ABSTRACT

Title of Dissertation: EXAMINING THE UTILITY OF THE ESSENCE SYNDROMIC SURVEILLANCE SYSTEM IN THE EARLY DETECTION OF HOSPITAL EMERGENCY DEPARTMENT CROWDING

Nathaniel Roosevelt Abrams Jr., Doctor of Public Health, May 2019

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The pertinent information synthesized by well-designed surveillance operations are essential to the planning, implementation, and evaluation of both public health and healthcare services. Divergent applications within existing surveillance initiatives have subsequently led to novel uses of health-related data becoming increasingly valuable. Heightened surveillance techniques, such as syndromic surveillance, have revealed pragmatic capabilities that adequately complement the dynamic nature of public health programming. As syndromic surveillance is still an emerging science, scholarly activities probing the utility of emergency department (ED)-based syndromic surveillance systems have remained noticeably narrow in scope. However, it is commonly speculated that the

inherent multifaceted functionalities of ED-based syndromic surveillance systems equip them with the potential to meaningfully enhance surveillance capacities, across a broader assortment of public health and healthcare settings.

The purpose of this dissertation study was to explore the utility of ED-based syndromic surveillance data for resolutions beyond infectious disease control and prevention. More specifically, this study examined ED utilization data, captured and forecasted by the Electronic Surveillance System for the Early Detection of Community-based Epidemics (ESSENCE), and its aptness for the early detection of ED crowding.

Pre-existing data extracted from the ESSENCE syndromic surveillance system and the County Hospital Alert Tracking System (CHATS), were cross-classified to test the principal hypotheses of this study. A multiple logistic regression model was employed to assess whether the odds of reported ED crowding increased on days when actual ED utilization counts surpassed the expected utilization counts forecasted by ESSENCE.

Findings from this investigative inquiry proved that ED-based syndromic surveillance data, may be able to serve as an early indicator of emergency department crowding. The increased odds observed in the multiple logistic regression supports our primary research hypothesis and warrants further exploration into the matter.

This dissertation was tailored for use as a foundational piece, to drive a series of studies to follow. Future research should seek to improve upon the examination methods modeled in this study, for the creation of a gauge for heightened awareness or increased risk of ED crowding. Ultimately, this study contributes to an increased understanding and

acknowledgment of the adroit capabilities that ED-based syndromic surveillance systems possess. Many of which could contribute to the development of innovative solutions to a great number of public health challenges, through both individual and larger organizational efforts.

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by

Nathaniel Roosevelt Abrams Jr.

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This dissertation is dedicated to my parents, Rosetta Fowler, Dwayne L. Fowler, and Nathaniel R. Abrams Sr., whom throughout my life have continued to demonstrate firsthand what it means to be true followers of Christ. Without their undying love and support, none of this would have been possible. To these individuals, I would like to say thank you for seeing in me, those many potentials I sometimes failed to see in myself. I love you both dearly.

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Chapter 1: Introduction

Background

Public health surveillance can be defined as the continuous, systematic collection, analysis, and interpretation of health-related data (Thacker & Berkelman, 1988). The pertinent information synthesized by well-designed surveillance operations are essential to the planning, implementation, and evaluation of both public health and healthcare services (World Health Organization [WHO], 2018). Heralded as a principal component of public health's core function of assessment, surveillance is distinguished as the cornerstone of public health practice (Institute of Medicine [IOM], 1988; Thacker, Qualters, & Lee, 2012). Amongst practitioners, there has been a distinct desire to expand upon the traditional methods of public health surveillance, which have been heavily grounded in population-based surveys, vital statistics, and administrative data (Thacker et al., 2012). In accordance with this shared pursuit of procedural reformation, surveillance practitioners have been able to capitalize on federally funded modernization campaigns. Progressive legislation such as the Health Information Technology for Economic and Clinical Health (HITECH) Act, have given way to purposive ideation and systemic integration within the public health surveillance community (Lenert & Sundwall, 2012). Hence, contemporary surveillance activities have been characterized by an influx of cutting-edge methodologies.

The emergence of multiple avenues for augmenting traditional surveillance approaches is a marked achievement, brought to fruition through the wielding of rapid advances in information technology (Richards et al., 2017). Divergent applications within

existing surveillance initiatives have subsequently led to novel uses of health-related data becoming increasingly valuable (Mardon et al., 2017). Also, public health entities' aspirations to bolster mainstay surveillance procedures continue to propagate (Richards et al., 2017). As opportunities for innovation steadily transpire, heightened surveillance techniques, such as syndromic surveillance, have revealed pragmatic capabilities that adequately complement the dynamic nature of public health programming.

Syndromic surveillance is a type of enhanced public health surveillance that collects data on the signs and symptoms of disease, preceding laboratory confirmation or clinical diagnoses (Katz, May, Baker, & Test, 2011). Operating in thousands of hospital emergency departments (EDs) throughout the nation, these sophisticated systems implement a near real-time monitoring technique that facilitates early detection, rapid intervention, and elevated situational awareness (Rha et al., 2013). The primary data source for emergency department-based syndromic surveillance systems are patients' reason for visit, when seeking care (Rha et al., 2013). These reasons for visit are more commonly referred to as chief complaints (Conway, Dowling, & Chapman, 2013). ED-based syndromic surveillance systems are regularly used to provide detailed epidemiologic data to public health agencies, at the local, state, and federal levels (Holtry, Hung, & Lewis, 2010).

