

# An Intelligent Web-based Decision Support Tool for Enhancing Asthma Guideline Adherence

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## ABSTRACT

Asthma is a leading chronic disease of children and currently affects about 6.2 million (8.5%) children in the United States. National Asthma Education and Prevention Program (NAEPP) Guidelines recommend a multimodal chronic care approach. However, both of the 1997 and 2007 NAEPP guidelines have not been widely adopted by primary care clinicians because implementing the guidelines in primary care setting requires changes and redesign in clinical practice and the use of Health Information Technology (HIT) to facilitate the changes. Existing electronic asthma care systems are either inefficient to be used in real clinical encounter or provide only after-fact feedback. This paper introduces a web-based clinical decision support system that integrates intelligent computer technology, complex guideline guidance and knowledge necessary for operationalizing guidelines to improve decision making for asthma care. This system is capable of collecting guideline-suggested diagnostic measures, automatically assessing asthmatic severity and control categories based on collected measures as well as providing guideline-appropriate medication regimen. The system is implemented in a model-view-controller principle with three tiers: web-server, core reasoning algorithms and back-end database. We develop the system in conjunction with University of Connecticut Health Center to enable preliminary evaluation of the decision support system and to design an efficient and user-friendly interface that requires minimum changes in the clinical routine for primary care physicians to adapt to the system when deployed into clinical settings.

## Categories and Subject Descriptors

D.2.11 [Software Engineering]: Software Architectures; D.2.13 [Software Engineering]: Reusable Software; J.3 [Life and Medical Sciences]: Medical Information Systems; H.3.4 [Information Storage and Retrieval]: Systems and Software; H.0 [Information Systems]: General

**General Terms:** Design, Experimentation, Algorithms, Performance

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## Keywords

Web-based systems, Clinical decision support, Chronic disease management, Asthma diagnosis and management, Guideline adherence

## 1. INTRODUCTION

The past several years have witnessed rapidly growing interest in establishing computational intelligence and infrastructures to improve various realms of medical practice and public health. For people who live with chronic disease, proper management of medications and life style factors are indispensable to keep symptoms under control. Chronic disease prevalence is increasing at an astonishing rate due to the rapid aging of the population and the greater longevity of people with a variety of chronic conditions [1]. The current health care system focuses primarily on acute and reactive care, not proactive care of patients with chronic conditions [2]. The poorly-organized delivery system with constraints in using modern information technology is a key bottleneck for the system to meet the high demands [3]. Today, doctors and researchers are engaged in an ambitious quality improvement initiative to identify the best practices in managing chronic diseases and the best design of clinical workflow for diagnosing and treating chronic diseases [4]. In our study, we build a web-based IT system that facilitates physicians' decision making to effectively manage asthmatic patients for improvement of guideline adherence.

Asthma is a chronic disease of the airways that has affected 32.6 million people in the United States, and is a leading chronic disease of children and currently affects about 6.2 million (8.5%) children in the United States [5]. Despite advances in asthma research and availability of increasingly effective therapy, morbidity and costs associated with the disease have been constantly rising [6-8]. Many people do not receive appropriate medications to control the disease [9-11], have overly relied on reliever medication [12], and lack of systematic follow-up primary care [13]. The situation is even worse for poor urban areas and among disadvantaged minority children who have significantly worse asthma rates, severity, and outcomes [14-21]. Both the 1997 and 2007 National Asthma Education and Prevention Program (NAEPP) Guidelines [22, 23] recommend a multimodal, chronic care approach. Implementing this approach in any setting of the current healthcare system is challenging, as it requires changes or redesign in clinical practice, such as proactive scheduling, tracking and follow-up, patient and provider education, and the use of health information technology (HIT) to facilitate these changes [24]. Barriers to change are greater in primary care settings where resources are limited and patients face

greater hardship. NAEPP guidelines have not been widely adopted by primary care clinicians [25-28]. We seek to develop a web-based disease-specific and cost-effective informatics infrastructure to enable innovations in practice in both low and adequately resourced environments.

## 2. RELATED WORK

Existing electronic systems for asthma care range from small tools for patient self-care, such as Asthma Tracker, to integrated systems that are designed to assist clinicians, such as UCAN-MAP[24, 29], Stop Asthma [30, 31] and a few clinical decision support systems [32-36]. Asthma Tracker is a small piece of software for Blackberries and provides a list of common asthma medications, common asthma triggers to avoid. UCAN-MAP is a decision support tool that references the patient's current status, the physicians' clinical decision regarding medication against the NAEPP asthma guidelines. It then provides feedback about the appropriateness of the medications prescribed by the physician and evaluates the physician's compliance with the guidelines. UCAN-MAP is not designed to offer real-time guidance at the point of care in terms of how to act; rather it confirms clinical decisions after the fact. Stop Asthma is a lived decision support system for pediatric asthma management. It is constructed using roughly 100 rules written by a few physicians and can help guide other physicians to manage asthma for children. Nevertheless, these rules are translation of the guidelines by a few physicians and need to be carefully evaluated for their effectiveness. Asthma programs such as Easy Breathing [37-40], validated for their effectiveness in enhancing asthma care at real clinical settings, are only paper-based, which limits their utilization in the era of electronic health records (EHR).

