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MODELING CHRONIC DISEASE PATIENT FLOWS DIVERTED FROM EMERGENCY DEPARTMENTS TO PATIENT-CENTERED MEDICAL HOMES

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Abstract

Chronic Disease is defined as a long lasting health condition, which can develop and/or worsen over an extended time, but which can also be controlled. The monetary and budgetary toll due to its persistent nature has become unsustainable and requires pressing actions to limit their incidence and burden. This paper demonstrates the utility of the System Dynamics approach to simulate the behavior of key factors involved in the implementation of chronic disease management. We model the patient flow diversion from emergency departments (ED) to patient-centered medical homes (PCMH), with emphasis on the visit rates, as well as the effect of insurance coverage, in an effort to assure continuity of quality care for Asthma patients at lower costs. The model is used as an evaluative method to identify conditions of a maintained health status through adequate policy planning, in terms of resources and capacity. This approach gives decision makers the ability to track the level of implementation of the intervention and generate knowledge about dynamics between population demands and the intervention effectiveness. The functionality of the model is demonstrated through the consideration of hypothetical scenarios executed using sensitivity analysis.

Keywords

System dynamics modeling; Patient Centered Medical Home; Intervention effectiveness; Decision analysis; Chronic disease management; Ambulatory Care

1. Introduction

Treatment of chronic disease forms a substantial portion of the U.S. healthcare expenditure. The number of adults with at least one chronic condition has risen from 34% in 2003 to 40% in 2009 (Tu and Cohen 2009). It is reported that nearly half of the U.S. healthcare

expenditure is incurred for the treatment of just five chronic conditions, namely mood disorders, diabetes, heart disease, asthma, and hypertension (Druss et al. 2001). On the whole, chronic diseases constitute nearly 75% of the U.S. healthcare expenditure (Dickens et al. 2012). By 2020, about 20% of the U.S. population is projected to be over age 65 (U.S. Census Bureau 2015). It has been indicated that 88% of the population above this age suffers from at least one chronic illness as compared to just 44% of the general population suffering from at least one chronic condition (Hoffman et al. 1996; Anderson and Horvath 2004; Tu and Cohen 2009; Smith et al. 2012). With the aging population and the higher prevalence of chronic conditions among the elderly, the problem of chronic disease is expected to escalate in the coming years (Colwill et al. 2008). Continuity of care which creates a provider-patient partnership and an integration of care which enables effective participation of relevant specialists are key tenets for efficient treatment in this matter (Holman 2004).

With continuity and integration being important elements of chronic disease management, treatment within hospital-based ambulatory settings especially in emergency departments (ED), calls for attention. A substantial part of chronically ill patients utilize ED as a venue for treatment of their condition (Yusuf et al. 2010; Wolfson et al. 2011; Prystajecy et al. 2012; Vandyk et al. 2012). A study by Peppe et al. (2007) reports that nearly 20% of ED visits are related to chronic conditions, with this percentage rising to 31% for frequent users (four or more visits annually). Analysis of data from the state of Missouri (Missouri Information for Community Assessment 2011) reveals that about 12% of ED visits are related to chronic conditions, although this may be based on conservative estimates. The aging of the population combined with the increase in chronic conditions impose a burden on the ED (Trzeciak and Rivers 2003), which will continue to increase. This burden is especially important for overcrowded departments as it may contribute to declines in healthcare service levels (Blais et al. 2010). Limited access to primary care physicians has appeared as one of the most critical causes for the high usage of the ED (McCusker et al. 2010; McNaughton et al. 2011; Crooks et al. 2012; Cao and Schoner 2014) along with insurance status (Sox et al. 1998).

It is generally accepted that ED cannot ensure continuity of care (Barbera et al. 2010). On the other hand, continuity of care has been associated with reduced ED visits and hospitalizations. Bird et al. (2007) proposes an integrated care facilitation for elderly patients with chronic disease after ED visits, in an effort to favor easy required health care services access, as well as comprehensive self-management strategy. Their results reveal reductions of about 20% in ED presentations, about 27% in hospital admissions, and 19.2% in bed-days. Scott et al. (2004) analyze the effectiveness of Cooperative Health Care Clinic (CHCC) group outpatient model, still, applied to an older population with previous ED treatments. The experiments show fewer hospitalizations and emergency visits combined with increased patient satisfaction and self-efficacy. Van Uden et al. (2005) also recommend treatment continuity through the implementation of an out-of-hours primary care physician (PCP) cooperative, recording 53% reduction in emergency care service utilization. For example, in the context of asthma, it has been shown that continuity of care resulted in a considerable reduction in both ED usage and hospital admissions (Cree et al. 2006).

Populations managed by patient-centered medical home (PCMH)¹ practices have evidenced nearly 30% fewer emergency visits and six percent fewer hospitalizations, both of which contribute to direct savings for the patients and overall savings for the health care system (Reid et al. 2010), while exhibiting positive opinions relative to delivered health services (Schoen et al. 2007). The results found by Mitchell (1997) steer in the same direction, indicating around a 17% drop in asthma patients' readmission, credited to the implementation of a nurse-led home management training intervention. Notice that the term PCMH is used in this paper to reference all ambulatory venues that differ from ED services, e.g., Primary Care Physician (PCP) offices and Health Departments.

A higher continuity of care standard results in better health outcomes with a lower likelihood of hospitalization (Menec et al. 2006). Thus, it is evident that the diversion of patients who seek regular care for chronic conditions from ED to alternative venues that ensure uninterrupted care is a feasible option. However, the implications of such diversion on the utilization levels of the relevant venues need to be ascertained to ensure that the diverted patients are able to find a source of regular care. Since interventions that divert these patients help in reducing medical complications related to chronic conditions, the healthcare delivery through emergency venues may be reduced while the utilization of alternative PCMH venues is increased (Van Uden et al. 2005). This capacity usage change underlies considerable feedback effects over time that may affect the future performance of these venues, for example, in reducing mortality (Roccaforte et al. 2005; Garcia-Lizana and Sarria-Santamera 2007), and the health of the targeted population in ways that are difficult to appreciate. Thus, the complexities associated with implementing patient diverting strategies may cause unintended consequences. For instance, as patient flows shift, an increasing difficulty in getting primary care appointments may be experienced (Steinbrook 2008). The Congressional Budget Office (2004) envisions that the short-term savings from disease management programs may be offset in the longer term by the rising utilization and cost for related and unrelated conditions resulting from the improved life expectancy of the enrollees.

Knowledge of the impact of diverting these flows on healthcare capacities is imperative for planning purposes since quality healthcare services require the best matching of the healthcare capacity with the health service demand (De Bruin et al. 2007; Kucukyazici et al. 2011; Diaz et al. 2012). This entails effectively configuring enough resources capable of meeting these requests. Growth in demand will also result from the expanding role of health professionals in case management, disease prevention, emergency care, and the early detection of chronic conditions (Bureau of Labor Statistics 2014). Thus, the central objective of this research is to present a framework that allows researchers and policy makers to understand how our near term policy decisions, with regard to the extent and placement of intervention strategies, will condition the flow of population health of selected (insured and uninsured) groups over time. The model demonstrates that successful interventions will not

¹US Agency for Healthcare Research and Quality (AHRQ) from the Department of Health and Human Services has developed a Web site to provide decision-makers and researchers with access to evidence-based resources about the medical home and its potential to transform primary care and improve the quality, safety, efficiency, and effectiveness of U.S. health care. Go to: <http://www.pcmh.ahrq.gov>.

only shift demand away from ED, but also cause, especially in the long term, an increase in demand at other non-emergent healthcare facilities. Estimating these values is critical to ensure that quality care is properly rendered and timely delivered at both ED and PCMHs.

2. Literature Review

The literature is full of examples demonstrating the high ED usage rates of chronic disease patients. A few significant ones are described in the following paragraphs.

Prystajecy et al. (2012) describe and examine ED visits for adult patients with cancer. The authors found a higher rate of ED utilization, compared to other chronic conditions. Vandyk et al. (2012) explore the range and prevalence of cancer treatment in ED. Similarly, other chronic disease patients have high ED utilization. Wolfson et al. (2011) find that acute and chronic clinical manifestations of sickle-cell disease (SCD) cause a significant healthcare utilization, especially in the emergencies. Yusuf et al. (2010) assess the traits of ED visits made nationally by patients with SCD. The authors conclude that a consistent number of ED visits occur among people with SCD, commonly due to pain symptoms.

The literature attributes many causes for the high usage of the ED by chronic disease patients. One of the most critical aspects is lack of access to a primary care physician (PCP). McNaughton et al. (2011) assert that low socioeconomic status patients suffering from Diabetes with limited access to primary care turn toward ED for treatment. Crooks et al. (2012) identify the implications of experiences of chronically ill patients unattached to any general or primary care doctor and conclude that this proved to be an obstacle for the improvement of health and health access. McCusker et al. (2010) analyze the relationship between physician locations and healthcare characteristics. The authors reveal that affiliation with physicians and perceived needs dictate medical visits, for patients with ambulatory care sensitive chronic conditions (ACSCC). Sharma et al. (2010) examine the effect of early follow-up visits with patients' PCP after a hospitalization, for patients with chronic obstructive pulmonary disease (COPD). The authors conclude that continuity with the patient's PCP following the hospitalization could contribute in lowering ED visit rates and readmissions.

As mentioned previously, the lack of uninterrupted care services can increase ED and hospital resource utilization, which generally leads to worse outcomes for the patient and a burden for the facility itself. One of the most important burdens on the ED is the issue of overcrowding. The literature has found the effects of overcrowding are diverse. Johnson and Winkelman (2011) summarize the findings of previous studies reporting delay in treatment, decreased satisfaction, and increased mortality as a result of ED overcrowding. However, the authors suspect effects of nursing in ED crowding, with potential strategies development which would provide high quality of care. Michelson et al. (2012) assess the effects of ED crowding on the likelihood of patients to be admitted and readmitted in the future. They conclude that an increase in ED crowding is responsible for the lower probability of both hospital admission and frequency of return visits within 48 hours. Sills et al. (2011) analyze the effects of ED crowding on the treatment quality for palliative patients. The researchers found that the crowding causes a drop in timely care delivery and effectiveness. Jo et al.