Statement of the Problem

As syndromic surveillance is still an emerging science, scholarly activities probing the utility of ED-based syndromic surveillance systems have remained noticeably narrow in scope. A simple database search, of associated literature on the subject, reveals

that most published works almost exclusively explore the systems' employment in investigations of communicable disease outbreaks. However, it is commonly speculated that the inherent multifaceted functionalities of ED-based syndromic surveillance systems equip them with the potential to meaningfully enhance surveillance capacities, across a broader assortment of public health and healthcare settings (Kunerth, Baker, Zelicoff, Elliot, & Syberg, 2017). This notion transcends the ideology that the most efficient usages of syndromic surveillance systems fail to extend outside the realm of infectious disease epidemiology (Buehler et al., 2009). Though empirical studies demonstrating inventive approaches to syndromic surveillance have increased in recent years, the breadth of selections is still deficient. Taking into account their numerous practicalities, there is a dire need to synthesize a substantial collection of applied research examining novel applications of ED-based syndromic surveillance systems.

Purpose of the Study

The purpose of this dissertation study was to explore the utility of ED-based syndromic surveillance data for resolutions beyond infectious disease control and prevention. More specifically, this study examined emergency department utilization data, captured and forecasted by the ESSENCE syndromic surveillance system, and its aptness for the early detection of ED crowding. In doing so, a better understanding, and broadened recognition, of both the advantageous properties and limitations of ED-based syndromic surveillance data was revealed. An additional benefit of this work is a potential progression in the propensities by which syndromic surveillance activities are incorporated into the delivery of health and human services. The methodological

discoveries of this examination may lead to systemic anomalies, such as emergency department crowding, becoming more manageable, through the documented foresight and rapid intervention that is facilitated by syndromic surveillance systems. Descriptive and inferential results from this investigation are likely to play a pivotal role in developing strategic plans to increase efficiency in the management of hospital ED resources, based on the identified utilization trends. Therefore, the practical implications of this inquiry are of considerable significance.

Chapter 2: Literature Review

The following literature review examined the known utilities of ED-based syndromic surveillance systems, through a comprehensive survey of published manuscripts. Additionally, this chapter briefly reviewed the scope of emergency department crowding in the U.S., the critical public health issue that this study's investigative methods were applied to. The information contained in this chapter supported the rationale that drove the selection of this study's primary data sources and principle analytic methods; as well as, delineated their distinct correlation to the topical emphasis of this dissertation.

In effort to obtain relevant literature concerning the principal concepts of this research, an electronic database search was implemented. Published articles from peer-reviewed journals, governmental websites, and professional organizations were identified and selected for review. The final assemblage also included articles obtained from a manual search of works cited in the initial publications. Keywords that powered this literature search included, but were not limited to, "Public Health Surveillance," "Epidemiologic Surveillance," "Syndromic Surveillance," "ESSENCE," "Emergency Department Crowding," "Emergency Department Overcrowding," "Capacity Management," and "Ambulance Diversion".

Conceptual Framework

ED-based syndromic surveillance systems monitor daily utilization of ED services as a means of detecting and predicting health-related events (Buehler et al., 2009). The following investigation sought to test a hypothesis related to the practicality

of wielding ED-based syndromic surveillance data for the early detection of emergency department crowding. To properly recognize the function that syndromic surveillance systems could lend in this exploit, the phenomenon of ED crowding was examined through an overarching framework. It was vital that the selected framework included pertinent factors that could be linked to the routine functions of ED-based syndromic surveillance initiatives.

In 2003, Dr. Brent Asplin et al. published the conceptual model of emergency department crowding, one of the most widely referenced schemas of how crowding presents itself in the acute care setting. The stated goal of Asplin's work is "to provide a practical framework on which an organized research, policy, and operations management agenda can be based to alleviate ED crowding" (Asplin et al., 2003, p. 178). Within the conceptual model of emergency department crowding, there are two specific constructs that are germane to syndromic surveillance data collection efforts. They are "Demand for ED care" and "Ambulance Diversion". These components of the framework are presented as two parallel factors contributing to ED crowding, with the Ambulance Diversion construct eventually becoming an input factor to the Demand for ED care construct (Asplin et al., 2003).

From this blueprint (Figure 1), we were able to gain a better understanding of how emergency department crowding is influenced by demand for ED services and ambulance diversions. As ED utilization data from the ESSENCE syndromic surveillance system and ambulance diversion data for the County Hospital Alert Tracking System (CHATS) were the primary data sources of this study, the conceptual model of emergency

department crowding served as suitable framework to guide this scientific inquiry. The overall alignment of the model with the stated purpose and planned analytic methods of this dissertation research supported its inclusion in this examination.