Substantial evidence suggests that computerized asthma decision support systems through an electronic health record are helpful in conforming to guidelines [32-36, 41]. Most of such kinds of clinical decision support systems (CDSS) are limited to one or two aspects of the recommended asthma care. For instance, two studies [34, 35] have reported the accuracy and validity of a computerized CDSS with respect to assessing asthma severity in accordance to 2007 Global Initiative for Asthma guidelines. Another study [36] has investigated and developed the measure of pediatric asthmatic symptom control. A comprehensive CDSS [32, 33] has been developed recently by a multidisciplinary team at Yale University. They have developed the system based on the NAEPP guidelines. The system is capable of providing a full range of guideline guidance, and has reported relatively accurate performance for assessment of asthma control in comparison to clinicians but not accurate for treatment plans. This system is not targeted for the use of primary care physicians (PCPs) and has been evaluated in a pediatric pulmonary clinic without a wide utilization in general clinical encounter. The limited adoption is probably partly due to the complexity of the system which may require a rather significant workflow change of pulmonologists relatively to the net benefits it can provide. However, this system represents a novel effort to use computer-mediated process to automatically converting guidelines that are written in vague and underspecified language into unambiguous rules that permit direct operationalization [33].

The goal of our project is, in spirit similar to [33], to enable intelligent reasoning of a decision support system that is capable of automatically diagnosing asthma, classifying asthmatic severity and levels of control, and providing a guideline-appropriate

treatment plan. However, our method will not only reference the guidelines but also the experience of practicing physicians who have successfully operationalize the guidelines in their successful asthma care programs. Hence, unlike in [33] where computer processes are used to facilitate de-abstraction and disambiguation of guideline knowledge for implementation, the proposed system integrates two sorts of knowledge: the knowledge contained in published guideline documents and the knowledge that is required to implement them by specialty experts in their already-validated programs.

## 3. METHOD

We decide to separate the creation and design of asthma decision support tool from the programming setting of any specific electronic medical records (EMR) or EHR. Although creating a CDSS within an EHR/EMR offers a direct deployment into clinical encounter, based on our study, a wide variety of EMR or EHR systems have been used across the state of Connecticut. For example, Pro-Health Physicians, Connecticut's leading primary care physician organization, enclosing 75 clinics with a few hundred clinicians, utilizes Allscripts EHR. Multiple family medicine centers affiliated with St. Francis Hospital have been using Centricity EHR. Connecticut Community Health Center, a meta-organization of a few sub-institutes largely uses eClinicalWorks EHR, and even within the organization, some facilities adopt different EHR systems. All current EHR systems use different programming environments and interfaces to operate their system. Devising an asthma decision support tool within one specific EHR will eliminate medical institutions using other EHRs from taking advantage of the system. We hence decide to design a web-based system that is independent of specific EHRs and available to physicians through secure registration and login process. However, our project can be extended in two directions (which are beyond the scope of the current article) for a more congruous integration into PCPs' workflow: (1) the developed system can be incorporated into an EMR by designing a set of encounter forms within the EMR such as Centricity by General Electric via its editing tool Visual Form Editor; (2) a long-term solution is to interact with a health information exchange (HIE) platform. Our system can be readily augmented with a function to output clinical data in XML [42] following HL7 [43] standards, and submit to the platform for communication between EMRs in either the centralized or federated HIE model [44].

There exists a gap between the information stated in guidelines and the knowledge that is necessary to implement the guidelines. A previous CDSS for pediatric asthma [33] was developed by tagging relevant sections of the guideline text and converting them into rules using EXTRACTOR transforms [32]. However, the sections about medication recommendation in the guideline were excessively ambiguous that the system was unable to translate the medication list into an existing level of treatment. In our method, we first identify successful asthma programs where specialists together with PCPs have translated the guideline-recommended medications into computable formats [24, 29] or precise specifications [45] that group medications of equal pharmacological potency and provide PCPs flexibility of choosing medications from an appropriate group. Some of the asthma programs have been used largely across the state of Connecticut and have been validated to reduce emergency department visits and hospitalizations [25, 39, 46]. We design the flowchart and algorithms in our system by merging the knowledge from guidelines, particularly those sections that are supported by strong