(2012), in addition to confirming the association between ED crowding with delayed antibiotics treatment in community acquired pneumonia (CAP) patients, hypothesize on the association of ED crowding with 28-day mortality. The results reveal that ED crowding measured by Emergency Department Occupancy (EDO) rate was associated with higher 28-day mortality in CAP patients after adjusting the time-to-first-antibiotic-dose (TFAD), pneumonia severity index (PSI), and laboratory markers. Sun et al. (2013) examine the relationship among ED crowding in hospitals, the rate of admission and patients' health who were already admitted. The results show that the periods of high ED crowding were associated with increased mortality and slight increases in length of stay, costs for admitted patients. Finally, Mahler et al. (2012) aim to determine the impact of ED overcrowding on Emergency Medicine (EM) resident education. Their study uncovers that EM residents saw fewer patients and performed fewer procedures, which is detrimental for their learning.

The literature also discusses how to measure overcrowding. Hwang et al. (2011) propose a systematic review of crowding measures and compare them, based on their validity. The results suggest that time intervals and patient counts constitute a reliable tool for measuring ED crowding. Winkin et al. (2013) compare and evaluate the correlation between the National Emergency Department Overcrowding Scale (NEDOCS) and the occupancy rate (OR) determination, with the crowding in ED. Their study shows that both scaling measures are equally accurate in the assessment of ED crowding. Beniuk et al. (2012) assess a list of several factors quantifying the ED crowding in order to estimate the state of medical department. The results provide a set of eight quantified crowding measures defining the effects of crowding on the ED operations.

The significance of overcrowding problem in EDs may be highlighted through some statistics. On the demand side, ED visits have increased significantly from 88.5 to 129.5 million in the period from 1991 to 2011. ED visits per 1000 have also increased from 351 to 415 during 1991 to 2011. Looking at the supply side, number of Emergency departments in the U.S. have reduced from 5108 to 5035 during the same period. Further, in 2010, 38% of EDs in all U.S. hospitals had capacity issues (17% "over" capacity and 21% "at" capacity). Major ED capacity issues were in the U.S. teaching (51% EDs with 32% "over" capacity and 19% "at" capacity) and urban (50% of EDs with 27% "over" capacity and 23% "at" capacity) hospitals. ED capacity issues in Rural (31% EDs with 11% "over" capacity and 20% "at" capacity) and non-teaching (36% of EDs with 14% "over" capacity and 22% "at" capacity) hospitals were relatively lower (American Hospital Association 2013). Trend in wait time at EDs is another issued related to overcrowding. From 2003 through 2009, the mean wait time in U.S. EDs increased 25%, from 46.5 minutes to 58.1 minutes. Mean wait times were longer in EDs that went on ambulance diversion or boarded admitted patients in hallways and in other spaces. Longer wait times were associated with EDs in urban areas (62.4 minutes) compared with nonurban areas (40.0 minutes). Finally, the mean wait time increased as annual ED visit volume increased; from 33.8 minutes in EDs with less than 20,000 annual visits, to 69.8 minutes in EDs with 50,000 or more annual visits (Hing and Bhuiya 2012).

Many solutions to overcrowding have been proposed in the literature. Rowe et al. (2011) examine the effectiveness of triage liaison physicians (TLP) on mitigating the effects of ED

overcrowding. The results support that, despite a weak research method, TLP effectively contributes to a decrease in ED overcrowding. Migita et al. (2011) state that delays in admission for inpatients greatly contributes to the overcrowding in ED. The authors propose a systematic and comprehensive effort aiming at decreasing ED length of stay, which leads to a reduction in patient admission. Qureshi et al. (2011) analyze the implementation and effect of an acute care emergency surgery service (ACCESS) on ED length of stay, surgical decision time and overcrowding. The results indicate that ACCESS contributes to the reduction of surgical decision time and the improvement in ED crowding. Chan et al. (2012) think that the problem should go beyond the examination of only ED, given the complex nature of crowding. The authors propose a model providing better illustration of the ED crowding phenomena, factors causing it and preventive and corrective strategies. Barish et al. (2012b) attribute the issue of overcrowding in ED to the overwhelming demand from patients, as well as the supply shortage of PCP, which push the patients toward ED. The authors suggest the launch of preventive actions in order to pinpoint causative factors contributing to ED crowding. Higginson (2012) seeks to analyze the causes and effects of ED crowding, along with potential solutions. The author asserts that the main cause of crowding is access block, given the high levels of hospital occupancy. Pines et al. (2013) assess the perceptions of ED crowding, using a survey of medical directors and chairs. Results reveal that patients boarding constitute a factor in ED crowding, which impact patient satisfaction and quality of treatment. Interventions, namely expedition of discharges, prioritization of ED patients for inpatient beds and ambulance diversion contribute to ED crowding reduction. Finally, Flores-Mateo et al. (2012) review organizational interventions meant to reduce emergency department utilization.

Another possible way to alleviate ED crowding is to reduce the demand with interventions in chronic disease patients. Barbera et al. (2010) assert that near death visits for patients suffering from cancer can be prevented. The authors propose a descriptive and retrospective study to get good insight into the reasons for those visits and design and implement adequate interventions. Blais et al. (2010) investigate rates of exacerbations, ED visits and hospitalizations for COPD, medication utilization, and treatment adherence associated with the use of budesonide/formoterol (BUD/FM) or fluticasone propionate/salmeterol (FP/SM). The authors found that the patients treated with BUD/FM had fewer ED visits and hospitalizations and used fewer doses of anticholinergic medication than patients treated with FP/SM, just over a year after the treatment had started. Small (2011) suggests a behavioral model for vulnerable populations in order to assess health utilization patterns in hospitalizations, physician, and ED visits. Dalal et al. (2011) analyze the characteristics of the costs of COPD patients in the hospital setting. The authors conclude a correlation between the increase in cost of the COPD treatment and the intensity of the treatments. The study of Tan de Bibiana (2013) revolves around the impact of Housing First (program consisting in granting a house to a homeless person with mental illness) within a year of ED visit. The results of implementing such intervention suggest lower ED utilization for Housing First participants.

Incidentally, no research study was found in the literature which models chronic disease patient flows diverted from EDs to PCMHs and which also measure utilization of the ED and PCMH venues as well as determine additional costs of various interventions. We

summarize below the contribution of this study with a focus on filling the gap between previous work and this research.

A System Dynamics (SD) approach is used in the proposed study which allows us to understand, as well as anticipate, the dynamic behavior of the population health dynamics of chronically ill patients as they are subject to diverting interventions over time. This approach lets us empirically demonstrate changes in the system's behavior which may be counterintuitive or would not have been evident if approached with more traditional causal methodologies. With our proposed approach, decision makers may simulate the interactions and 'ripple effect' of adopting any combination of intervention policy options and the sensitivity of various sub-populations to these potential interventions over time. For demonstration purposes, we develop a case study in which the flow of Asthma patients through EDs is diverted to PCMHs. Drawing from state, regional and national data, the dynamic flows of these patients are replicated over time. Different intensities of a projected diverting flow strategy are then applied to determine the magnitude of the shift. This intervention is conceptualized so that it considers access to primary care and can be applied across the insured/uninsured status spectrum. Reductions in ED visits, additional visits to PCMH, venue utilization, and costs implications resulting from the implementation of this intervention are determined.

3. SYSTEM DYNAMICS MODEL DEVELOPMENT

System dynamics modeling is mostly used in long-term, strategic models and assumes high level of aggregation of objects being modeled: people, products, events, and other discrete items are represented in SD models by their quantities. Therefore they lose any individual properties, histories or dynamics. If this level of abstraction is acceptable for a problem, SD may be the right method to use. If, however, individual details are considered important, all or part of the model can be re-conceptualized using Agent Based or Discrete Event (process-centric) methods. This reasoning provided motivation for using a system dynamics approach to study long term chronic disease management utilizing different ambulatory settings under various intervention levels. Through a SD approach, the measurement of the dynamic impacts of chronic disease management interventions over time are meant to allow policy makers to interpret the information differently by allowing alteration of mental models. Mental models are unable to accommodate the complexity of interactions that are some distance from the immediate problem. Traditional approaches have not been well suited to anticipate the second and third order health related consequences of competing policy options upon particular population segments (e.g., uninsured and underinsured patients) and, in some instances, have resulted in policy resistance (e.g., resulting in unanticipated changes in PCMHs utilizations).

System Dynamics is a simulation tool that employs the notion of feedback as a critical component. Feedback is typically defined as a process in which a change in the magnitude of a system parameter affects the prospective magnitude of the same parameter in the future. Feedback effects result from causal loop effects. Such loops are common in many simple systems, e.g., population growth. In System Dynamics, the behavioral patterns produced by a complex system are the result of the interaction within such feedback structures. The

replication of the feedback structures that collectively makes up a given system is accomplished through the characterization of a “dynamic hypothesis.” This hypothesis is capable of endogenously describing the observed performance of the studied system. These causal loop structures facilitate the development of the “stock and flow models” which are executable representations capable of replicating system behavior over time (Sterman 2000b). Recent applications of SD in the public health context includes policy and reform strategies, chronic disease management (Milstein et al. 2010; Chen et al. 2011; Ghaffarzadegan et al. 2011; Hirsch et al. 2012), health economics (Whitehead and Ali 2010), and ambulatory utilization issues (Iezzoni 2010; Jia and Lubetkin 2010), among others. Table 1 presents pros and cons of different simulation methods.

Our research proposes a modeling and simulation (M&S) framework based on SD to represent and simulate interactions between intervention strategies and public health. The three basic avenues incorporated in the SD that bind our approach include: 1) representing the general flow of insured and underinsured patient populations with chronic diseases, 2) representing the main steps in the implementation of intervention strategies, 3) representing the driving forces and potential interventions to maximize the management of chronic conditions.

3.1. PATIENT FLOW, INSURED AND UNDERINSURED POPULATIONS WITH CHRONIC DISEASES

The population health model presented in this paper seeks to characterize the flow of patients that suffer from Asthma and seek healthcare services. The patient population is a fraction of the different cohorts that comprise the total U.S. population. This population is classified into two flows determined by their insurance status, ambulatory insured and uninsured patients, serving the need to effectively track the different characteristics which these groups present.