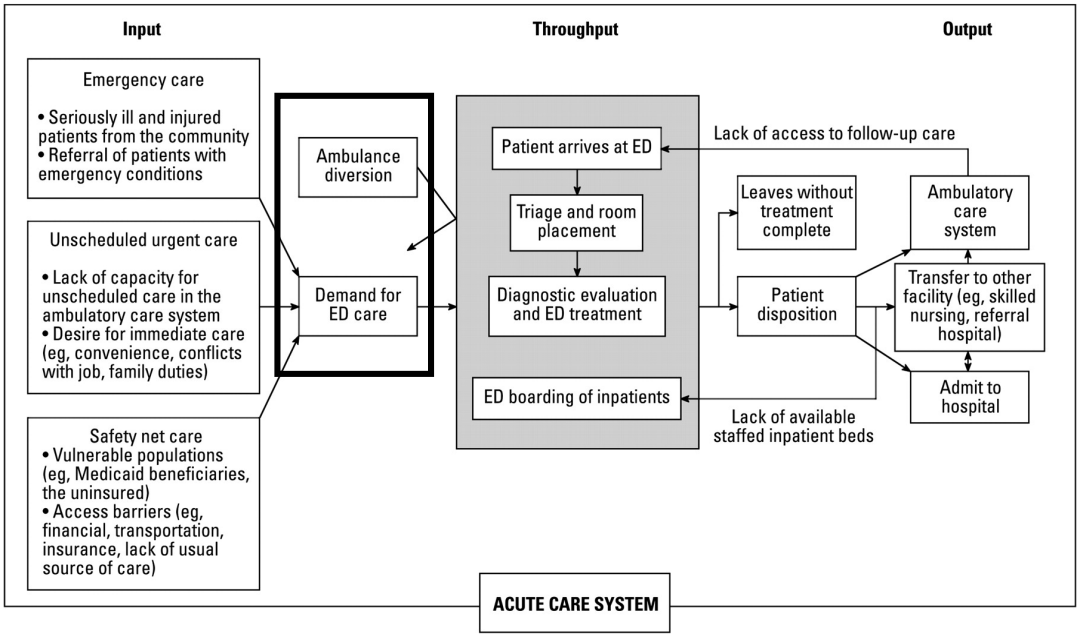

Figure 1. The input-throughput-output conceptual model of ED crowding. Adapted from "A Conceptual Model of Emergency Department Crowding," by Asplin, B.R., Magid D.J., Rhodes K.V., Solberg L.I., Lurie N., and Camargo Jr., C.A., 2003, *Annals of Emergency Medicine*, *42(2)*, p. 176. Copyright 2003 by the American College of Emergency Physicians.

The Evolution of Public Health Surveillance

The functional underpinnings of ED-based syndromic surveillance systems were detailed within the proceeding excerpts of this chapter, and deliberated in the closing discussion; however, it was equally as important that we discussed the historical realities which have led to the current state of syndromic surveillance agendas in the United States. Public health surveillance has evolved from a collection of loosely associated procedures, into a robust body of purposefully structured methodologies (Choi, 2012). The advanced practices within contemporary surveillance activities have been designed

to combat one or more of the profuse challenges associated with safeguarding the health and well-being of the global community (Thacker et al., 2012). Nearly 700 years ago, the idea of using scientifically derived evidence as a precursor for public health interventions was modeled during the European renaissance era (Declich & Carter, 1994). Centuries later this tactical train of thought, and its foundational precepts, have been broadly disseminated, slowly ripening into one of the most widely-recognized components of public health research and practice. However, long before the universal diffusion and uptake of this procedural ideology, its utilization within primitive surveillance approaches was meticulously recorded throughout the archives of human history.

Amongst the earliest verified examples of public health surveillance are found the strategies employed during one of the most vehement epidemics known to man, the pneumonic/bubonic plague (Choi, 2012). During the "Black Death" pandemic, government officials in Italy began appointing what would now be considered public health surveillance officers to track all vessels transporting disease-ridden individuals, throughout the region (Choi, 2012). In examining the preventative measures taken during this perilous outbreak, we can extrapolate how the coarse tracking techniques of eld have contributed to modern-day surveillance methods.

Accompanying marked advancements in science, industry, and social institutions, the rudimentary investigation tactics of the fourteenth century underwent an enrichment phase in the proceeding eras (Choi, 2012). This development resulted in the formulation of more comprehensive approaches to disease control and prevention, featuring the incorporation of more refined analytic processes (Mazur, 2016). One prime example of

this temporal progression in surveillance practices can be observed in the exertions of John Graunt, during his analysis of "Bills of Mortality" records in 1662 (Mazur, 2016). This investigation, which occurred during the London plague outbreak of the time, is considered one of the first documented accounts of the analysis and interpretation of "Big Data," for public health purposes (Mazur, 2016).

Nearly a century later, we can trace the origins of epidemiologic surveillance in the United States to the establishment and advancement of the colonial settlements (Thacker, 2000). During this era, chronicled accounts described the process by which communicable conditions such as small pox, cholera, and yellow fever were surveilled through an organized system of observation and reporting, instituted in local taverns (Thacker, 2000). Though the public health pursuits of the early European settlers were influential in shaping future surveillance practices, without question the most renowned contributions to the contemporary surveillance methods utilized in the United States today are those of Dr. Alexander D. Langmuir.