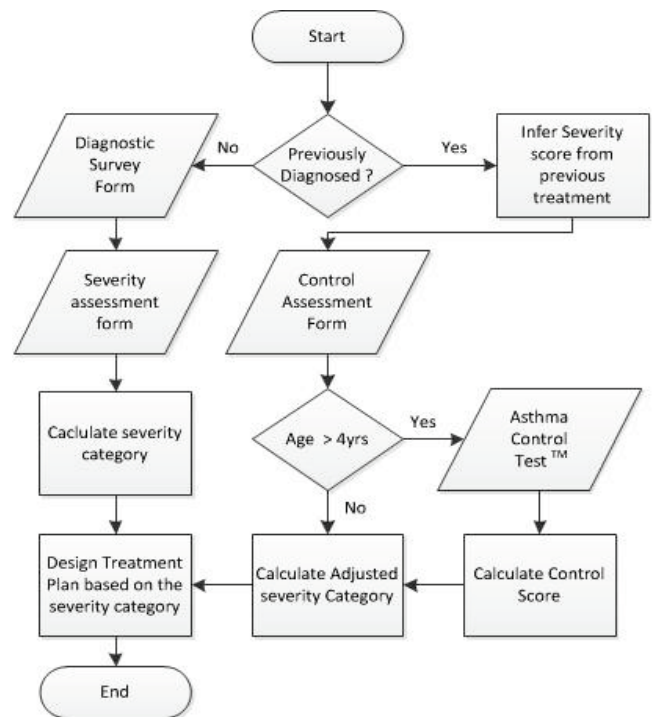
evidence, and the guidance knowledge from effective guideline implementations by clinicians who operationalize guidelines.

In this paper, we focus on the software design of our system that is used to represent and operationalize the desired knowledge. We follow several design goals in developing our system:

- (a) Specify precisely the combinations and sequences of activities in diagnosing, assessing and treating asthmatic patients. The system delineates a diagnostic route which flows information from one component to the next. Pre-defined questions related to asthma symptoms and/or lab results will be collected in a proper data entry form. Asthma severity or control is classified based on the collected information. Treatment plans will then be recommended based on the classification.
- (b) Provide an ease-of-use design for an easy integration into clinical workflow. Although the developed system is expected to influence clinician’s behavior, if the system requests a complex sequence of activities to be fulfilled which takes a significant chunk of clinicians’ time to interact with the system at the exam room, clinicians may be reluctant to adapt their clinical routine to the system. Hence, our system uses only extensively-validated diagnostic survey questionnaire, such as Asthma Control Test™[47], and effective webpage design which populates questions with pre-specified answer options in dropdown boxes with auto-completion.
- (c) Facilitate future modifications to the system to reflect the latest research discovery and the updated guidelines. As new knowledge is discovered, guideline recommendations may be revised or augmented. The system needs to reflect the updates. Our application is implemented following the model-view-controller principle so the logic functions are independent from the user interface. The system’s modular structure enables modifications only to a relevant module without a dramatic change of the overall system. For example, a new drug goes on market and is added to the list of suggested medications. Then the list of medications, maintained in a database table in our system, needs to be updated with the new drug’s data. An administration module AdminModule will assist the application administrators in entering the new drug information using medication update page.
- (d) Access the developed system only through a secured interface. The system is aimed at practicing clinicians, especially PCPs although it does allow other types of users to use. The level of accessibility and the type of functionality performed by the system are regularized by the specific roles of the users.

We design the information flow during diagnosis and treatment as depicted in Figure 1. The system first prompts the physician to query if the patient is already under any type of asthma medication or the system looks up the historical records if any in the system. If the patient is currently not under medication and asthma is not previously diagnosed (previously diagnosed – No) the system will prompt the doctor to complete the diagnostic survey form, which will help to find the symptoms likely due to asthma, family history of asthma or allergies and identify precipitating factors that affect asthma. If this step determines the

patient has asthma, in the next step, the system will flow to the *Assessment* page where 7 pre-defined questions will be asked. The asthma severity of the patient will then be classified based on the answers to these questions, and shown on the screen as a chosen radio button from one of the categories of “intermittent”, “mild persistent”, “moderate persistent” and “severe persistent”. Once the severity category is found, appropriate medication combinations will be designed and shown on the *Medication* page for the clinician to choose. If the patient is previously diagnosed with asthma or under medication (Previously diagnosed - Yes), more emphasis is given on management of the symptoms of asthma. The patient’s severity category previously assessed will be inferred based on his/her current treatment or previous records. On the *Assessment* page, 5 pre-defined questions for control assessment are prompted to solicit answers. For the patient older than 4 years of age there will be an option to complete Asthma Control Test™ [47]. This will determine the level of control. The system then uses this control classification of “good”, “marginal” or “inadequate” to adjust the severity category. A treatment plan with appropriate medication combinations based on the adjusted severity category will be shown on the *Medication* page.



**Figure 1. The information flow in our system.**

The system runs a set of algorithms at the back-end with logic reasoning on the provided information of the patient. We provide examples in the next two subsections to illustrate how we convert guideline suggestions into computer algorithms. An example on assessment is given where the asthma severity of patients of 0-4 years of age is classified according to Section 3 of [22]. Another example is given on medication treatment design for the severity category of “mild persistent” which includes the daily treatment plan, sick treatment plan and possible arrangement for emergency. We focus on the description of daily treatment plan.