The access to care shows differences between these populations, with insured patients more likely to receive usual care from primary care physicians (DeVoe et al. 2003). It is reported that long term uninsured adults face much greater unmet health needs, compared to their insured counterparts (Ayanian et al. 2000), making the issue of insurance coverage very relevant, in order to achieve substantial clinical improvements. Both populations in the model follow the same process during the intervention, which helps detect major health risks and assess treatment plan. The model also addresses the gap in cost treatments lying between the insurance statuses. Long and short term uninsured adults show a higher likelihood to defer treatment (Bogdan et al. 2004), due to excessive out of pocket expenses , which eventually contribute to a poorer health status. The lack of insurance constitutes a factor in the convergence of uninsured patients toward ED, which have grown to become the first resort for these patients, considering the legal obligation of hospital based emergency services to deliver care regardless of the ability to receive payment (Barish et al. 2012). It potentially leaves a high financial strain on hospitals with considerable unpaid bills (Gusmano et al. 2002). According to Schoen et al. (2008), close to half of uninsured and underinsured patients population report difficulty paying for treatment costs, which results in outstanding balance due. The unpaid costs are thus a function of the number of uninsured

patients in both PCMH and ED facilities, which is measured based on the total number of visits. The stock of money due helps determine the revenues generated for these care providers and ultimately assess the intervention efficiency and cost-effectiveness.

3.2. IMPLEMENTATION OF INTERVENTION STRATEGIES

Important components involved in the implementation of the intervention are represented in the model. The complex nature of the flow of patients from ED to PCMHs involves multiple considerations, related to capacity factors such as the number of healthcare personnel available, the perceived efficiency and quality, waiting time, the access to the facility, the acuity level, and the tendency to defer treatment. These factors constitute weighting venue selection that influence patients in their quest to quality care. A portion of the patient flow coming to either venue moves to admission, in which patients are temporarily hospitalized. A second part of the patient flow is treated through outpatient ED care. A marginal portion is assumed to die as they move through the ED. The rest of the patients are hospitalized or treated in a venue through outpatient care in which most patients move to a recovery stock. After the first visitation to the ED or PCMH, the flow of either type of patient may visit the same venue or switch facility for the next visit. Once the patient has visited a facility, the patient recovers, worsens, or dies. The flow of patients that goes through a venue is also constrained by the weight of venue selection and potential interventions that effectively constrain the flow of patients through the healthcare delivery process. The model integrates the effects of the intervention on mortality as it assumes that the death rate is reduced which increases longevity and the propensity of this population flow to seek ambulatory services as they age. The ED and PCMH utilization of the patients is a function of the aggregated capacity of the venue and the total outpatient, inpatient hospitalization, and recovery levels (Fisher et al. 2000; McConnell et al. 2005). Figure 1 presents a simplified version of the stock and flow diagram that models the flow of COPD/Asthma patients as they engage in both EDs and PCMHs.

3.3. INTERVENTION DRIVING FACTORS

The effects of the interventions lead to a decrease in ED visits. The diverting effect of the intervention influences the flow of the patients seeking medical ED services into steering toward PCMH. Continuity of care leads to a decrease in the need for emergency hospitalization, with a lower likelihood for health complications. It is assumed the health status of the patients improves resulting in an increase in expected lifespan. The emergency department utilization, the PCMH venue utilization are aggregated in an overall ambulatory utilization that measures the efficiency of the strategy. These mechanisms are tested given the variation of key variables involved in the model. These are constants expressing realistic situations, which help explore the behavioral patterns of the overall system. The ED and PCMH capacities are important factors, as they illustrate management targets helping to determine the condition of patients' flow and diversion possibilities. The capacities can be expressed in number of visits, workforce size, and amount of time per visit. The costs of treatments in these facilities are also critical as they shape the characteristics of the health services delivery system. The insurance status of patients and their inability to pay combined with treatments cost structure influence the nature of care to be provided (Gusmano et al.

2002). The variation of these measurements translates the quality of the intervention and provides insight into the course of the intervention mechanism

4. PATIENT DIVERSION INTERVENTION DEVELOPMENT

The use of System Dynamics modeling technique in our study fulfills the purpose of gaining valuable insight into the behavior of the system, that is, the trends generated from the complex interactions between the different variables illustrating patients flow, ED and PCMH capacities, medical workforce and costs. In the environment of medical intervention, this paradigm serves as a practical decision-support tool for public health management and policy makers. This simulation technique helps identify critical issues of the process and draws direct attention to them (Bendoly 2013), so as to provide resolution. Also, SD is appropriate to analyze and model systems over various time horizons, short- and long-term which can extend for days (Duggan 2012) or years (Ansah et al. 2013). The presence of multiple feedbacks (Sterman 2000b) in the model helps capture the behavior of the system over the course of the simulation, rendering the output more robust.

4.1. INTERVENTION FRAMEWORK

The operations management literature points out diverse mechanisms that spur the utilization of facilities by targeted populations. The idea behind an intervention as presented in this paper is to redirect ED chronic disease patients demand from pursuing emergency services to more sustainable continuity care schemes that reduces the chance of condition exacerbation, as well as improve opportunities for an increasing quality of care through engaging in PCMH care (Schoen et al. 2013). As indicated earlier, the basic structure of the model describes the diversion of patients suffering from Asthma, more specifically in the Hampton Roads region in the state of Virginia, from ED to PCMH while maintaining quality of care and continuity. Figure 2 displays an overview of the high-level conceptual model representing the relevant dynamics of this intervention.

Since the present study is concerned with emergency department and ambulatory care utilization for Asthma, it is essential to gauge the total visits to ED for all chronic conditions. Asthma visits are thus expressed in this model as a fraction of these overall ED visits. A visit to an ED may result in the hospitalization of the patient or the patient may be treated on an outpatient basis and discharged. The option of hospitalization is illustrated in the reinforcing loop *Asthma Intervention Diverting Effects*, which increases the likelihood for crowding and pressure for patients' diversion. More resources are needed therefore in an effort to improve the effectiveness of the intervention and reduce the number of ED visits. The balancing loop *Total Asthma Ambulatory Utilization Effects* describes the negative correlation between ED visits and PCMH resource utilization. That is, a drop in emergency visit favors a rise in nonemergency visits and alleviates ED resource use strains. The loop *Asthma Intervention Admission Effects* expresses the effect of the intervention, with an improvement of health outcomes for patients, which leads to an overuse of PCMH capacity and eventually an increase in ED visits. The loop *Asthma Intervention Financial Effects* measures the economic effects of the intervention. The diversion to PCMH facilities leads to improvement in health finances and savings generation. However, over time, the rise of

nonemergency visits causes the emergency visits to go back up and ultimately pose a financial threat.

4.2. MAIN ASSUMPTIONS

The evaluation of chronic disease management interventions is a complex problem that requires a framework capable of capturing and processing: (a) the complexities associated with representing the targeted population; and (b) the intricacies related to the implementation of a given set of interventions.

Our first assumption resides in the formulation of the problem. One perspective for solving it involves formulating the problem as a demand-supply model (Murray M 2003). One may conceive the demand as targeted populations seeking healthcare services (Ansari et al. 2006), while healthcare institutions provide these services in the form of interventions (Voss et al. 2011). The impact of this demand for services on these organizations may be measured by the total utilization of the healthcare institutions (National Center for Health Statistics 2010). The management of chronic illnesses has an impact on the utilization of ambulatory services, and therefore, on the available capacity to provide these services. In the present study the supply is assumed to be a constant value representing the capacity of the aggregate healthcare delivery venues to handle the number of patient visits per day. This assumption serves as the rationale to perform a comparative scenario analysis.

Our second assumption regards the measurement of the effect of the intervention on healthcare venue utilization. The reduction in ED visits is used as a measure of effectiveness in our study, for the Asthma management intervention, similarly to the study of Bourbeau et al. (2003). As a means of including the intervention impact into the SD model, a 1 to 5 Likert scale has been adopted. The projected percentage of reduction in the ED visits due to a given intervention is converted into a discrete equivalent on a 1 to 5 scale and included within the model. The scale offers flexibility in terms of accommodating some qualitative information, in case the precise value of reduction in ED visits is not known or is undeterminable. In the base case a value of zero is assigned to this effectiveness factor, which represents the absence of any intervention effort.

The last assumption concerns the data given in Table 2 to be inputted into the model. Those are the constants, as well as, the functions applied. The descriptions, values, and sources are provided. A key aspect in the implementation of the model is the determination of the various fractions that divide the ED into the groups that are of interest. Although the above analysis is presented at a regional level (U.S. Hampton Roads), few data used in the model are on the state level. In addition, aggregated data from the southern part of the U.S. (Florida, West Virginia, Virginia, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Alabama, Louisiana, Mississippi, and Arkansas) are used, enabling the derivation of the required fractions. Note that these extrapolations are reasonably relevant and do not impair the accuracy of our results as this very aggregation implies similar trends all across the regions considered, including the studied region.

The governing equations for Ambulatory Healthcare Capacity Model for Chronic Disease Management used as part of calculations in the proposed model are described below and given as equations labeled (1) through (9).

The number of patients is represented by the stock *Asthma/COPD*, *ACC*. This population depends on *asthma/COPD* rate, β ; *rate to visit ED*, α ; and *diverting to alternative PCMH through intervention* rate, δ . Rate of change in *Asthma/COPD* is given by:

$$dACC/dt = \beta - \alpha - \delta \quad (1)$$

β is the proportion of the population who presents with asthma/COPD. It depends on the total number of patients flowing through the ED, with chronic conditions, *PERCC*.

α is obtained by relationships between *Asthma/COPD*, *ACC*, and *percent effect*, *PE*, and influenced by congestion level, *K*. *PE* expresses the percentage of the effects the application of the interventions has on the population health. These effects are the function of the *effectiveness of the intervention*.

$$\alpha = (1 - PE) \times ACC(t) \quad (2)$$

δ , the diverting patient rate, represents the number of patients diverting from visits in the emergency departments.

$$\delta = PE \times ACC(t) \quad (3)$$

The stock *Visit to ED for Asthma*, *VERA*, is the number of visits in the ED from the population. This population depends on the *rate to visit ED*, α ; *rate of patient admission*, μ ; and *rate of discharge of the patients from the ER*, π . Rate of change in *Visit to ED for asthma* is given by:

$$dVERA/dt = \alpha - \mu - \pi \quad (4)$$

μ expresses the percentage of patients presenting Asthma/COPD admitted. It depends on the *actual percentage of admission*, *APOA*, and the *total number of ED visits* by the patients, *VERA*.

$$\mu = APOA \times VERA(t) \quad (5)$$

π , is the rate of discharge of the patients from the ED. Similarly to μ , this rate depends on *APOA* and *VERA*.

$$\pi = (1 - APOA) \times VERA(t) \quad (6)$$

Changes in *Inpatient hospitalization*, *IH*, and *PCMH Outpatient care*, are given by:

$$dIH/dt = \mu - \eta \quad (7)$$

$$dOC/dt = \pi - \lambda \quad (8)$$

η is the rate of inpatient return to continuity care. This represents the proportion of the patients under PCMH that experience gains from continuity care, and were admitted, $IH(t)$. λ is the rate of outpatient return that depends on PCMH *Outpatient Care* over time, $OC(t)$.