Considered the father of public health surveillance, Dr. Alexander Langmuir was the first chief epidemiologist at the Communicable Disease Center, known today as the Centers for Disease Control and Prevention (CDC; Thacker et al., 2012). Amid joining the CDC in 1949, Langmuir's visionary conjectures within the biomedical sciences led to the manifestation of some of the most celebrated works in applied epidemiology (Schultz & Schaffner, 2015). Dr. Langmuir's active surveillance of the 1955 polio outbreak is considered one of the greatest demonstrations of the value of efficient surveillance practices, in our nation's history (Schultz & Schaffner, 2015). During this landmark

investigation, he and his colleagues effectively linked the cause of the outbreak to the mass distribution of faulty vaccines, originating from a tainted supplier (Thacker et al., 2012). Today in the United States, and across the globe, Dr. Langmuir's influence on the process by which health-related data are collected, reported, and analyzed is both timeless and immemorial (Kumar & Raut, 2014).

Successive innovations in public health surveillance procedures have been shaped by an iterative process, that has ushered in an era accentuating practically and versatility (Hall, Correa, Yoon, & Braden, 2012). An increasing number of public health organizations have now begun to incorporate more behavioral and event-based data streams into their routine surveillance efforts (Kumar & Raut, 2014). From measuring dynamic shifts in health status following natural disasters to the unerring tracking of time sensitive events such as drug overdose and suicide, the current landscape of applied epidemiology is now imbued with an abundance of fresh approaches (Harmon, Proeshcoldbell, Marshall, & Waller, 2014; Kumar & Raut, 2014; Kuramoto-Crawford, Spies, & Davies-Cole, 2017). Among these inventive designs we can find the emerging method of public health surveillance that constitutes the primary focus of this study, syndromic surveillance.

The Advent of Syndromic Surveillance

Though the real-time monitoring of health-related indicators is an operational process that has been in existence for decades, its significance, and subsequently the significance of syndromic surveillance, ascended to the forefront of national conversations following the events of September 11th, 2001 (Lee & Thacker, 2011).

During this time, the health of millions was put at risk due to a series of premeditated attacks. One specific example was the deliberate dispersal of the Bacillus anthracis bacteria through our nation's postal system (Fleischauer et al., 2004). After suffering such a devastating impedance of national security and public trust, the U.S. government swiftly prioritized the fortification of our defense mechanisms against potential terroristic threats (Mandl et al., 2004). Consequently, the paramount objectives amongst federal government entities emphasized the need to protect our nation against exposures to weaponized pathogens (Fleischauer et al., 2004). Throughout this time of conflict and uncertainty, the socio-political climate, in the U.S. and across the globe, continued to perpetuate concerns of biowarfare (Paterson & Durrheim, 2013). Even prior to the tragic events of September 11th, 2001, strong support and financial backing, at the federal level, prompted surveillance practitioners to begin establishing practical solutions to combat bioterrorism (Koplan, 2001). After scouring for the most effective means of detecting signs of biowarfare, syndromic surveillance systems were recognized as a plausible method of accomplishing this feat (Buehler, Berkelman, Hartley, & Peters, 2003).

The Electronic Surveillance System for the Early Notification of Community-based Epidemics

One of the most reputable syndromic surveillance systems operating in the United States is the Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE). ESSENCE was first developed by scientists from the Johns Hopkins Applied Physics Laboratory (JHU-APL), in conjunction with the United States Department of Defense (DoD; Lombardo et al., 2003a). The ESSENCE program

was sponsored through special funding from the DoD's Defense Advanced Research Projects Agency (DARPA), an intra-agency faction dedicated exclusively to pioneering advanced technical solutions (Lombardo et al., 2003a; Defense Advanced Research Projects Agency [DARPA], 2018). The original ESSENCE system, known as ESSENCE I, was designed to monitor the occurrence of infectious disease conditions within U.S. military bases (Lombardo, Burkom, & Pavlin, 2004). As the ESSENCE I system was being implemented to surveil the health status of military personnel, the JHU-APL team began the development of a similar indicator-based surveillance system (Lombardo et al., 2004). This newly contrived instrument, ESSENCE II, would be used to provide the same type of early detection and situational awareness as the EESENCE I program, with the exception that it would operate exclusively for civilian purposes (Lombardo, 2003b).

In its infancy the ESSENCE II pilot program, incubated in the national capital region (NCR), was only intended to perform a limited amount of surveillance tasks (Lombardo, 2003b). As local public health practitioners and other operators of ESSENCE became acclimated to its operational capacities, the system began to undergo a series of trial runs in a more expansive set of initiatives (Hurt-Mullen & Coberly, 2005). Utilization of ESSENCE II eventually transcended the NCR test-bed, with various public health and healthcare organizations across the country espousing the unique system (Marsden-Haug et al., 2007; O'Connell, Zhang, Leguen, Llau, & Rico, 2010). Recently adopted as the chief analytic tool of the National Syndromic Surveillance Program (NSSP), ESSENCE serves as an essential apparatus for an astute community of surveillance practitioners (Centers for Disease Control and Prevention [CDC], 2017a).

