEST.106.4_SUPPLEMENT.248S.

34. Forbis, S. *et al.* (2006) ‘Barriers to Care of Inner-City Children With Asthma: School Nurse Perspective’, *Journal of School Health*, 76(6), pp. 205–207. doi: 10.1111/j.1746-1561.2006.00097.x.
35. Free, C. *et al.* (2013) ‘The Effectiveness of Mobile-Health Technology-Based Health Behaviour Change or Disease Management Interventions for Health Care Consumers: A Systematic Review’, *PLoS Medicine*. Edited by T. Cornford. Public Library of Science, 10(1), p. e1001362. doi: 10.1371/journal.pmed.1001362.
36. Friend, M. and Morrison, A. (2015) ‘Interventions to Improve Asthma Management of the School-Age Child’, *Clinical Pediatrics*. SAGE PublicationsSage CA: Los Angeles, CA, 54(6), pp. 534–542. doi: 10.1177/0009922814554500.
37. van Gaalen, J. L. *et al.* (2013) ‘Long-term outcomes of internet-based self-management support in adults with asthma: randomized controlled trial.’, *Journal of medical Internet research*. JMIR Publications Inc., 15(9), p. e188. doi: 10.2196/jmir.2640.
38. Garrett, J. *et al.* (1994) ‘Prospective controlled evaluation of the effect of a community based asthma education centre in a multiracial working class neighbourhood’, *Thorax*, 49, pp. 976–983. doi: 10.1136/thx.49.10.976.
39. Gergen, P. J., Mullally, D. I. and Ill, R. E. (1988) ‘Pedbb cs National Survey of Prevalence of Asthma Among Children in the United States, 1976 to’, *NUMBER I PEDIATRICS*, 81(1). Available at: http://pediatrics.aappublications.org.proxy.lib.utk.edu:90/content/pediatrics/81/1/1.full.pdf (Accessed: 21 June 2018).
40. Ghani, Z. *et al.* (2018) *The Cost Effectiveness of M-health Interventions for Older Adults: Protocol for a Systematic Review*. Available at: http://www.diva-portal.org/smash/get/diva2:1223957/FULLTEXT01.pdf (Accessed: 26 July 2018).
41. Gorelick, M. H. *et al.* (2004) ‘Performance of a novel clinical score, the Pediatric Asthma Severity Score (PASS), in the evaluation of acute asthma.’, *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine*, 11(1), pp. 10–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/14709423 (Accessed: 19 June 2018).
42. Guerri, J. C. *et al.* (2009) ‘A mobile device application applied to low back disorders’, *Multimedia Tools and Applications*. Springer US, 42(3), pp. 317–340. doi: 10.1007/s11042-008-0252-x.
43. Haijin, Z. *et al.* (2012) ‘Clinical and immunological heterogeneity of COPD View project The role of airway epithelial cells in TDI-induced asthma View project’. doi: 10.1089/tmj.2011.0218.
44. Hendrik W.Bode, W. K. H. (2011) *Systems engineering | Britannica.com*. Available

at: https://www.britannica.com/topic/systems-engineering (Accessed: 9 June 2018).
45. Holzer, A. and Ondrus, J. (2011) 'Mobile application market: A developer's perspective', *Telematics and Informatics*. Pergamon, 28(1), pp. 22–31. doi: 10.1016/J.TELE.2010.05.006.
46. Huckvale, K. *et al.* (2012) 'Apps for asthma self-management: a systematic assessment of content and tools', *BMC Medicine*. BioMed Central, 10(1), p. 144. doi: 10.1186/1741-7015-10-144.
47. Hulshof, C. D. and de Jong, T. (2006) 'Using just-in-time information to support scientific discovery learning in a computer-based simulation', *Interactive Learning Environments*. Routledge , 14(1), pp. 79–94. doi: 10.1080/10494820600769171.
48. de Jong, C. C., Ros, W. J. and Schrijvers, G. (2014) 'The Effects on Health Behavior and Health Outcomes of Internet-Based Asynchronous Communication Between Health Providers and Patients With a Chronic Condition: A Systematic Review', *Journal of Medical Internet Research*, 16(1), p. e19. doi: 10.2196/jmir.3000.
49. Kelly, S. *et al.* (1999) 'FOCUS ISSUE ON LEGACY INFORMATION SYSTEMS AND BUSINESS PROCESS CHANGE: A BUSINESS PERSPECTIVE OF LEGACY INFORMATION SYSTEMS LEGACY INFORMATION SYSTEMS AND BUSINES PROCESS CHANGE FOCUS ISSUE ON LEGACY INFORMATION SYSTEMS AND BUSINESS PROCESS CHANGE: A BUSI', 2(7). Available at: http://delivery.acm.org/10.1145/380000/374164/a7-kelly.pdf?ip=192.249.3.239&id=374164&acc=ACTIVE SERVICE&key=A79D83B43E50B5B8.61146380CA860EFC.4D4702B0C3E38B35.4D4702B0C3E38B35&__acm__=1528598638_c94af8cd3882739fd6a397e712218638 (Accessed: 9 June 2018).
50. Kumar, S. *et al.* (2013) 'Mobile health technology evaluation: the mHealth evidence workshop.', *American journal of preventive medicine*. NIH Public Access, 45(2), pp. 228–36. doi: 10.1016/j.amepre.2013.03.017.
51. Laster, N. *et al.* (2009) 'Barriers to Asthma Management Among Urban Families: Caregiver and Child Perspectives', *Journal of Asthma*, 46(7), pp. 731–739. doi: 10.1080/02770900903082571.
52. Lemieux-Charles, L. and McGuire, W. L. (2006) 'What Do We Know about Health Care Team Effectiveness? A Review of the Literature', *Medical Care Research and Review*, 63(3), pp. 263–300. doi: 10.1177/1077558706287003.
53. Liberatos, P. *et al.* (2013) 'Challenges of Asthma Management for School Nurses in Districts With High Asthma Hospitalization Rates', *Journal of School Health*, 83(12), pp. 867–875. doi: 10.1111/josh.12105.
54. Liew, S.-M. *et al.* (2009) 'Text messaging reminders to reduce non-attendance in