The stock PCMH *Alternative care due to interventions*, $ACDI$, depends on the *diverting rate to alternative venue through intervention*, δ , and the population rate benefited from continuity care through PCMH *outpatient care*, θ . Rate of change in *Alternative care due to interventions* is given by:

$$dACDI/dt = \delta - \theta \quad (9)$$

4.3. VALIDATION

The System Dynamics model is solved via the Vensim[®] simulation software package. The approach of validation is performed to test the closeness of our model to reality. It begins with testing the general structure of the model relative to known behavior. If the structure of the model is perceived to be adequate, then this is followed by testing the behavior accuracy (Barlas 1996).

The dynamic nature of hospital activities imposes that the simulation model reflect complexity, uncertainty, variability and limited resources (Harper 2002). In that regard, Homer and Hirsch (2006) label the system modeling methodology of the SD paradigm as well suited to address and mirror these characteristics. The SD model developed in this paper describes the complex interrelationships between capacity, costs and patients. This method presents the uses of time delay functions, feedback loops, or exponential growth (Größler et al. 2008), along with other nonlinear effects (Davis et al. 2007), expressing the uncertainty of the outcomes stemming from these relations. The mix of these features affects the behavior of variables (Sterman 2000a), which inject some variability in the entire system.

Having established the adequacy and structure of the paradigm, we, under suggestions from Sterman (2000a), perform several structure tests including parameter verification test, direct extreme conditions test, and dimensional consistency test.

Simulation models are simplified synthetic representations of the real world setting in which critical system components' parameters are explicitly represented while capable of mimicking a system's behavior over time (Diaz and Behr 2010). The selection of these parameters for this paper is based on three critical sources of information that include: 1) the existing literature on the subject, 2) subject matter expert information from our teaching hospital partner in a particular region, and 3) the empirical evidence collected from surveys

performed by the authors. The parameter selection has therefore solid ground on which to stand and provides more reliability to the model.

This work has been presented and discussed with our teaching hospital partner in the Hampton Roads region in the state of Virginia describing the diversion of patients suffering from Asthma, from ED to PCMH while maintaining quality of care and continuity. Computational results reported in Tables 2, 3, 4 and 5 pertaining to ED visits, additional visits to PCMHs, utilization levels of EDs and PCMHs and unpaid costs by uninsured patients, closely matched with historical patient discharge and cost management data maintained by the teaching hospital partner in this study. It also helped in ascertaining the effect of chronic disease management on capacity utilization of the relevant ambulatory venues to ensure that the diverted patients are able to find a source of regular care. Various scenarios analyzed facilitated quantifying the behavior of capacity of the ambulatory healthcare system when subject to disease management interventions as well as in understanding the effects of these interventions on such capacities. These efforts produced capacity needs estimates intended to be informative for the healthcare system in the Hampton Roads region, as well as design capacity characterization whose demand component impact is discussed in this paper.

Direct extreme condition testing evaluates the model governing equations under extreme conditions and assesses the likelihood of the resulting values against anticipation of what would happen under similar conditions in real life. For instance, we check that if there is no rate of exposure of the population, then, there are no visits to both/either ED or PCMH facilities, and no rate of recovery. If there is no ED capacity (no visits in ED), then, no patients are assigned there. The PCMH capacity reaches its fullest and equals the sum of resource utilization of PCMH and ED in normal conditions. The reverse scenario takes place if there is no PCMH capacity.

Last, we test the dimensional consistency. Specifically, we check all the variables of the model as well as their equations in order to test their dimensions and units of measurement. The test reveals positive results, showing the variables are set/linked up appropriately to one another and their measurements accurate.

5. COMPUTATIONAL RESULTS

The scenarios analyzed in this paper are developed based on the ED population demand, different levels of interventions' effectiveness, and appropriate ED's congestion levels. The term "Effectiveness of intervention" is representative of the ability of the particular intervention technique to reduce emergency department visits. Accordingly, three theoretical scenarios wherein the term "Effectiveness of intervention" takes the low (1), intermediate (2), and the high-impact (3) value with the base case (no-intervention) having zero impact. The model is simulated for the time frame with an arbitrary time value of 10 years. For demonstration purposes, we use as capacity, the combined number of visits both in ED and PCMH. At the national level, the number of visits to physician offices for patients with Asthma equals 14.2 million (Centers for Disease Control and Prevention 2010b), and the number of visits to hospital outpatient departments, 1.3 million (Centers for Disease Control

and Prevention 2010a). This gives a total of 15.5 million for PCMH facilities. The number of visits to ED for patients with Asthma as primary diagnosis is 1.8 million (Centers for Disease Control and Prevention 2010a). Considering the prevalence percentage of 8.51% (Kiger 2010) in the HR, the threshold capacity in PCMH and ED are 1,319,438 and 153,225 visits, respectively. These referential values are used to determine how utilization changes as the intensity of diverting interventions increase.

The number of Asthma patients, both insured and uninsured that visit the ED is presented in Table 3. The number of ED visits by insured patients in the absence of intervention that diverts these patients to PCMH increases as population grows at a steady pace. When a low impact intervention is applied, the number of visits decreases to an average of 7,409 visits in ten years which corresponds to a projected reduction of 11.28%. Likewise, for the mid and high impact interventions, the projected visits decrease to 7,372 and 7,319 on average, which reduces the base case scenario values to approximately 11.73% and 12.35%. The same table shows that at the no intervention level, the average visits for the uninsured is 2,691 while experiencing visit reductions approximately of 13.5%, 13.9%, and 14.6% when exposed to low, mid, and high impact diverting interventions.

As the number of ED visits decreases, the number of PCMH visits increases as shown in Table 4. Both visit types are influenced by the number of individuals whose longevity has been extended. For the insured population, the additional number of patients that will be diverted to PCMH venues increases from 633 visits (average) when patients are exposed to a low-impact diverting strategy to 940 for mid-impact and 1,247 additional visits for high-impact. Correspondingly, in the low- to mid- to high-impact intervention scenarios, the number of extra visits that are expected to PCMHs increases from 198 to 294 to 390 visits, for the uninsured population. In both cases, there appears to be an increase of about 32% and 24% from low- to mid- impact and from mid- to high-impact, revealing a similar impact of the intervention on the patients, from the insurance status standpoint. As patients engage in continuity of care, the propensity to live longer increases, and therefore, produces an increase in the volume of visits of insured and uninsured patients that seek ambulatory healthcare services as they age.

To understand the impact of diverting chronically ill patients on EDs, it is necessary to analyze the effects on utilization of both EDs and PCMHs. Assuming that current capacity of the ED system is invariant while an important number of patient shifts from EDs to PCMHs over time, reductions in ED utilization are experienced. The average utilization of the no intervention scenario is calculated at about 74%. For the mid-impact intervention, the average ratio decreases to 63% while at the high-impact intervention intensity, 55.7% is obtained. One can also determine how the potential utilization of PCMHs is affected by additional Asthma patients diverted to these venues. At a low-impact intervention level, the utilization is approximately 39%, while 80% for the high-impact as additional patients engage in continuity of care activities. Table 5 provides utilization rates of EDs and PCMHs affected by various intervention policies.

The relevance of the insurance coverage of patients can be seen by the impact on the intervention economics. Any increase in visits favors unpaid treatment costs, given the

increase of the uninsured population. The raise in dues jumps from 13% to 19% in low and mid impact and reaches about 26% in the case of high-impact (Table 6). In addition, these increases can be explained by the double standard in pricing established by medical providers, with many uninsured often charged about 2.5 times what most insurance providers actually pay and more than 3 times the hospital's Medicare allowable costs (Anderson 2007). Depending on the variation of ED and PCMH service prices, measures can be taken to control or ameliorate the coverage system and make practical predictions over the intervention benefits and cost-effectiveness.

Given the logic behind the causal diagram built for our proposed model, the possible limiting system elements are identified: patients' visits (which condition the proportions for choosing either ED or PCMH), hospital capacity (which limits the resource utilization) and patients' health coverage status (which conditions treatment costs). Regarding these key system elements, that is, those variables to which the effects of the intervention implementation are analyzed, propositions are enunciated. Given the results of the scenarios:

P1: A diversion intervention policy is recommended in a relatively near or medium term, in order to prevent and control ED overcrowding.

P2: A diversion intervention policy is recommended in a relatively near or medium term, in order to control costs and increase revenues accordingly.

P3: A diversion intervention policy is as efficient for insured patients as for uninsured ones. This initiative shows relatively similar effects for both patients' insurance coverage statuses and more consistent effects on financial benefits generation.

The model is able to produce behavior which resonates with the observations in the literature, and thus, forms a valid basis for scenario analysis and for applications to case studies. The results of the intervention indicate that increasing access to PCMHs may constrain providers' capacity (Steinbrook 2008; Long and Masi 2009). With increasing longevity of chronically ill patients, this population increases and as a result the utilization of healthcare increases, in general, in spite of improvements in health outcomes for this class of patients. This is in alignment with the findings of Carret et al. (2009), who associate the growing number of visits in ED with age and income. Thus, even though, and as expected, the aging population tend to, over time, repeatedly use ED resources, its ability to pay through either high income or insurance coverage limit the financial strains of these institutions and offset eventual unpaid dues from uninsured. In addition, the similarity in intervention effects between insured and uninsured patients conform with the study of Weber et al. (2008), who note lesser impacts from the uninsured population, regarding recourse to ED as it has remained constant over the years.

6. Discussion

Until recently, policymakers have tried to control rising health care costs primarily through cost containment measures (Fierro 2006). Policymakers at all levels of government are facing tough choices among funding priorities in light of these trends. The chronic diseases causing these costs increases can be better managed. Moving from an acute care model to one that emphasizes total care management will require a fundamental shift in the way the

U.S. healthcare delivery system operates, especially as it relates to how providers are paid and their approach to patients. This new approach will lead to providing for a continuity of care resulting in fewer hospital admissions and less revenue (Weinstein et al. 2001).