Currently, ESSENCE processes data from over 4,000 locations, a volume equating to nearly 65% of all hospital ED visits in the country (CDC, 2017b).

One of the key attributes of ESSENCE is its rapid processing of real-time data, for the early detection of health-related events (Lombardo et al., 2003a). The main benefit of employing ESSENCE in the ED setting is that instead of waiting for a patient to be examined and diagnosed by a professional, the ESSENCE system instantaneously uses reported signs and symptoms as a forewarning of possible ailments. This ability to improve timeliness of intervention, in both public health and healthcare settings, has been confirmed to contribute to improved health outcomes (Lateef, 2012).

Traditional Applications of ED-based Syndromic Surveillance Systems

As we have recounted the chronological progression of epidemiologic surveillance, the stated purpose of this dissertation solicited that we explore those eccentric surveillance capacities, which are still being revolutionized today. The ensuing writings examined a series of scholarly works detailing both mainstream and novel approaches to ED-based syndromic surveillance. To commence this process, we began with a succinct appraisal of peer-reviewed investigations highlighting traditional applications of syndromic surveillance systems.

The first major cluster of published literature regarding ED-based syndromic surveillance systems evaluated their suitability as a real-time detection mechanism, for unforeseen acts of bioterrorism (Paterson & Durrheim, 2013). Following 2005, scientific literature exploring syndromic surveillance methods experienced an influx in studies substantiating its' more expanded operational capacities (Paterson & Durrheim, 2013).

This redirection came on the cusp of federal, state, and local public health agencies acknowledging that the biodefense-based detection protocols of syndromic surveillance systems were easily transferrable, to the detection of more casual health-related events (Griffin et al., 2009). Among the post-bioterrorism era studies were key initiatives that supported the case for further investment into syndromic surveillance systems, even after the social and political climates around the world became more stable (Holtry et al., 2010). Table 1 provides summative information on serval publications exemplifying traditional applications of syndromic surveillance systems.

Table 1

Traditional Applications of Syndromic Surveillance Systems

Article Title / Authors	Methodology	Implications for Practice
Title Code-based Syndromic Surveillance for Influenzalike Illness by International Classification of Diseases, Ninth Revision Authors Marsden-Haug, N., Foster, V., Gould, P., Elbert, E., Wang, H., and Pavlin, J. (2007)	Comparison of Influenzalike Illness (ILI) syndrome data extracted from ESSENCE, against laboratory confirmed cases reported to two Influenza Surveillance Networks managed by the DoD and CDC. Study conducted a correlation analysis	Results of trend analysis displayed that data from ESSENCE were correlated with nearly half of the laboratory-confirmed respiratory infections. ESSENCE was found generate surveillance warnings regarding ILI trends in a more timely fashion compared to the laboratory-based programs from the DOD and CDC. Findings from this study substantiate that automated syndromic surveillance systems are just as suitable as their traditional counterparts, in detecting seasonal patterns in infectious disease outbreaks. (continued)

Table 1

Traditional Applications of Syndromic Surveillance Systems (continued)

Article Title / Authors	Methodology	Implications for Practice
Title Early Detection of Influenza Outbreaks Using the DC Department of Health's Syndromic Surveillance System Authors Griffin, B., Jain, A., Davies-Cole, J., Glymph, C., Lum, G., Washington, S., and Stoto, M. (2009)	Comparison of performance between three syndromic surveillance algorithms, in capturing the onset of influenza outbreaks.	Within the syndromic surveillance system, the Cumulative Sum (CUSUM) algorithm outperformed the two additional algorithms under evaluation. Syndromic surveillance systems operating in hospital EDs have the capacity to be efficient in the timely detection of influenza outbreaks, and signaling the need for more concentrated surveillance efforts in these given situations.
Title Utility of the ESSENCE Surveillance System in Monitoring the H1N1 Outbreak Authors Holtry, R., Hung, L., and Lewis, S. (2010)	Retrospective analysis of Influenzalike Illness (ILI) syndrome data, from the ESSENCE system, for the years 2008 & 2009.	ESSENCE was able to accurately detect a substantial increase in ILI syndrome counts during the H1N1 outbreaks of 2009, when comparing the data collected between 2008 & 2009. Results of this study support the capability of the ESSENCE SS system for the detection of community-based outbreaks.
Title Innovative Uses for Syndromic Surveillance Authors O'Connell, E., Zhang, G., Leguen, F., Liau, A., and Rico, E. (2010)	This study compared data from a standard query of ESSENCE's "chicken pox" subsyndrome to actual cases confirmed via hospital records. Researchers constructed three customized syndrome categories in effort to increase rate of detection.	The construction of custom syndrome categories was found to enhance ESSENCE's ability to detect cases of "chicken pox". The custom approach modeled in this study identified outbreaks that would have otherwise gone undetected by the standard syndrome categories.