chronic disease follow-up: a clinical trial.', *The British journal of general practice : the journal of the Royal College of General Practitioners*. British Journal of General Practice, 59(569), pp. 916–20. doi: 10.3399/bjgp09X472250.

55. Liu, W.-T. *et al.* (2011) 'A mobile telephone-based interactive self-care system improves asthma control.', *The European respiratory journal*. European Respiratory Society, 37(2), pp. 310–7. doi: 10.1183/09031936.00000810.
56. M.Jones , J.Bradley, N. S. (2015) 'JSON Web Token(JWT0', *Internet Engineering Task Force (IETF)*. Available at: https://www.rfc-editor.org/rfc/pdfrfc/rfc7519.txt.pdf (Accessed: 8 June 2018).
57. Maier, M. W. and Rechtin, E. (2000) 'THE ART OF SYSTEMS ARCHITECTING', (2), p. 308. Available at: https://sdincose.org/wp-content/uploads/2017/10/TheArtOfSystemsEngineering_inaugural.pdf (Accessed: 9 June 2018).
58. Malvoni, K. and Knezovic, J. (2014) 'Are Your Passwords Safe: Energy-Efficient Bcrypt Cracking with Low-Cost Parallel Hardware'. Available at: https://www.usenix.org/system/files/conference/woot14/woot14-malvoni.pdf (Accessed: 8 June 2018).
59. Martin, A. J. *et al.* (1980) 'The natural history of childhood asthma to adult life'. Available at: https://www.bmj.com/content/bmj/280/6229/1397.full.pdf (Accessed: 21 June 2018).
60. van der Meer, V. *et al.* (2010) 'Weekly self-monitoring and treatment adjustment benefit patients with partly controlled and uncontrolled asthma: an analysis of the SMASHING study', *Respiratory Research*, 11(1), p. 74. doi: 10.1186/1465-9921-11-74.
61. Monica Anderson (2015) *U.S. Technology Device Ownership 2015* | *Pew Research Center*. Available at: http://www.pewinternet.org/2015/10/29/technology-device-ownership-2015/ (Accessed: 21 June 2018).
62. Mulvaney, S. A. *et al.* (2012) 'A pilot test of a tailored mobile and web-based diabetes messaging system for adolescents.', *Journal of telemedicine and telecare*. NIH Public Access, 18(2), pp. 115–8. doi: 10.1258/jtt.2011.111006.
63. Naar-King, S. *et al.* (2009) 'Feasibility of adapting multisystemic therapy to improve illness management behaviors and reduce asthma morbidity in high risk African American youth: A case series', *Journal of Child and Family Studies*. Springer, 18(5), pp. 564–573.
64. Nahum-Shani, S. *et al.* (2014) 'Just-in-time adaptive interventions (JITAIs): An organizing framework for ongoing health behavior support'. Penn State. Available at: https://methodology.psu.edu/media/techreports/14-126.pdf (Accessed: 18 July 2018).