Populations at risk for one chronic disease are often at risk for multiple chronic diseases. Coordinated strategies, such as those involving supportive public policy, social and physical environments, system changes, media, and technology, are required to address nearly all chronic disease risk factors and conditions (Collins et al. 2009). Adopting healthy behaviors is much easier if we establish supportive community norms and adopt a philosophy that embraces health in all policies and settings. We must promote proven social, environmental, policy, and systems approaches that support healthy living for individuals, families, and communities (Centers for Disease Control 2009). If prevention and treatment interventions are implemented, employers and /or Medicaid will bear much of the costs of the interventions. Employers and/or Medicaid also will reap much of the savings that occur prior to Medicare eligibility. After Medicare becomes the primary insurer, employers and/or Medicaid will typically become the secondary payer. While employers and/or Medicaid will see some of the savings from these interventions, Medicare will see the majority of the savings (O'Grady and Capretta 2009). If prevention and treatment interventions are not implemented, employers and/or Medicaid who do not pay for the costs of the interventions, incur most of the costs of complications prior to Medicare eligibility and receive only a smaller percentage after Medicare eligibility. The model proposed in this paper shows that in the long term, investment in patients' diversion intervention can accrue positive savings from national healthcare expenditures.

Prevention is one of the best ways to help Americans live longer, healthier lives and increase our nation's productivity (Partnership to Fight Chronic Disease 2015). Our model is an important instrument that can be used to accomplish these goals and plan for the future. The model provides valuable insights into the effects of successful chronic disease interventions on the overall health care system. Successful interventions will decrease the number of patients with chronic diseases from presenting at the emergency department. However, the model also shows that this will increase, especially in the long term, the utilization of nonemergency healthcare venues. Thus, the model provides policy makers a tool to more reliably plan for the future.

7. CONCLUSION AND FUTURE RESEARCH

Treatment of chronic disease forms a major portion of the U.S. healthcare spending and affects a large portion of the U.S. population. This calls for approaches to better deal with such conditions to reduce patient suffering and mortality. At the same time the need to curb healthcare spending calls for addressing these issues in a manner that helps reduce healthcare costs. Chronic disease management has emerged as a successful approach in dealing with chronic conditions. However, the cost saving potential of such efforts is still a point of contention and depends on numerous characteristics of the particular intervention. What remains to be investigated is the result of such efforts on the capacity utilization of the relevant venues.

In this study we have developed a simulation framework to study major interactions. Different reinforcing and balancing loops were identified and examined. The present paper proposes a SD model that helps capture the important dynamics and feedbacks in the system under consideration. The emphasis is on determining the effect of chronically ill patient diversion from EDs to alternative venues of regular care. Such analysis is essential for ensuring that the diverted patients are able to be accommodated within the alternative options without any significant disadvantage to both care givers and receivers. This enables advance planning for creation and acquisition of human and material resources necessary for creating enough capacity that matches the demand with the supply.

The scenario analysis performed on the proposed model demonstrates a behavior which draws resemblance with the observations in the relevant literature. The scenario analysis thus helps confirm that the proposed model confers with the findings of the scientific literature, and therefore, forms a valid basis for future development and analysis. Based on the results obtained, some recommendations are proposed to perform, in an accurate manner, the patients' diversion. It is important to point out that these recommendations are obtained by using an exemplified model and numerical hypothesis. The present model can thus be significantly expanded by a more explicit representation of the intervention structures. This may be done by inclusion of additional variables that represent the factors that determine the magnitude of impact that a particular intervention would have on a particular cohort. Such factors would include relevant characteristics of the patient in addition to their insurance status, the intervention, and the healthcare providers. The aspect of capacity can be extended to human and material resources dynamics, which would address some aspects ignored here with a static capacity factor.

Abbreviations

ACCESS	Acute Care Emergency Surgery Service
ACDI	Alternative Care Due to Interventions
ACSCC	Ambulatory Care-Sensitive Chronic Conditions
APOA	Actual Percentage Of Admission
BUD/FM	Budesonide/Formoterol
CAP	community-acquired pneumonia
CHCC	Cooperative Health Care Clinic
COPD	Chronic Obstructive Pulmonary Disease
ED	Emergency Department
EDO	Emergency Department Occupancy
EM	Emergency Medicine
FP/SM	Fluticasone Propionate/Salmeterol
IH	Inpatient Hospitalization

M&S	Modeling and Simulation
NEDOCS	National Emergency Department Overcrowding Scale
OC	Outpatient Care over time
OR	Occupancy Rate
PCMH	Patient Centered Medical Home
PCP	Primary Care Physician
PE	Percent Effect
PERCC	Patients Flowing Through the ED, with Chronic Condition
PSI	Pneumonia Severity Index
SCD	Sickle-Cell Disease
SD	System Dynamics
TFAD	Time-To-First-Antibiotic-Dose
TLP	Triage Liaison Physician
VERA	Visit to ED for Asthma

References

- Akerman MJ, Sinert R. A successful effort to improve asthma care outcome in an inner-city emergency department. *Journal of Asthma*. 1999; 36(3):295–303. [PubMed: 10350227]
- American Hospital Association. *Trendwatch Chartbook 2013 - Trends Affecting Hospitals and Health Systems*. Washington, DC: 2013. Retrived July 5, 2014 from <http://www.aha.org/research/reports/tw/chartbook/ch1.shtml>
- Anderson G, Horvath J. The growing burden of chronic disease in america. *Public Health Reports*. 2004; 119:263–270. [PubMed: 15158105]
- Anderson GF. From ‘Soak The Rich’ to ‘Soak The Poor’: Recent trends in hospital pricing. *Health Affairs*. 2007; 26(3):780–789. [PubMed: 17485757]
- Ansah JP, Matchar DB, Love SR, Malhotra R, Do YK, Chan A, Eberlein R. Simulating the impact of long-term care policy on family eldercare hours. *Health Services Research*. 2013; 48(2 pt 2):773–791. [PubMed: 23347079]
- Ansari Z, Laditka JN, Laditka SB. Access to health care and hospitalization for ambulatory care sensitive conditions. *Medical Care Research and Review*. 2006; 63(6):719–741. [PubMed: 17099123]
- Ayanian JZ, Weissman JS, Schneider EC, Ginsburg JA, Zaslavsky AM. Unmet health needs of uninsured adults in the United States. *JAMA*. 2000; 284(16):2061–2069. [PubMed: 11042754]
- Barbera L, Taylor C, Dudgeon D. Why do patients with cancer visit the emergency department near the end of life? *Canadian Journal of Emergency Medicine*. 2010; 182(6):563–568.
- Barish RA, Mcgauly PL, Arnold TC. Emergency Room crowding: A marker of hospital health. *Transactions of American Clinical and Climatological Association*. 2012; 123(1):304–311.
- Barlas Y. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*. 1996; 12(3):183–210.
- Bendoly E. System Dynamics understanding in projects: Information sharing, psychological safety, and performance effects. *Production and operations management*. 2013; 0(0):1–18.

- Beniuk K, Boyle AA, Clarkson PJ. Emergency department crowding: Prioritising quantified crowding measures using a Delphi study. *Emergency Medicine Journal*. 2012; 29(11):868–871. [PubMed: 22199142]
- Bird SR, Kurowski W, Dickman GK, Kronborg I. Integrated care facilitation for older patients with complex health care needs reduces hospital demand. *Australian Health Review*. 2007; 31(3):451–461. [PubMed: 17669069]
- Blais L, Forget A, Ramachandran S. Relative effectiveness of budesonide/formoterol and fluticasone propionate/salmeterol in a 1-year, population-based, matched cohort study of patients with chronic obstructive pulmonary disease (COPD): Effect on COPD-related exacerbations, emergency department visits and hospitalizations, medication utilization, and treatment adherence. *Clinical Therapeutics*. 2010; 32(7):1320–1328. [PubMed: 20678680]
- Bogdan GM, Green JL, Swanson D, Gabow P, Dart RC. Evaluating patient compliance with nurse advice line recommendations and the impact on healthcare costs. *American Journal Management Care*. 2004; 10(8):534–542.
- Bourbeau J, Julien M, Maltias F, Rouleau M, Beaupre A, Begin R, Renzi P, Nault D, Borycki E, Schwartzman K, Singh R, Collet JP. Reduction of Hospital Utilization in Patients With Chronic Obstructive Pulmonary Disease. *Archives of Internal Medicine*. 2003; 163:585–591. [PubMed: 12622605]
- Bureau of Labor Statistics. Occupational Outlook Handbook, Respiratory Therapists. 2014–15. 2014. Retrieved August 08, 2014 from <http://www.bls.gov/ooh/healthcare/respiratory-therapists.htm>
- Cao X, Schoner J. The influence of light rail transit on transit use: An exploration of station area residents along the Hiawatha line in Minneapolis. *Transportation Research Part A: Policy and Practice*. 2014; 59(0):134–143.
- Carret MLV, Fassa AG, Domingues MR. Inappropriate use of emergency services: A systematic review of prevalence and associated factors. *Cadernos de Saúde Pública*. 2009; 25(1):7–28. [PubMed: 19180283]
- Centers for Disease Control and Prevention. National hospital ambulatory medical care survey: 2010 Emergency Department summary tables. *Ambulatory and Hospital Care Statistics*; 2010a.
- Centers for Disease Control and Prevention. National ambulatory medical care survey: 2010 summary tables. *Ambulatory and Hospital Care Statistics*; 2010b.
- Centers for Disease Control and Prevention. The Power of Prevention: Chronic Disease ... the public health challenge of the 21st century. Atlanta, GA: National Center for Chronic Disease Prevention and Health Promotion; 2009.
- Chan C-L, Huang H-T, You H-J. Intelligence modeling for coping strategies to reduce emergency department overcrowding in hospitals. *Journal of Intelligent Manufacturing*. 2012; 23(6):2307–2318.
- Chen H-Y, Baumgardner DJ, Rice JP. Health-Related Quality of Life Among Adults With Multiple Chronic Conditions in the United States. *Preventing Chronic Disease*. 2011; 8(1):1–9.
- Coleman EA, Magid DJ, Beck A, Eilertsen TB, Conner D, Kramer AM. Reducing emergency visits in older adults with chronic illness: A randomized, controlled trial of group visits. *Effective Clinical Practice*. 2001; 4(2):49–57. [PubMed: 11329985]
- Collins JL, Marks JS, Koplan JP. Chronic disease prevention and control: coming of age at the Centers for Disease Control and Prevention. *Preventing Chronic Disease*. 2009; 6(3):A81. [PubMed: 19527583]
- Colwill JM, Cultice JM, Kruse RL. Will generalist physician supply meet demands of an increasing and aging population? *Health Affairs*. 2008; 27(3):w232–w241. [PubMed: 18445642]
- Congressional Budget Office. An Analysis of the Literature on Disease Management Programs. 2004
- Cree M, Bell NR, Johnson D, Carriere KC. Increased Continuity of Care Associated with Decreased Hospital Care and Emergency Department Visits for Patients with Asthma. *Disease Management*. 2006; 9(1):63–71. [PubMed: 16466343]
- Crooks VA, Agarwal G, Harrison A. Chronically ill Canadians' experiences of being unattached to a family doctor: A qualitative study of marginalized patients in British Columbia. *BMC Family Practice*. 2012; 13(1):69. [PubMed: 22799280]