(continued)

Table 1

Traditional Applications of Syndromic Surveillance Systems (continued)

Article Title / Authors	Methodology	Implications for Practice
Title Summary of Data Reported to CDC's National Automated Biosurveillance System, 2008 Authors Tokars, J., English, R., McMurray, P., and Rhodes, B. (2010)	Summary of data sent to the BioSense surveillance system during 2008. Data Sources included 333 DoD facilities, 770 VA clinics, 532 hospital EDs, and a few hundred outpatient facilities.	Amongst the standard syndrome categories used in the BioSense platform, the respiratory (205 per 1000) and gastrointestinal syndromes (144 per 1000) had the highest reported rates, within ED chief complaints data. Overall, 45 of the 78 reported sub-syndromes, were within syndrome categories representing infectious disease conditions.
Title Syndromic Surveillance for Local Outbreak of Lower-Respiratory Infections: Would It Work? Authors van den Winjngaard, C., et al. (2010)	Simulation of lower-respiratory infections (LRI), using pre-existing hospitalization data from 1999-2006. Detection rates among simulated LRI clusters, were compared to discharge data from confirmed cases of respiratory infections.	This study displays the ability of syndromic surveillance systems to identify spikes in the frequency of infectious disease conditions, using spatial analysis.
Title Biosurveillance: A Review and Update Author Kman, N., and Bachmann, D. (2012)	Review article, describing effective methods of detecting weaponized pathogens, and the proficiency of these techniques.	Across the United States, syndromic surveillance systems serve as an early detection mechanism for surges in the occurrence of communicable disease conditions within various communities.

(continued)

Table 1

Traditional Applications of Syndromic Surveillance Systems (continued)

Article Title / Authors	Methodology	Implications for Practice
Title Syndromic Surveillance for Influenza In The Emergency Department – A Systematic Review Authors Hiller, K., Stoneking, L., Min, A., and Rhodes, S. (2013)	Systematic review of published literature, examining ED-based syndromic surveillance systems. Study examines the most common sources of data used by SS systems, for the detection of influenza outbreaks,.	Amongst the syndromic surveillance systems working across the U.S., the most commonly used sources of data were chief complaints, and discharge diagnoses. Novel data sources, such as ED capacity, ambulance dispatch data, and telephone triage calls have also been used in several studies.
Title Emergency Department Visit Data For Rapid Detection and Monitoring Of Norovirus Activity, United States Authors Rha, B., et al. (2013)	Secondary analysis of chief complaint data from the BioSense surveillance system. "Diarrhea" or "Nausea" and "Vomiting" subsyndromes linked back to confirmed cases of Norovirus from 2007-2010.	Out of all the ED data, utilization of the Diarrhea subsyndrome was deemed to be a dependable method of detecting norovirus activity.
Title Validity and Timeliness of Syndromic Influenza Surveillance During the Autum/Winter Wave of A (H1N1) Influenza 2009 Author Rosenkotter, N., et al. (2013)	Assessment of local, regional, and national surveillance data for the detection of the 2009 H1N1 influenza pandemic. Data sources included records from an emergency medical dispatch, an emergency physician service, and a hospital emergency department.	Syndromic surveillance data collected in the hospital emergency department setting was found to be highly efficient, for the detection of influenza. Emergency medical services data was also found to useful for the bolstering of influenza surveillance.

(continued)

Table 1

Traditional Applications of Syndromic Surveillance Systems (continued)

Article Title / Authors	Methodology	Implications for Practice
Title Understanding the Utility of Over-The-Counter (OTC) Medications and Emergency Department (ED) Chief Complaints Data in a Syndromic Surveillance System Author Russell, J.A. (2014)	Retrospective analysis of seasonal outbreak data in Montgomery County Maryland, 2007-2010. Comparison of OTC and ED syndromic surveillance data extracted from the ESSENCE system if effort to distinguish which data offered the most rapid detection for a host of infectious disease conditions.	Findings from this study showed that OTC data may not precede ED syndromic surveillance in certain cases. Timeliness of detection depended on specific syndrome being monitored, and the criteria being used to generate the ESSENCE alerts.
Title Forecasting Respiratory Infectious Outbreaks Using ED-based Syndromic Surveillance for Febrile ED Visits In A Metropolitan City Author Kim, T., et al. (2019)	Utilized national emergency department data information system (NEDIS) records from 2013-2014, to construct a forecasting model for detecting respiratory infection outbreaks.	Study proved that the ARIMA forecasting model was well-suited for the early detection of outbreaks of respiratory infections, within the ED setting.

From the inquiries charted in Table 1, we gained valued insight into the potential advantages of using ED-based syndromic surveillance systems for communicable disease outbreak investigations. The individual manuscripts exemplified a diversity in operational frameworks, a quality apropos to describing the many uses of syndromic surveillance.

Furthermore, it appears that the notably rich versatility of syndromic surveillance architectures served to enable their employment in a wide-variety of public health settings. The next collection of published works, reviewed in this section, accentuated a host of non-traditional applications of ED-based syndromic surveillance.