### 3.1 Assessment of asthma severity

For a patient who is at 0-4 years of age, according to the guideline, level of severity is examined by both impairment and

risk as shown in Figure 2, copied from the guideline [22]. The impairment domain is assessed by the patient's /caregiver's recall of any asthmatic symptoms in the previous 2-4 weeks. The level of severity is determined to the most severe category in which any feature/symptom occurs.

Components of Severity		Classification of Asthma Severity (Children 0–4 years of age)			
		Intermittent	Persistent		
Impairment	Symptoms	<2 days/week	>2 days/week but not daily	Daily	Throughout the day
	Nighttime awakenings	0	1–2x/month	3–4x/month	>1x/week
	Short-acting beta <sub>2</sub> -agonist use for symptom control (not prevention of EIB)	<2 days/week	>2 days/week but not daily	Daily	Several times per day
	Interference with normal activity	None	Minor limitation	Some limitation	Extremely limited
Risk	Exacerbations requiring oral systemic corticosteroids	0–1/year	>2 exacerbations in 6 months requiring oral steroids, or >4 wheezing episodes/1 year lasting >1 day AND risk factors for persistent asthma		
		Consider severity and interval since last exacerbation. Frequency and severity may fluctuate over time.			
		Exacerbations of any severity may occur in patients in any severity category			

Figure 2. Classification of asthma severity of children of 0-4 years old in the 2007 NAEPP guideline.

A data collection form is design within the *Assessment* page. Each component in Figure 2 corresponds to a pre-specified question for which, four options of answers, each defining one of the four severity categories, are given in a dropdown box. The answer the patient chooses or physician enters into the system to each question is stored in a variable. For example, “symptoms” constitutes a variable named “symp\_var”, we assign scores to each of the options, such as “<=2days/week” (symp\_var=1), “>2 days/week but not daily” (symp\_var=2), etc. If information is provided for the risk effect, such as “at least two exacerbations in 6 months”, a “risk\_var” variable is used to take the information. These variable values will be pushed into a table of the back-end database. Then a simple and fast inference algorithm interacts with database to determine appropriate level of severity.

```

Assessment_severity_score(impair_var, risk_var, age)
{
  if (age >=0 & age <=4)
  symp_var = impair_var(1);
  nightsymp_var = impair_var(2);
  sabasymp_var = impair_var(3);
  interference_var = impair_var(4);
  Score =max(symp_var, nightsymp_var,
             sabasymp_var, interference_var);
  findSeverity(Score) {
    if (Score==1) severity="Intermittent";
    if (Score==2) severity="Mild Persistent";
    if (Score==3) severity="Moderate Persistent";
    if (Score==4) severity="Severe Persistent";
  }
  adjustSeverity(severity, risk_var);
  ...
}

```

A set of such simple functions are combined to form an algorithm that determines the patient asthma severity level based

on the variable values pushing into the database at the data collection step.

### 3.2 Treatment design for “mild persistent”

A list of appropriate medications is determined based on the severity and control levels together with age of the patient. The 2007 NAEPP guideline suggests 6 steps in designing the daily medications based on the severity category as shown in Figure 3. In our database, the medications are organized into groups of equal potency specified by the pulmonologists in our clinical standards committee. Then the database table consists of a field that specifies suitable steps of these medications.

For new patient, the system assesses his/her severity level and for a returning patient, the system adjusts the severity category after assessing the control level of his/her symptoms. For a not-well-controlled patient, even if the physician decides to regulate the patient’s symptoms in the same severity level, medications of stronger potency (higher step) may be in the suggested list to better control the symptoms. This is developed in consultation to an effective asthma management program [46]. We show a simple example of how the medications are populated for the severity category of “mild persistent”. The suggested medicines are retrieved from the database as a list by functions associated with medication types. This list is then displayed on the web page. A function may return an empty list if the respective type of medications is not suitable for the specific severity category.