- Dalal AA, Shah M, D'Souza AO, Rane P. Costs of COPD exacerbations in the emergency department and inpatient setting. *Respiratory Medicine*. 2011; 105(3):454–460.
- Davis JP, Eisenhardt KM, Bingham CB. Developing theory through simulation methods. *Academy of Management Review*. 2007; 32(2):480–499.
- De Bruin AM, van Rossum AC, Visser MC, Koole GM. Modeling the emergency cardiac in-patient flow: an application of queuing theory. *Health Care Management Science*. 2007; 10(2):125–137. [PubMed: 17608054]
- DeVoe JE, Fryer GE, Phillips R, Green L. Receipt of preventive care among adults: Insurance status and usual source of care. *American Journal of Public Health*. 2003; 93(5):786–791. [PubMed: 12721145]
- Diaz, R.; Behr, J. Discrete-event simulation. *Modeling and Simulation Fundamentals: Theoretical Underpinnings and Practical Domains*. Sokolowski, JA.; Banks, CM., editors. New Jersey: Wiley; 2010. p. 57-98.
- Diaz R, Behr JG, Tulpule M. A System Dynamics model for simulating ambulatory health care demands. *Simulation in Healthcare*. 2012; 7(4):243–250. [PubMed: 22722706]
- Dickens C, Katon W, Blakemore A, Khara A, McGowan L, Tomensou B, Jackson J, Walker L, Guthrie E. Does depression predict the use of urgent and unscheduled care by people with long term conditions? A systematic review with meta-analysis. *Journal of Psychosomatic Research*. 2012; 73(5):334–342. [PubMed: 23062805]
- Druss BG, Marcus SC, Offson M, Tanielian T, Ellinson L, Pincus HA. Comparing the national economic burden of five chronic conditions. *Health Affairs*. 2001; 20(6):233–241. [PubMed: 11816664]
- Duggan, J. An extended SIR model to explore the impact of syndromic data sources on social distancing policy; Gallen, Switzerland. 30th International Conference of the System Dynamics Society; 2012.
- Fierro, M. Costs of chronic diseases: What are states facing. *Trends Alerts*. 2006. Retrieved July 10, 2014 from <http://hit.state.tn.us/Reports/ChronicTrendsAlert120063050306.pdf>
- Fisher ES, Weinberg JE, Stukel TA, Skinner JS, Sharp SM, Freeman JL, Gittelsohn AM. Associations among hospital capacity, utilization, and mortality of US Medicare beneficiaries, controlling for sociodemographic factors. *Health services research*. 2000; 34(6):1351–1362. [PubMed: 10654835]
- Flores-Mateo G, Violan-Fors C, Carrillo-Santistevé P, Peiro S, Argimon J-M. Effectiveness of organizational interventions to reduce emergency department utilization: a systematic review. *PLoS ONE*. 2012; 7(5):e35903. [PubMed: 22567118]
- Garcia-Lizana F, Sarria-Santamera A. New technologies for chronic disease management and control: a systematic review. *Journal of Telemedicine and Telecare*. 2007; 13:62–68. [PubMed: 17359568]
- Ghaffarzadegan N, Lyneis J, Richardson GP. How small system dynamics models can help the public policy process. *System Dynamic Review*. 2011; 27(1):22–44.
- Ginde AA, Sullivan AF, Camargo CA. National study of the emergency physician workforce, 2008. *Annals of Emergency Medicine*. 2009; 54(3):349–359. [PubMed: 19398242]
- Größler A, Thun J-H, Milling PM. System Dynamics as a structural theory in operations management. *Production and Operations Management*. 2008; 17(3):373–384.
- Gusmano MK, Fairbrother G, Park H. Exploring the limits of the safety net: Community health centers and care for the uninsured. *Health Affairs*. 2002; 21(6):188–194. [PubMed: 12442854]
- Harper PR. A framework for operational modelling of hospital resources. *Health Care Management Science*. 2002; 5(3):165–173. [PubMed: 12363044]
- Higginson I. Emergency department crowding. *Emergency Medicine Journal*. 2012; 29(6):437–443.
- Hing, E.; Bhuiya, F. Wait Time for Treatment in Hospital Emergency Departments: 2009. NCHS Data Brief. 2012 Aug. Retrieved September 15, 2014 from <http://www.cdc.gov/nchs/data/databriefs/db102.pdf>
- Hirsch, G.; Homer, J.; Milstein, B.; Scherrer, L.; Ingersoll, C.; Landy, L.; Serman, J.; Fisher, E. ReThink Health Dynamics: Understanding and Influencing Local Health System Change; St. Gallen, Switzerland. 30th International Conference of the System Dynamics Society; 2012.

- Hockemeyer J, Smyth J. Evaluating the feasibility and efficacy of a self-administered manual-based stress management intervention for individuals with asthma: Results from a controlled study. *Behavioral Medicine*. 2002; 27(4):161–172. [PubMed: 12165970]
- Hoffman C, Rice D, Sung HY. Persons with chronic conditions: Their prevalence and costs. *Journal of American Medical Association*. 1996; 276(18):1473–1479.
- Holman H. Chronic Disease—The Need for a New Clinical Education. *JAMA*. 2004; 292(9):1057–1059. [PubMed: 15339897]
- Homer JB, Hirsch GB. System Dynamics modeling for public health: Background and opportunities. *American Journal of Public Health*. 2006; 96(3):452–458. [PubMed: 16449591]
- Hwang U, McCarthy ML, Aronsky D, Asplin B, Crane PW, Craven CK, Epstein SK, Fee C, Handel DA, Pines JM, Rathlev NK, Schafermeyer RW, Zwerner FL, Bernstein SL. Measures of crowding in the emergency department: A systematic review. *Academic Emergency Medicine*. 2011; 18(5): 527–538. [PubMed: 21569171]
- Iezzoni LI. Multiple Chronic Conditions and Disabilities: Implications for Health Services Research and Data Demands. *Health Services Research*. 2010; 45(5 p 2):1523–1540. [PubMed: 21054370]
- Jia H, Lubetkin EI. Trends in Quality-Adjusted Life-Years Lost Contributed by Smoking and Obesity. *American Journal of Preventive Medicine*. 2010; 38(2):138–144. [PubMed: 20117569]
- Jo S, Kim K, Lee JH, Rhee JE, Kim YJ, Suh GJ, Jin YH. Emergency department crowding is associated with 28-day mortality in community-acquired pneumonia patients. *Journal of Infection*. 2012; 64(3):268–275. [PubMed: 22227383]
- Johnson KD, Winkelman C. The effect of emergency department crowding on patient outcomes: A literature review. *Advanced Emergency Nursing Journal*. 2011; 33(1):39–54. [PubMed: 21317697]
- Kiger, PG. A statewide strategic plan and call to action for asthma in Virginia, Virginia Asthma Coalition. 2010. Retrieved October 5, 2014 from <http://www.virginiaasthmacoalition.org/>
- Kucukyazici B, Verter V, Mayo NE. An analytical framework for designing community-based care for Chronic Diseases. *Production and Operations Management*. 2011; 20(3):474–488.
- Long SK, Masi PB. Access and affordability: an update on health reform in Massachusetts, fall 2008. *Health Affairs*. 2009; 28(4):w578–w587. [PubMed: 19477874]
- Mahler SA, McCartney JR, Swoboda TK, Yorek L, Arnold TC. The Impact of emergency department overcrowding on resident education. *The Journal of Emergency Medicine*. 2012; 42(1):69–73. [PubMed: 21536400]
- Martin JA, Hamilton BE, Osterman MJK, Curtin SC, Mathews TJ. Births: Final data for 2012, Centers for Disease Control and Prevention. 2013; 62:1–87.
- McConnell KJ, Richards CF, Daya M, Bernell SL, Weathers CC, Lowe RA. Effect of increased ICU capacity on Emergency Department length of stay and ambulance diversion. *Annals of Emergency Medicine*. 2005; 45(5):471–478. [PubMed: 15855939]
- McCusker J, Roberge D, Levesque JF, Ciampi A, Vadeboncoeur A, Larouche D, Sanche S. Emergency department visits and primary care among adults with chronic conditions. *Medical Care*. 2010; 48(11):972–980. [PubMed: 20856143]
- McNaughton CD, Self WH, Slovis C. Diabetes in the emergency Department: Acute care of Diabetes patients. *Clinical Diabetes*. 2011; 29(2):51–59.
- Menec VH, Sirski M, Attawar D, Katz A. Does continuity of care with a family physician reduce hospitalizations among older adults? *Journal of Health Services Research & Policy*. 2006; 11(4): 196–201. [PubMed: 17018192]
- Missouri Information for Community Assessment (MICA). Missouri Department of Health and Senior Services. 2011. Retrieved on October 10, 2014 from <http://health.mo.gov/data/mica/MICA/>
- Michelson KA, Monuteaux MC, Stack AM, Bachur RG. Pediatric emergency department crowding is associated with a lower likelihood of hospital admission. *Academic Emergency Medicine*. 2012; 19(7):816–820. [PubMed: 22724551]
- Migita R, Beccaro MD, Cotter D, Woodward GA. Emergency department overcrowding: Developing emergency department capacity through process improvement. *Clinical Pediatric Emergency Medicine*. 2011; 12(2):141–150.
- Milstein B, Homer J, Hirsch G. Analyzing national health reform strategies with a dynamic simulation Model. *American Journal of Public Health*. 2010; 100(5):811–819. [PubMed: 20299653]