Non-Traditional Applications of ED-based Syndromic Surveillance Systems

Policymakers and researchers alike support the adoption of novel data sources, to guide our nation's crusade against the mounting opioid crisis (Martinez, 2018). Legal analyst Catherine Martinez has written extensively on the issue, citing the efforts of several major public health entities. Organizations such as the New Hampshire Department of Health and Human Services, the Massachusetts Department of Public Health, and the Rhode Island Department of Health (RIDOH) have each incorporated syndromic surveillance systems in their statewide opioid initiatives (Martinez, 2018). Within the state of New Hampshire, Daly et al. (2017) crafted a special study of data parsed from 25 ED-based syndromic surveillance systems, spanning the years 2011-2015. The variables of interest included sex, age, city and state of residence, and date of ED visit (Daly et al., 2017). These selected indicators enabled researchers to identify trends in the frequency of opioid overdose, ultimately revealing a persistent rise of such occurrences throughout the observational period (Daly et al., 2017). Findings from this study proved vital in informing local and state opioid response efforts, in New Hampshire (Daly et al., 2017).

In Rhode Island, the RIDOH created the Opioid Overdose Reporting System, based on a recommendation from the CDC (McCormick, Koziol, & Sanchez, 2016).

According to McCormick et al. (2016), this system conducts a near real-time tracking and reporting of opioid overdoses, presented in the hospital ED. From these speedy alerts, practitioners are equipped with the ability to intervene in a timely manner, linking at-risk individuals with a host of treatment options and preventative services (McCormick et al., 2016). In addition to the studies discussed thus far, similar investigations have featured the use of ED-based syndromic surveillance data for the instantaneous identification of drug-induced ailments. Prominent examples include the NYC-DOHMH's innovative reclassification of substance abuse syndrome categories, and the population-based studies crafted using North Carolina's NC DETECT system (Harmon et al., 2014; Nolan, Kunins, Lall, & Paone, 2017). Federal funding sources, such as the CDC's Enhanced State Opioid Overdose Surveillance grant program, and the U.S. Department of Health and Human Service's Prescription Drug Overdose Data-Driven Prevention Initiative continue to support these ongoing initiatives (Martinez, 2018).

ED-based syndromic surveillance data have also been exercised for the monitoring of weather-related illnesses and injuries. Markedly, Dr. Christopher Fuhrmann led a team of expert researchers in efforts to craft a temporal analysis of heat-related illnesses using the NC Detect state-wide syndromic surveillance system (Fuhrmann, Sugg, Konrad, & Waller, 2016). Compiling data from 2007-2011, their efforts were able to link national weather alerts for extreme heat to increased frequencies of ED visits for adverse health concerns (Fuhrmann et al., 2016). The team identified a positive correlation that included a rise in the reporting of heat exhaustion, heat stroke, and heat fatigue chief complaints (Fuhrmann et al., 2016). In addition to heat-related

ailments, this study also examined the how extreme heat influenced the manifestation of various underlying health concerns (Fuhrmann et al., 2016). The most prevalent comorbidities identified included increases in cardiovascular conditions, nervous system disorders, and respiratory illnesses such as pneumonia, bronchitis, and emphysema (Fuhrmann et al., 2016).

A comparable study by the NYC-DOHMH examined the correlation between daily weather conditions and deaths associated with extreme heat (Mathes, Ito, Lane, & Matte, 2017). Their research team aggregated ED chief complaint data from 1999-2013 and were able to identify a 5% increase in mortality rates the day following extreme heat events (Mathes et al., 2017). The aforementioned studies, by both Fuhrmann et al. (2016) and Mathes et al. (2017), display the value of examining historical trends of ED-based syndromic surveillance data. Such investigations can be used to establish protocols to address potential health concerns that may arise from similar events in the future.

Wielding ED-based syndromic surveillance data for environmental health measures is a novel application that has been demonstrated in several scientific publications. Environmental Protection Agency researchers Ana Rappold et al. (2011) were able to use the NC Detect system to assess the impact of a juristic reduction in air quality following a major wildfire in North Carolina, occurring in 2008. Wildfires have been known to result in the release of criteria air pollutants, that may negatively impact population health (Rappold et al., 2011). The byproduct of this retrospective analysis was the discovery of an increased risk for infirmities including asthma, COPD, pneumonia, and bronchitis, within the exposed communities (Rappold et al., 2011). Likewise, the

California Department of Public Health recently conducted a retrospective query of syndromic surveillance data/ICD-9 codes collected following the 2007 San Diego wildfires (Hutchinson et at., 2018). During this series of fires, the health of millions of San Diego county residents was put at risk (Hutchinson et al., 2018). Analyses were able to associate 5-day exposure terms to wildfire smoke with increased rates of ED visits for respiratory and cardiovascular ailments (Hutchinson et al., 2018).

Novel applications of ED-based syndromic surveillance data can also be found whilst exploring epidemiologic activities relating to mass-gatherings. During large-scale events, public health practitioners have sought innovative methods of increasing readiness to meet the mirage of health issues that may occur (Fleischauer & Gaines, 2017). For example, London's Health Protection Agency (HPA) provided daily updates focusing on potential health-related threats, at the 2012 Olympic Games (Morbey et al., 2015). In effort to meet the public health needs of the games' international visitors, the HPA's Real-Time Syndromic Surveillance Team (ReSST) created two freshly designed nationwide networks (Morbey et al., 2015).