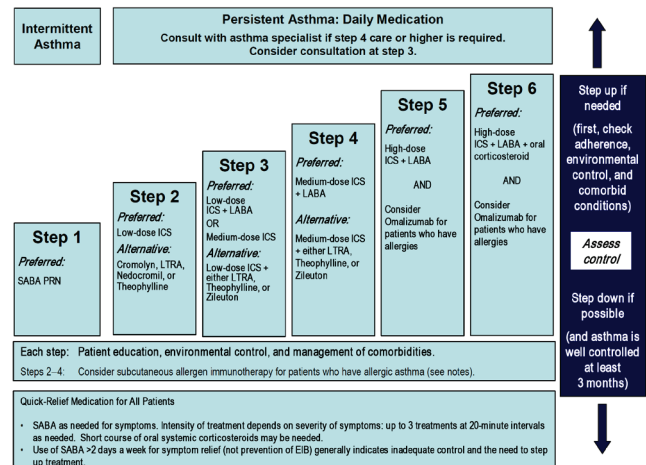


Figure 3. Stepwise medication regimen recommended in the 2007 NAEPP guideline.

```

Medication_populateMedications(severity, step)
{
  If (severity = "mild persistent" & step==3){
    List ld_ics = getListofLow_Dose_ICS(severity, step);
    // list of low dose ICS
    List ltra = getListofLTRA(severity, step); // List of LTRA
    List cromolyn = getListOfCromolyn(severity, step);
    // List of Cromolyn
    List nedocromil = getListofNedocromil(severity, step);
    // List of nedocromil
    List theophylline = getListofTheophylline(severity, step);
    // List of theophylline
    List md_ics = getListofMedium_Dose_ICS(severity, step);
    // List of medium dose ICS }
}

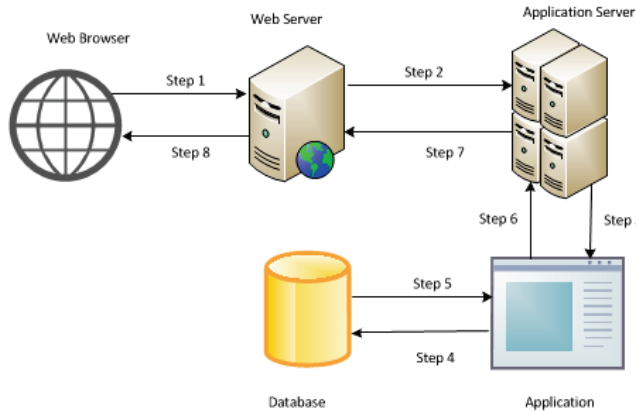
```

## 4. SOFTWARE DESIGN

Our system is developed on top of cutting-edge open-source frameworks such as Spring, or Hibernate. The architecture is well positioned with necessary capabilities of implementing the proposed decision support functions in conjunction with the consideration of cost effectiveness and ease-of-use.

### 4.1 Architecture

Figure 4 shows a three-tier architecture comprising of a web server, an application server and a back-end database.



**Figure 4. Overview of the software architecture of our system.**

Physicians access to the application through a web browser which sends the request to the web server (Step 1 in Figure 4). Then the web server routes the request to the application server (Step 2) on which our application functions reside. The application server parses and initiates the request to the appropriate application functions (Step 3). The application functions may access the database if needed and make SQL calls to the database (Step 4). The set of data requested will be returned to the application to run relevant algorithms (Step 5). The results of the algorithms as formatted data are sent back to the application server as responses to the request (Step 6). The application server then forwards the responses to the web server where the responses are rendered as HTML pages (Step 7). The web server will then send the response HTML pages to show on the web browser (Step 8).

### 4.2 Modularity design through model-view-controller principle

Model-View-Controller (MVC) is a software engineering architecture which has been widely used as an approach for developing systems that deal with more than one view of the same data. MVC helps to decouple the underlying business logic from the user interface. It makes the system easy to manage as it enables the developers to develop, test and maintain the three main components: models, view and controller, independently.

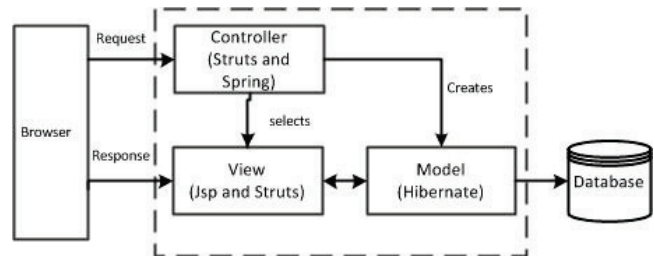
In the MVC principle, controller layer processes the request and alters the models or the views appropriately. It communicates between the model layer and the view layer by listening to the request and instantiating the model classes which are used to alter the view as required. The controller layer defines the behavior of the application.

The view layer manages the visual representation of the data. The view is changed according to the changes in the data model.

It can be seen as a wrapper around the model, and is capable of displaying a subset of the data that is encapsulated in the model.

The model layer manages and operates on the data of the application. It contains the business logic to access and update the data. It receives requests from the controller layer and sends responses to the view layer.

The design based on MVC isolates the three logical components of the application. It facilitates to develop, maintain and test each of these components independently. For example, a particular function in the model layer needs to be revised due to the update on the newly discovered drugs. A function called, for instance, `getListofNewDrug()` is then developed for the medication recommendation functionality of the system to accommodate the new drugs after the new drugs' specifications have been pushed into the database. No changes will be needed at all for any other model and all functions in the other two layers. It results in a minimum amount of revision to the system. We use the Struts, Spring and Hibernate frameworks to implement the principle of MVC as shown in Figure 5. These are the widely accepted open source frameworks in the IT industry.



**Figure 5. The implementation of model-view-controller.**

Modules heavily based on Struts (v2.5)[48] and JSP (Java server pages v2.0) are used to implement the view layer. Apache tiles (v2.2) is also employed to manage reusable components in the view layer. JavaScript (v1.8.2) is in use for programming in the view layer to, for instance, manage HTML pages.