- Mitchell EA. Preventing readmissions to hospital for Asthma. *Thorax*. 1997; 52(3):207–208. [PubMed: 9093332]
- Moorman JE, Akinbami LJ, Bailey CM, Zahran HS, King ME, Johnson CA, Liu X. National Surveillance of Asthma: United States, 2001–2010, *Vital Health Statistics*. 2012
- Prystajecy M, Lang E, Wang D, Lonergan K, Simon J, Sinnarajah A, Lynn T, Martin W, Murray A, Hagen N, Waller A, Bultz B, Carlson L, Groff S, McRae A, Thomas B. Emergency department utilization by adult cancer patients: A prospective cohort study. *Canadian Journal of Emergency Medicine*. 2012; 14(S1) Online.
- Murray MBDM. Advanced access: Reducing waiting and delays in primary care. *JAMA: The Journal of the American Medical Association*. 2003; 289(8):1035–1040. [PubMed: 12597760]
- National Center for Health Statistics. *Health, United States*. Atlanta. GA: 2010.
- O'Grady, M.; Capretta, JC. Health-care cost projections for diabetes and other chronic diseases: The current context and potential enhancements, Partnership to Fight Chronic Disease. 2009. Retrieved November 15, 2014 from <http://www.fightchronicdisease.org/sites/fightchronicdisease.org/files/docs/PFCD%20Overview.pdf>
- Peppe, EM.; Mays, JW.; Chang, HC.; Becker, E.; DiJulio, B. Characteristics of Frequent Emergency Department Users. Menlo Park, CA: The Henry J. Kaiser Family Foundation; 2007.
- Partnership to Fight Chronic Disease. The value of prevention. Partnership for prevention. 2015. Retrieved December 10, 2014 from <http://www.fightchronicdisease.org/sites/fightchronicdisease.org/files/docs/PFCD%20Overview.pdf>
- Pines JM, Isserman JA, Kelly JJ. Perceptions of emergency department crowding in the Commonwealth of Pennsylvania. *Western Journal of Emergency Medicine*. 2013; 14(1):1–10. [PubMed: 23451289]
- Qureshi A, Smith A, Wright F, Brennenman F, Rizoli S, Hsieh T, Tien HC. The Impact of an acute care emergency surgical service on timely surgical decision-making and emergency department overcrowding. *Journal of the American College of Surgeons*. 2011; 213(2):284–293. [PubMed: 21601487]
- Reid RJ, Coleman K, Johnson EA, Fishman PA, Hsu C, Soman MP, Trescott CE, Erikson M, Larson EB. The group health medical home at year two: cost savings, higher patient satisfaction, and less burnout for providers. *Health Affairs*. 2010; 29(5):835–843. [PubMed: 20439869]
- Roccaforte R, Demers C, Baldassarre F, Teo KK, Yusuf S. Effectiveness of comprehensive disease management programmes in improving clinical outcomes in heart failure patients. A meta-analysis. *The European Journal of Heart Failure*. 2005; 7:1133–1144. [PubMed: 16198629]
- Romero, CC. Virginia Health Statistics. Virginia Department of Health; 2014. Retrieved September 12, 2014 from <http://www.vdh.state.va.us/HealthStats/stats.htm>
- Rowe BH, Guo X, Villa-Roel C, Schull M, Holroyd B, Bullard M, Vandermeer B, Ospina M, Innes G. The role of triage liaison physicians on mitigating overcrowding in emergency departments: A systematic review. *Academic Emergency Medicine*. 2011; 18(2):111–120. [PubMed: 21314769]
- Schoen C, Collins SR, Kriss JL, Doty MM. How many are underinsured? Trends among U.S. adults, 2003 and 2007. *Health Affairs*. 2008; 27(4):w298–w309. [PubMed: 18544591]
- Schoen, C.; Guterman, S.; Zezza, M.; Abrams, M. Confronting Costs. Stabilizing US health spending while moving toward a high performance health care system, NY: The Commonwealth Fund Commission on a High Performance Health System. 2013.
- Schoen C, Osborn R, Doty MM, Bishop M, Peugh J, Murukutla N. Toward Higher-Performance Health Systems: Adults' Health Care Experiences In Seven Countries, 2007. *Health Affairs*. 2007; 26(6):717–734.
- Scott JC, Conner DA, Venohr I, Gade G, McKenzie M, Kramer AM, Bryant L, Beck A. Effectiveness of a group outpatient visit model for chronically ill older health maintenance organization members: A 2-year randomized trial of the cooperative health care clinic. *Journal of the American Geriatrics Society*. 2004; 52(9):1463–1470. [PubMed: 15341547]
- Sharma G, Kuo YF, Freeman JL, Zhang DD, Goodwin JS. Outpatient follow-up visit and 30-day emergency department visit and readmission in patients hospitalized for chronic obstructive pulmonary disease. *Archives of Internal Medicine*. 2010; 170(18):1664–1670. [PubMed: 20937926]

- Sills M, Fairclough DL, Ranade D, Mitchell MS, Kahn MG. Emergency department crowding is associated with decreased quality of analgesia delivery for children with pain related to acute, isolated, long-bone fractures. *Academic Emergency Medicine*. 2011; 18(12):1330–1338.
- Small LFF. Determinants of physician utilization, emergency room use, and hospitalizations among populations with multiple health vulnerabilities. *Health*. 2011; 15(5):491–516. [PubMed: 21169208]
- Smith S, Soubhi H, Fortin M, Hudon C, O'Dowd T. Interventions for improving outcomes in patients with multimorbidity in primary care and community settings. *Cochrane Database System Review*. 2012; 18(4)
- Sox CM, Burstin HR, Edwards RA, O'Neil AC, Brennan TA. Hospital admissions through the emergency department: does insurance status matter? *The American journal of medicine*. 1998; 105(6):506–512. [PubMed: 9870837]
- Steinbrook R. Health care reform in Massachusetts—expanding coverage, escalating costs. *New England Journal of Medicine*. 2008; 358(26):2757–2760. [PubMed: 18579809]
- Sterman, J. *Business Dynamics*. New York: Irwin-McGraw-Hill; 2000a.
- Sterman, JD. *Business Dynamics -System Dynamics for a complex world*. New York: McGraw Hill Higher Education; 2000b.
- Sullivan AF, Richman NB, Ahn CJ, Auerbach BS, Pallin DJ, Schafermeyer RW, Clark S, Camargo CA. A profile of US emergency departments in 2001. *Annals of Emergency Medicine*. 2006; 48(6):694–701. [PubMed: 17067721]
- Sun BC, Hsia RY, Weiss RE, Zingmond D, Liang LJ, Han W, McCreath H, Asch SM. Effect of emergency department crowding on outcomes of admitted patients. *Annals of Emergency Medicine*. 2013; 61(6):605–611. [PubMed: 23218508]
- Tan de Bibiana, J. *Population and Public Health*. Vancouver, BC, Canada: University of British Columbia. Master of Science - MSc.; 2013. Housing first and emergency department utilization among homeless individuals with mental illness in Vancouver; p. 88
- Trzeciak S, Rivers EP. Emergency Department overcrowding in the United States: An emerging threat to patient safety and public health. *Emergency Medicine Journal*. 2003; 20(5):402–405. [PubMed: 12954674]
- Tu, HT.; Cohen, GR. Financial and health burdens of chronic conditions grow, Center for Studying Health System Change. 2009.
- U.S. Census Bureau. New Census Bureau Report Analyzes U.S. Population Projections Release Number: CB15-TPS.16. 2015. Retrieved March 15, 2015 from <http://www.census.gov/newsroom/press-releases/2015/cb15-tps16.html>
- Van Uden CJ, Winkens RA, Wesseling G, Fiolet HF, van Schayck OC, Crebolder HF. The Impact of a primary care physician cooperative on the caseload of an emergency department: The Maastricht integrated out-of-hours service. *Journal of General Internal Medicine*. 2005; 20(7):612–617. [PubMed: 16050847]
- Vandyk AD, Harrison MB, Macartney G, Ross-White A, Stacey D. Emergency department visits for symptoms experienced by oncology patients: A systematic review. *Supportive Care in Cancer*. 2012; 20(8):1589–1599. [PubMed: 22526151]
- Virginia Department of Health. Overview Of Asthma In Virginia. 2007. Retrieved December 5, 2014 from <https://www.vdh.virginia.gov/news/PressKits/Asthma/Overview.pdf>
- Virginia Department of Health. Virginia Chronic Disease self-management program (CDSMP). 2014. Retrieved September 20, 2014 from http://www.aoa.gov/AoA_Programs/HPW/ARRA/Docs/VA_Profile_on_template.pdf
- Vincken W, van Noord JA, Greefhorst APM, Bantje ThA, Kesten S, Korducki L, Cornelissen PJG. Improved health outcomes in patients with COPD during 1 yr's treatment with tiotropium. *European Respiratory Journal*. 2002; 19(2):209–216. [PubMed: 11871363]
- Voss R, Gardner R, Baier R, Butterfield K, Lehrman S, Gravenstein S. The care transitions intervention: Translating from efficacy to effectiveness. *Archives of Internal Medicine*. 2011; 171(14):1232–1237. [PubMed: 21788540]

- Weber EJ, Showstack JA, Hunt KA, Colby DC, Grimes B, Bacchetti P, Callahan ML. Are the uninsured responsible for the increase in Emergency Department visits in the United States? *Annals of Emergency Medicine*. 2008; 52(2):108–115. [PubMed: 18407374]
- Weinstein MC, Toy EL, Sandberg EA, Neumann PJ, Evans JS, Kuntz KM, Graham JD, Hammitt JK. Modeling for health care and other policy decisions: uses, roles, and validity. *Value in Health*. 2001; 4(5):348–361. [PubMed: 11705125]
- Whitehead SJ, Ali S. Health outcomes in economic evaluation: the QALY and utilities. *Oxford journals*. 2010; 96(1):5–21.
- Wilson AR, Bargman EP, Pederson D, Wilson A, Garrett NA, Plocher DW, Ailiff PL. More preventive care, and fewer emergency room visits and prescription drugs--Health care utilization in a consumer-driven health plan. *Benefits quarterly*. 2007; 24(1):46–54. [PubMed: 18543833]
- Winkin V, Pinckaers V, D'Orio V, Ghuyssen A. Overcrowding estimation in the emergency department: Is the simplest score the best? *Critical Care*. 2013; 17(Suppl 2):P258.
- Wolfson JA, Schragger SM, Coates TD, Kipke MD. Sickle-cell disease in California: A population-based description of emergency department utilization. *Pediatric Blood & Cancer*. 2011; 56(3): 413–419. [PubMed: 21225920]
- Yusuf HR, Atrash HK, Grosse SD, Parker CS, Grant AM. Emergency department visits made by patients with Sickle Cell Disease: A descriptive study, 1999–2007. *American Journal of Preventive Medicine*. 2010; 38(4, Supplement):S536–S541. [PubMed: 20331955]