65. National Science Foundaiton (2016) *What is Convergence? | NSF - National Science Foundation*, *NSF*. Available at: https://www.nsf.gov/od/oia/convergence/index.jsp (Accessed: 9 June 2018).
66. National Security Agency (2000) *Participating in SELinux Development - NSA.gov*. Available at: https://www.nsa.gov/what-we-do/research/selinux/ (Accessed: 8 June 2018).
67. Newman, S., Steed, L. and Mulligan, K. (2004) 'Self-management interventions for chronic illness', *The Lancet*. Elsevier, 364(9444), pp. 1523–1537. doi: 10.1016/S0140-6736(04)17277-2.
68. Nhlbi (2007) 'Asthma Action Plan'. Available at: https://www.nhlbi.nih.gov/files/docs/public/lung/asthma_actplan.pdf (Accessed: 18 June 2018).
69. Nielsen, J., Molich, R. and Bitnet Denmark, J. (1990) 'CHI 90 Proceedings HEURISTIC EVALUATION OF USER INTERFACES'. Available at: http://delivery.acm.org/10.1145/100000/97281/p249-nielsen.pdf?ip=192.249.3.239&id=97281&acc=ACTIVE SERVICE&key=A79D83B43E50B5B8.61146380CA860EFC.4D4702B0C3E38B35.4D4702B0C3E38B35&__acm__=1531268079_4233e880d43ca16c8f3eb3fbb7186855 (Accessed: 10 July 2018).
70. NSF (2016) *Characteristics of Convergence Projects | NSF - National Science Foundation*, *National Science Foundation*. Available at: https://www.nsf.gov/od/oia/convergence/characteristics.jsp (Accessed: 9 June 2018).
71. Odom, L. and Christenbery, T. (2016) 'There is an "app" for that', *Journal of the American Association of Nurse Practitioners*, 28(11), pp. 583–590. doi: 10.1002/2327-6924.12375.
72. Ostojic, V. *et al.* (2005) 'Improving Asthma Control Through Telemedicine: A Study of Short-Message Service', *Telemedicine and e-Health*, 11(1), pp. 28–35. doi: 10.1089/tmj.2005.11.28.
73. Palermo, T. M., Valenzuela, D. and Stork, P. P. (2004) 'A randomized trial of electronic versus paper pain diaries in children: impact on compliance, accuracy, and acceptability.', *Pain*, 107(3), pp. 213–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/14736583 (Accessed: 18 July 2018).
74. Parra, J. *et al.* (2014) 'RESTful Discovery and Eventing for Service Provisioning in Assisted Living Environments', *Sensors*. Multidisciplinary Digital Publishing Institute, 14(5), pp. 9227–9246. doi: 10.3390/s140509227.
75. Partridge, M. R. and Hill, S. R. (2000) 'Enhancing care for people with asthma: the role of communication, education, training and self-management. 1998 World

Asthma Meeting Education and Delivery of Care Working Group.', *The European respiratory journal*. European Respiratory Society, 16(2), pp. 333–48. Available at: http://www.ncbi.nlm.nih.gov/pubmed/10968512 (Accessed: 19 June 2018).

76. Pautasso, C., Zimmermann, O. and Leymann, F. (2008) 'RESTful Web Services vs. " Big " Web Services: Making the Right Architectural Decision'. Available at: http://wwwconference.org/www2008/papers/pdf/p805-pautassoA.pdf (Accessed: 5 June 2018).
77. Provos, N., Mazières, D. and Mazi, D. (1999) 'THE ADVANCED COMPUTING SYSTEMS ASSOCIATION A Future-Adaptable Password Scheme A Future-Adaptable Password Scheme'. Available at: http://www.usenix.org (Accessed: 8 June 2018).
78. Rebolj, D., Menzel, K. and Menzel, K. (2004) 'MOBILE COMPUTING IN CONSTRUCTION', *ITCon*, 9. Available at: http://www.itcon.org/2004/19/ (Accessed: 21 June 2018).
79. Reearch2guidance (2017) *325,000 mobile health apps available in 2017 – Android now the leading mHealth platform*, *Reearch2guidance*. Available at: https://research2guidance.com/325000-mobile-health-apps-available-in-2017/ (Accessed: 21 June 2018).
80. Rouse, W. B. and Sage, A. P. (2009) *Handbook of systems engineering and management*. John Wiley & Sons. Available at: https://books.google.com/books?hl=en&lr=&id=eFRwQuzPnEcC&oi=fnd&pg=PA1&dq=introduction+to+Systems+Engineering&ots=fh5BUU2NCG&sig=gzkM4ToMswgAPgnlGffsK_HM5OE#v=onepage&q&f=false (Accessed: 9 June 2018).
81. Russo, C. A. and Andrews, R. M. (2006) *The National Hospital Bill: The Most Expensive Conditions, by Payer, 2004: Statistical Brief #13*, *Healthcare Cost and Utilization Project (HCUP) Statistical Briefs*. Agency for Healthcare Research and Quality (US). Available at: http://www.ncbi.nlm.nih.gov/pubmed/21938850 (Accessed: 21 June 2018).
82. Samaras, G. M. and Horst, R. L. (2005) 'A systems engineering perspective on the human-centered design of health information systems', *Journal of Biomedical Informatics*. Academic Press, 38(1), pp. 61–74. doi: 10.1016/J.JBI.2004.11.013.
83. Schneier, B. (2005) 'Risks of third-party data', *Communications of the ACM*, 48(5), p. 136. doi: 10.1145/1060710.1060744.
84. Van Sickle, D. *et al.* (2013) 'Remote Monitoring of Inhaled Bronchodilator Use and Weekly Feedback about Asthma Management: An Open-Group, Short-Term Pilot Study of the Impact on Asthma Control', *PLoS ONE*. Edited by H. R. Baradaran, 8(2), p. e55335. doi: 10.1371/journal.pone.0055335.