The controller layer is implemented based on Struts (v2.5) and Spring Framework (V 3.0.5)[49]. Requests are processed by the controller servlets of the Struts framework and delegates to the service layer which is implemented using Spring. The service layer instantiates the required classes in the model layer and is also responsible for reusing the classes. The database connection is also managed by the service layer.

Hibernate (V 3.6.1)[50] is the object-relational mapping tool in the model layer. Main components of this layer include Data Access Objects (DAOs) and Data Objects (DOs). DAOs manage the communication with the data sources such as a database. They separate the data source implementation from the controller layer and the view layer. They manage the queries on the database in order to obtain information using Hibernate Query Language (HQL). DOs are java objects which represent the database tables. They are used by DAOs to retrieve data from the database. Hibernate makes the application independent of the underlying database vendor.

### 4.3 Database design

We used relational data schema to model the data for the website. My-SQL is the database vendor we used to develop this project,

and can be changed to any other database easily due to the use of Hibernate. A variety of tables are designed to store different types of data and to manage the relations among the data. Main tables include tables containing medications and their types based on the guidelines, tables containing all the pre-defined questions and answers of all the data entry forms and tables consisting of the login information for the physicians. Figure 6 shows an example of a few relational tables used in our application.

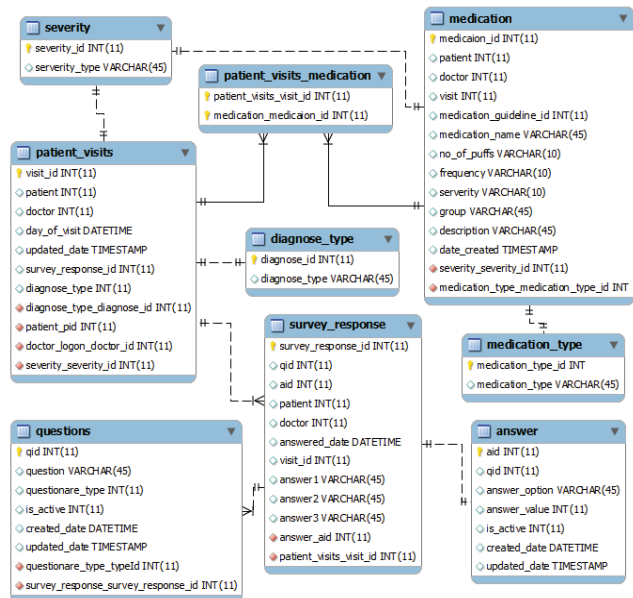


Figure 6. Sample tables in the database.

The names of medications together with their proper dosage, their proper usage, and the identifier of the severity category which they are suitable to are all stored in the *medication* table. This table is linked with the *severity* table by the severity identifier so to help the grouping of the medications based on severity. It also connects to the *medication\_type* table which specifies if the medication is an inhaled corticosteroids (ICS), short acting beta agonists (SABA) or long acting beta agonists (LABA) etc.

Pre-defined questions for the survey and assessment are stored in the *questions* table and the pre-specified answers to these questions are stored in the *answer* table. Foreign key references are used to link these two tables. The Status field will help to find the active questions in the table. As an example, if a question later on becomes unnecessary, we do not intend to remove it from the table. Instead we set the question to an inactive status in the table, which makes it possible to recover the system with early-version questions. Both tables are linked to the *survey\_response* table.

The *survey\_response* table is used to store the patient's responses to the questions defined in the *questions* table at specific visits. Through the *answer* identifier, this table is also linked to the *answer* table. Date of the question being answered is also stored in this table. The *patient\_visits* table is connected to the *survey\_response* table so the patient's responses at previous visits can be retrieved from this table by the patient identifier. The *patient\_visits* table saves other details of the patient visit. Details about any previous visit of the patient if available to our system can be retrieved using this table. The *patient\_visits* table also relates to the *patient\_visits\_medication* table and *diagnose\_type* table to retrieve the diagnosis and medications determined at the specific visit.

Physicians' registration and login information is all stored in the *login* table which is not shown in Figure 6. The system accesses to the *login* table to authenticate and authorize the physician login. The role and permission tables are devised to store the role of the user as, "practicing clinician", "patient" and "administrator", and "guest user" etc. and to control the different access levels of different logins. For example, a practicing clinician is allowed to set up his own table of patient records within his/her account, and shown on the webpage when he/she logs into the system. The "administrator" has a full access to the different accounts and may have capability of helping users to recover their data.

## 5. IMPLEMENTATION

We develop the system in conjunction with University of Connecticut Health Center with inputs on the clinical workflow from family medicine centers at Hartford to enable preliminary assessment of the decision support system and to design an efficient and user-friendly interface that aims at minimum changes in the clinical routine for PCPs to adapt to the system when deployed into clinical settings. Although the core of the system can be easily embedded into a specific EMR, as a stand-alone web system, it needs an efficient user interface.