Figure 1.
Simplified Stock and Flow Diagram

Figure 2. High-level simplified causal loop influence diagram of the proposed model

Table 1

Showing Pros and Cons of three popular simulation modelling approaches

	Pros	Cons
Discrete Event Simulation (DES)	<ul style="list-style-type: none"> • A flexibility to model various levels of detail and complexity • Allowing the modeling of uncertainty and dynamic (time changing) systems • Advances and variety in DES software (such as those mentioned above) 	<ul style="list-style-type: none"> • Like most numerical techniques, DES provides only approximations/estimates of your model outputs, which is all that is possible in most complex systems • DES is heavily reliant on statistics, which most engineers are not comfortable with
System Dynamics Modeling	<ul style="list-style-type: none"> • System dynamics models (even just conceptual models) are useful learning tools which help improve system understanding and foster system thinking skills and knowledge integration for modelers and end users • With the advances in the development of high level dynamic modeling software applications (such as ithink, Vensim and Powersim), computational system dynamics modeling has become widely accessible to people (even with minimal technical background) • The system dynamics literature has made rich contributions to approaches that inform the modeling process, including: data collection methods, knowledge elicitation/mapping techniques, and policy analysis 	<ul style="list-style-type: none"> • Relative simplicity of linking variables, meaning that models can quickly grow in size and complexity. It may result in developing elegant but less useful models • The existence of user-friendly graphic interfaces has sometimes offered false impression that modeling is always easy and additional variables and processes can be included effortlessly • Inclusion of uncertain or postulated feedback loops may create complex model behavior that does not correspond to real world behavior and that is often very difficult to verify or validate
Agent Based Modeling	<ul style="list-style-type: none"> • Captures emergent phenomena (which result from the interactions of individual entities) • Provides a natural description of a system • Flexible (i.e., easy to add more agents, tuning the complexity of agents and change levels of description and aggregation) • Low cost and time saving approach for reproducing and analyzing a broad variety of complex problems, difficult to study by other means that might be too expensive 	<ul style="list-style-type: none"> • Tend to be less useful (and less interesting!) with few or no emergent outcomes • Often harder to develop, verify, validate and document • Need more computational power to simulate and results are more difficult to interpret

Table 2

Input for all sub-models

Input	Values (Unit)	Definition/References
Net Immigration Effect	1.45 (Dmnl)	Effect of the immigration on the birth rate of the population (Martin et al. 2013; Romero 2014)
Birth Rate	13.079 (1/Day)	Births per 1,000 of a population year (Romero 2014). Those concern the births from mothers residing in the Hampton Roads area.
Death Rate	7.5 (1/Day)	Deaths per 1,000 of a population year (Romero 2014). Those concern the people residing in the Hampton Roads area.
Acuity Calibration Factor	0.10 (Dmnl)	Degree of perceived acuity of the disease over a one year period (Moorman et al. 2012)
General Percent with Chronic Disease	0.33 (Dmnl)	Portion of patient with chronic disease, among insured and uninsured patients (Virginia Department of Health 2014)
Average Number of Physician in ED	4.17 (Physician/ED)	Number of physician in ED services. (Sullivan et al. 2006; Ginde et al. 2009)
Number of EDs	1834 (ED)	Number of ED services (Sullivan et al. 2006)
Unreported Patients Factor	WITH LOOKUP(Insurance status)	Insured and uninsured ambulatory groups. It expresses the relationship between the patient registered as uninsured and insured and the number of non-registered patients. (Diaz et al. 2012)
Multiple Visit Compensation	1.11 (Dmnl)	Replacement of multiple visits to the hospital. (Wilson et al. 2007)
Efficiency of intervention	0.50 (Dmnl)	Efficiency of the intervention for the case of chronic conditions (e.g., asthma, chronic obstructive pulmonary disease, congestive heart failure, diabetes, and heart disease patients (Coleman et al. 2001)
Effectiveness of Intervention	Random Normal (1, 5,[2,3,4], 0.2)	Characterization of intervention impact for the case of Asthma patients (Akerman and Sinert 1999; Hockemeyer and Smyth 2002) – These values indicate (lower limit, upper limit, [mean], standard deviation).
Intervention Percent Effect	WITH LOOKUP(Net effect of intervention)	This variable expresses the scope of the effect of the intervention in the choice of patients to go either to ED or other medical alternatives. (Vincken et al. 2002)
Percent Asthma	0.163 (Dmnl)	Percentage of Asthma patients in Virginia (Virginia Department of Health 2007)

Note: The insured patients refer to those having private insurance, Medicare, Medicaid, work compensation or any combination of these insurance coverage types.

ED Visits – Insured/Uninsured Patients

Year	Insured ED Visits						Uninsured ED Visits							
	No Intervention	Low-Impact Intervention	Mid-Impact Intervention	High-Impact Intervention	No Intervention	Low-Impact Intervention	Mid-Impact Intervention	High-Impact Intervention	No Intervention	Low-Impact Intervention	Mid-Impact Intervention	High-Impact Intervention		
	Visits	Visits	Percent Reduction	Visits	Percent Reduction	Visits	Percent Reduction	Visits	Percent Reduction	Visits	Percent Reduction	Visits	Percent Reduction	
1	7,726	7267	5.94%	7231	6.40%	7181	7.06%	2322	2190	5.69%	2180	6.15%	2164	6.81%
2	7,868	7330	6.84%	7291	7.33%	7238	8.01%	2404	2227	7.36%	2215	7.85%	2199	8.52%
3	8,010	7248	9.52%	7214	9.94%	7165	10.55%	2487	2220	10.73%	2209	11.15%	2194	11.75%
4	8,152	7391	9.34%	7353	9.81%	7299	10.46%	2568	2282	11.16%	2270	11.62%	2253	12.26%
5	8,294	7485	9.75%	7449	10.19%	7398	10.81%	2650	2329	12.11%	2318	12.53%	2302	13.14%
6	8,436	7290	13.58%	7252	14.04%	7198	14.68%	2732	2286	16.31%	2274	16.75%	2257	17.37%
7	8,578	7460	13.03%	7421	13.48%	7368	14.11%	2814	2358	16.20%	2346	16.63%	2329	17.24%
8	8,720	7425	14.85%	7390	15.25%	7340	15.83%	2896	2365	18.32%	2354	18.70%	2338	19.25%
9	8,862	7610	14.13%	7574	14.54%	7523	15.11%	2978	2443	17.95%	2432	18.34%	2415	18.89%
10	9,008	7585	15.79%	7542	16.27%	7484	16.92%	3056	2455	19.68%	2441	20.13%	2422	20.75%
Average	8,365	7,409	11.28%	7,372	11.73%	7,319	12.35%	2,691	2,316	13.55%	2,304	13.99%	2,287	14.60%

Table 4

Additional Visits to PCMHs

Year	Additional Visits to PCMHs					
	Insured			Uninsured		
	Low-Impact Intervention	Mid-Impact Intervention	High-Impact Intervention	Low-Impact Intervention	Mid-Impact Intervention	High-Impact Intervention
1	594	894	1194	179	270	360
2	643	945	1246	195	287	379
3	615	918	1221	188	281	374
4	613	918	1223	189	283	378
5	558	864	1171	174	269	364
6	557	866	1174	175	271	368
7	749	1059	1368	237	335	433
8	708	1020	1331	226	325	424
9	658	971	1284	211	312	412
10	633	947	1262	205	307	408
Average Visit	633	940	1,247	198	294	390
Increase percent		32.69%	24.64%		32.68%	24.63%

Table 5

Effects on Utilization of EDs and PCMHs under Diversion Intervention Policies

Year	ED			PCMHs		
	No Intervention	Mid-Impact Intervention	High-Impact Intervention	Low-Impact Intervention	High-Impact Intervention	
1	70.00%	61.00%	52.00%	33.90%	75.00%	
2	70.50%	61.50%	52.70%	35.00%	76.00%	
3	72.00%	61.90%	53.80%	37.00%	77.00%	
4	73.00%	62.20%	54.80%	37.20%	80.00%	
5	74.00%	62.60%	54.60%	38.00%	81.00%	
6	75.00%	62.80%	55.90%	39.00%	81.50%	
7	75.50%	63.00%	57.00%	42.00%	81.70%	
8	76.00%	64.00%	57.30%	42.20%	82.30%	
9	77.00%	65.00%	58.00%	43.00%	83.00%	
10	77.00%	66.00%	61.00%	43.10%	83.10%	
Average	74.00%	63.00	55.71%	39.04%	80.05%	

Table 6

Unpaid costs by uninsured patients

Year	Unpaid Costs							
	No Intervention		Low-Impact Intervention		Mid-Impact Intervention		High-Impact Intervention	
	Costs	Percent Increase	Costs	Percent Increase	Costs	Percent Increase	Costs	Percent Increase
1	50,077.15	14.44%	58,100.52	14.44%	62,040.16	22.20%	66,100.44	30.20%
2	56,350.27	15.39%	65,020.80	15.39%	69,280.36	22.95%	73,670.02	30.73%
3	62,270.17	12.22%	69,870.89	12.22%	74,390.41	19.47%	79,040.42	26.93%
4	68,540.26	14.22%	78,280.88	14.22%	83,150.16	21.31%	88,150.28	28.61%
5	75,180.03	12.97%	84,920.96	12.97%	90,080.56	19.83%	95,380.29	26.87%
6	82,200.00	12.68%	92,620.20	12.68%	98,120.11	19.37%	103,760.38	26.23%
7	88,440.78	12.85%	99,800.92	12.85%	105,600.07	19.39%	111,530.81	26.11%
8	94,930.80	10.54%	104,940.78	10.54%	110,990.85	16.92%	117,190.73	23.45%
9	101,670.76	11.43%	113,290.77	11.43%	119,650.87	17.68%	126,160.94	24.09%
10	108,670.39	13.78%	123,650.39	13.78%	130,380.83	19.98%	137,270.34	26.32%
Average	7,890.56	13.05%	8,905.61	13.05%	9,437.24	19.91%	9,982.96	26.95%