85. Silva, B. M. C. *et al.* (2015) ‘Mobile-health: A review of current state in 2015’, *Journal of Biomedical Informatics*. Academic Press, 56, pp. 265–272. doi: 10.1016/J.JBI.2015.06.003.
86. Smith, S. R., Baty, J. D. and Hodge, D. (2002) ‘Validation of the pulmonary score: an asthma severity score for children.’, *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine*, 9(2), pp. 99–104. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11825832 (Accessed: 19 June 2018).
87. Statista (2018a) *Healthcare apps available Apple App Store 2018 | Statistic*. Available at: https://www.statista.com/statistics/779910/health-apps-available-ios-worldwide/ (Accessed: 26 July 2018).
88. Statista (2018b) *Number of smartphone users in the U.S. 2010-2022 | Statista*. Available at: https://www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us/ (Accessed: 26 July 2018).
89. Statista (2018c) *Smartphone sales by OS worldwide 2009-2018 | Statistic*. Available at: https://www.statista.com/statistics/266219/global-smartphone-sales-since-1st-quarter-2009-by-operating-system/ (Accessed: 26 July 2018).
90. Ugburo, E. O. (2015) ‘Effects of telephonic SMS reminders influence on adherence to scheduled medication pick up appointments among adults on antiretrovirals at the Swakopmund State Hospital ART clinic Namibia’. University of the Western Cape. Available at: http://etd.uwc.ac.za/handle/11394/4735 (Accessed: 21 June 2018).
91. Vital Wave Consulting (2009) ‘mHealth for Development The Opportunity of Mobile Technology for Healthcare in the Developing World’, p. 70. Available at: http://www.globalproblems-globalsolutions-files.org/unf_website/assets/publications/technology/mhealth/mHealth_for_Development_full.pdf (Accessed: 21 June 2018).
92. Wang, X. *et al.* (1994) ‘A longitudinal study of the effects of parental smoking on pulmonary function in children 6-18 years.’, *American Journal of respiratory and critical care medicine*. Am Thoracic Soc, 149(6), pp. 1420–1425.
93. Wensley, D. and Silverman, M. (2004) ‘Peak Flow Monitoring for Guided Self-management in Childhood Asthma’, *American Journal of Respiratory and Critical Care Medicine*, 170(6), pp. 606–612. doi: 10.1164/rccm.200307-1025OC.
94. WHO (2011) *WHO Global Observatory for eHealth. New horizons for health through mobile technologies.* 3rd edn. Geneva: World Health Organization. Available at: http://www.who.int/about/ (Accessed: 21 June 2018).
95. World Health organization (2012) *Spending on health: A global overview*, *World Health Organization*. Available at: http://www.who.int/en/news-room/fact-sheets/detail/spending-on-health-a-global-overview (Accessed: 21 June 2018).

96. World Health Organization (2017) *Asthma*. Available at: http://www.who.int/news-room/fact-sheets/detail/asthma (Accessed: 21 June 2018).
97. Wyatt, T. H. and Hauenstein, E. J. (2008) 'Pilot Testing Okay With Asthma ™: An Online Asthma Intervention for School-Age Children', *The Journal of School Nursing*. SAGE Publications, 24(3), pp. 145–150. doi: 10.1177/1059840522334455.
98. Zhang, L. (2005) 'Accuracy of parental and child's report of changes in symptoms of childhood asthma', *Indian pediatrics : journal of the Indian Academy of Pediatrics.* [Calcutta] :, pp. 1220–1225.
99. Zhao, L. *et al.* (2017) 'Praising Young Children for Being Smart Promotes Cheating', *Psychological Science*. SAGE PublicationsSage CA: Los Angeles, CA, 28(12), pp. 1868–1870. doi: 10.1177/0956797617721529.

Vita

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