In particular, we pay attention to the web design. The web pages are built with the Auto Complete options and dropdown menus to be used with tablets and desktop/laptop computers. We notice that most of our collaborating family medicine centers equip their exam rooms with laptops. If the laptops are tablet ones, the dropdown menus are efficient that the physicians can just touch the screen with their fingers to choose. However, if the laptop only has a touchpad mouse, it will take physicians a significantly longer time to click the mouse over 20 times at the dropdown boxes to answer all required questions. In this situation, physicians often prefer to the direct type-in of the text, so we provide auto complete option to all the dropdown menus. Although the system offers assessment and prompt appropriate list of medication, it allows physicians to select a different choice if he/she feels more comfortable with it, but the system will highlight the discrepancy on the webpage or pop up a free-text box with the discrepancy information and suggest him/her to enter a specific reason for it.

### 5.1 Portability and security

This system is built on top of tools which are compliant with Java specifications and therefore portable across all compatible application servers that run Java. Currently the system is deployed on Tomcat server as an application server and an apache server is used as a web server.

Even though the developed system is not intended to store patient data as the same manner of an EMR, we provide multiple security means to protect the data stored at physicians' accounts through secured login. The application can be accessed only through a secured login with password protection. The "administrator" has authority to re-generate a random key when a user forgets his/her password. The *Login* module will authenticate the username and password and the accessibility is controlled by the roles of the users. Patient information is tagged only to the primary care physician who has generated the records, and is not shared between the physicians unless the physicians agree to share. Then the "administrator" can link multiple accounts to share patient records among the specific group of physicians.

The application uses AdminModule to update the database. Any changes in diagnostic questions, assessment questions or medication are updated using this module. For example when NAEPP updates the guidelines with new drugs, application administrators can easily update the medication table in the database using “Update Medication” pages in the AdminModule.

The backup option in the AdminModule runs backups of the system data everyday at a time specified by the site administrator. An administrator can setup a down time for the system and trigger the backup job. This will create back-up files which can be written to any storage media and help in restoring the data with minimal loss of data in case of operational mistakes. These backup files are encrypted flat files and named using the current timestamp to avoid overwriting of files.

The current evaluation system is deployed in the academic setup which does not hold real patient data. The final production version will be deployed in clinical premises where the actual patient data is stored and managed under the auspices of the appropriate institutional review board (IRB).

Due to the model-view-controller design, as pointed out in Section 4.2, the system has enough flexibility to incorporate new evidence-based results updated in a later version of the guidelines without dramatically re-programming the entire system. The MVC design also helps the support team to make changes easily since all the logical components are loosely coupled.

The system is currently in a fine-tuning process and is undergoing a preliminary evaluation stage with many insightful suggestions from our clinical standards committee. The design of the system has been well received. We show in the next section a simple case on how to use this system. Although this system has not yet been deployed into real clinical encounter, given the programs we computerized have established evidence on their effectiveness of medication management [39, 46], we anticipate the computerized system is able to extend the same efficacy.

## 5.2 Simple demonstration

The web-based system currently has five tagged pages including “Face Sheet”, “Diagnostic Survey”, “Assessment”, “Medication” and “Summary”. The information and data flow from the “Face Sheet” which contains the patient’s demographics and previous diagnosis together with insurance information all the way through to the “Summary” page which provides a summary for the physician and a summary for the patient to take home. We emphasize on the simplicity of representing the system in a web interface for ease-of-use. Sample screens on “Assessment” and “Medication” are given in Figure 7 and Figure 8 for a patient with the severity level of “intermittent”.

For a previously-diagnosed patient, if the previously assessed severity category is available (either through the previous records in this system or through the patient’s EMR records if available or through the inference from the current asthma medications), it will automatically be populated to the assessment screen as a chosen radio button corresponding to the specific category. The physician may choose to skip the “Diagnostic Survey” page. If it is not available, the severity radio button will not be selected. The “Diagnostic Survey” form may need to be completed. At the “Assessment” page, five questions are required for all patients for control assessment. For a patient of 4 years older where the age is automatically determined by the demographics of the patient on the “Face Sheet”, Asthma Control Test will be suggested and automatically shown on the website. For each question of the test,

a score is assigned based on the answer, and shown on the screen together with the total score summing answers to all the questions.

The screenshot shows the 'Assessment' page of a web application. At the top, there is a navigation bar with tabs for 'Face Sheet', 'Diagnostic Survey', 'Assessment' (selected), 'Medication', and 'Summary'. The 'Assessment' section contains a dropdown menu for 'Does this child have asthma?' set to 'Yes - Previously Diagnosed'. Below this are five dropdown menus for: 'Nocturnal Symptoms' (None), 'Exercise tolerance' (Good), 'School/Work absenteeism (for asthma)' (None), 'Use of PRN medications' (None), and 'Use of prednisone(Since last visit)' (None). A button labeled 'Hide Control test' is visible. The 'Asthma Control Test' section contains several questions with dropdown menus: 'In the past 4 weeks how much of the time did your asthma keep you from getting as much done at work, school or at home?' (All of the time), 'During the past 4 weeks, how often have you had shortness of breath?' (More than once a day), 'During the past 4 weeks, how often did your asthma symptoms (wheezing, coughing, shortness of breath, chest tightness or pain)' (4 or more nights a week), 'During the past 4 weeks, how often have you used your rescue inhaler or nebulizer medication (such as albuterol)?' (3 or more times per day), and 'How would you rate your asthma control during the past 4 weeks?' (Not controlled at all). Below these questions is a score calculation: 'How did this adolescent score?' with input fields for Q1-Q5 and a total score of 5. At the bottom, there are radio buttons for 'Current Asthma control is' (Good, Marginal, Inadequate) and 'Asthma Severity is' (Intermittent, Mild Persistent, Moderate Persistent, Severe Persistent). An 'Assess' button and a 'Submit' button are also present.

Figure 7. The assessment data entry form for a previously diagnosed patient.

If the patient is assessed with the severity level of “intermittent”, as shown in Figure 8, a treatment plan is designed with flexibility for physicians to choose among different recommended choices. The treatment plan comprises a daily treatment plan, a sick treatment plan and an emergency plan. For instance, in the daily treatment plan, physicians need to choose one medication and only one medication from each of the two boxes with suggested drugs as shown in Figure 8. The suggested medications may be grouped into leveled groups labeled as “lower potency” or “higher potency”. The emergency plan is usually a blank free-text box so physicians can enter specific instructions or the box can be pre-populated with instructions from previous records if the patient’s treatment records have been stored in the system before.

## 6. CONCLUSION

We have designed a decision support system to facilitate effective and patient-centered asthma management. The 1997 and 2007 NAEPP Guidelines both recommend a multimodal chronic care approach to asthmatic patients. However, they have not been widely adopted by primary care physicians because implementing the guidelines in primary care setting requires changes and redesign in clinical practice and the use of Health Information Technology (HIT) to facilitate the changes. Existing electronic asthma care systems are either inefficient to be used in real clinical encounter or provide only after-fact feedback. Our web-based decision support system integrates intelligent computer technology and complex guideline guidance together with the knowledge needed for implementing the guidelines to improve decision making for asthma care. This system is able to collect guideline-suggested diagnostic measures, automatically assess asthmatic severity and control categories based on collected

measures as well as provide guideline-appropriate medication regimen.

The screenshot shows a web interface for selecting a medication regimen. At the top, there is a navigation bar with tabs for 'Face Sheet', 'Diagnostic Survey', 'Assessment', 'Medication', and 'Summary'. Below this, the 'Medication' tab is active. The main heading is 'Select Medication Regimen'. Underneath, there is a dropdown menu for 'Patient Severity Category' set to 'Intermittent Persistent'. The form is organized into three main sections:

- Daily Treatment Plan:** A dropdown menu with the following options:
  - Albuterol 1 vial premix (0.083 %) solution by nebulizer
  - Albuterol 1 vial premix (0.083 %) 2 puffs MDI as needed
  - Albuterol 1 vial premix (0.083 %) 2 puffs before exercise (for exercise symptoms)
  - Xopenex (0.63 mg) solution by nebulizer as needed and before exercise
  - Xopenex (1.25 mg) solution by nebulizer as needed and before exercise
- Sick Treatment Plan:** A dropdown menu with the following options:
  - Albuterol 1 vial premix (0.083 %) solution by nebulizer
  - Albuterol 1 vial premix (0.083 %) 2 puffs 4 times /day and 2 more times at night if needed and before exercise
  - Xopenex (0.63 mg) solution by nebulizer 3 times / day
  - Xopenex (1.25 mg) solution by nebulizer 3 times / day
  - Xopenex HFA 2 puffs 4 times/day and 2 more at night if needed
- Emergency Plan:** A text box containing the following text:
 

If the Asthma attack is not getting better after you have been on the Sick Treatment Plan for 2 days  
 on M-F, 8:00am - 4:30pm call the office @ 714-4332  
 After hours and on weekends call 714-4000 and ask for the doctor covering Adolescent medicine.

A 'Submit' button is located at the bottom right of the form.

**Figure 8. The sample form of the suggested treatment plan for a patient with the severity level of intermittent.**

An effective asthma management consists of multiple components as suggested in NAEP guidelines, such as physician's compliance to the guided measures of assessment and monitoring process, education for a partnership in asthma care, control of environmental factors and co-morbid conditions, together with appropriate use of pharmacologic therapy. Our current system aims to improve physicians' adherence to the latest NAEP guidelines during their clinical encounter of patient visits. We plan to extend the system to include more self-care management strategies and education for patients to better manage their own symptoms with better awareness.

Our system currently does not directly make use of insurance information to decide which medications are within a formulary and under coverage of the patient insurance company. We plan to augment our system with additional modules to automatically highlight favorable medications according to specific insurance policy the patient holds.

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