The General Practitioner out-of-hours and unscheduled care syndromic surveillance system (GPOOHSS) and the Emergency Department syndromic surveillance system (EDSSS) were formed to serve as the main data collection instruments for the team (Morbey et al., 2015). The rationale supporting the establishment of these new systems was that individuals who were new to the area would likely seek care in an emergency department or urgent care setting, opposed to scheduling a visit with a general practitioner (Morbey et al., 2015). Results of the study showed that during the Olympic

competition no critical health-related injuries or illnesses occurred (Morbey et al., 2015). Investigators noted that the opportunity to regularly inform the public that no major health crises were detected, was a major benefit of the study (Morbey et al., 2015). Additionally, providing quantitative evidence to pacify patron safety concerns was identified as a key function of the ReSST syndromic surveillance systems (Morbey et al., 2015). Studies conducted during the 2015 Pan American Games and 2015 Special Olympics World Games, used similar approaches (van Dijk, Dawson, Moore, & Belanger, 2017; Kajita, Luarca, Wu, Hwang, & Mascola, 2017).

The preceding passages of this chapter form a synopsis of the import of ED-based syndromic surveillance as an enduring component of the U.S. public health system. Each of the studies, reviewed in this survey of literature, serve as an impetus for the adoption and implementation of syndromic surveillance within public health and healthcare systems across the globe. Whether used for traditional infectious disease surveillance or more ancillary purposes, emergency department-based syndromic surveillance systems have been firmly established, and stakeholders need only to be informed of their unique capabilities. One particular public health phenomenon, that may be mitigated by ED-based syndromic surveillance initiatives, is emergency department crowding.

The Scope of Emergency Department Crowding in the United States

In the United States, ED crowding is considered one of the foremost threats to optimal functioning within the emergency care system (Moskop et al., 2018). The most widely accepted definition of crowding describes a condition in which the availability of ED resources is inadequate in comparison to the strenuous patient demand (American

College of Emergency Physicians, 2013). In its landmark 2007 report, the Institute of Medicine stressed the identification of causes, effects, and solutions to ED crowding as a leading priority for the U.S. healthcare system.

Over the years, numerous studies have sought to unveil the exact causes of ED crowding, many of which recognizing systemic inefficiencies as a key contributor (Moskop et al., 2018). When considering direct impact on patient health and wellbeing, ED crowding has been linked to increased risk of mortality, delays in accurate assessment and treatment, and an overall reduction in quality of care (Morley, Unwin, Peterson, Stankovich, & Kinsman, 2018). Alarmingly, research has also revealed that the economic tolls of ED crowding have nearly as much of an impact on the administration of reputable care as the operational impediments. Crowding in the ED setting has been found to increase expenses for care seekers, while simultaneously decreasing profitability for healthcare organizations (Sun et al., 2013; Salway, Valenzuela, Shoenberger, Mallon, & Viccellio, 2017). The difficulties associated with the sustained overburden of ED capacity has led public health, and healthcare organizations, to identify crowding as a genuine public health conundrum (Yarmohammadian, Rezaei, Haghshenas, & Tavakoli, 2017). Moreover, ED crowding's recognized hindrance to the satisfactory delivery of health services goes highly noticed, but frequently unresolved (Moskop et al., 2018).

Known solutions aimed at reducing the occurrence of ED crowding include a wide range of techniques spanning from social interventions to more policy-based approaches (Morley et al., 2018). The following segment of this chapter briefly discusses a well-researched strategy of controlling ED crowding, ambulance diversion. Particularly,

we reviewed Maryland's preeminent ambulance diversion system, along with the role it plays within the state's public health surveillance initiatives.

Ambulance Diversion and the County Hospital Alert Tracking System

Ambulance diversion is commonly used as both an indicator of, and solution to, emergency department crowding (Geiderman, Marco, Moskop, Adams, & Derse, 2015). Ambulance diversion protocols temporarily require ambulances destined for one facility to be reconducted to another facility, in accordance with guidelines that are normally set by a governing emergency medical services (EMS) system (Geiderman et al., 2015). In the state of Maryland, the Maryland Institute of Emergency Medical Services System (MIEMSS) manages all facets of county and regional EMS systems (Maryland Institute of Emergency Medical Services System [MIEMSS], 2018a). One of the premier undertakings of the MIEMSS is its continuous employment of the highly efficient ambulance diversion system, CHATS.

The County Hospital Alert Tracking System (CHATS) works around the clock to provide a real-time listing of custom alerts, signifying present availability of medical services and resources (MIEMSS, 2017a). Similar to most EMS alert systems, CHATS incorporates a customized demarcation of its alert codes. Each unique alarm is accompanied by a working definition, and a host of conditional stipulations (MIEMSS, 2005). The CHATS Yellow Alert, representative of ED overcrowding, is the most commonly used alert-type amongst all facilities in the MIEMSS (MIEMSS, 2017a). This allows the system to effectively contribute to the alleviation of ED crowding, through its reliable ambulance diversion signaling (MIEMSS, 2017b). Including Yellow Alerts, the County Hospital

Alert Tracking System functions using six different alert-types, each of which are thus explained:

Yellow Alert: A Yellow Alert is instituted when a facility's emergency department is undergoing an overwhelming demand for services, such that some care-seekers may not be handled safely. The Yellow Alert signifies that "the ED temporarily requests that it receive absolutely no patients needing urgent medical care" (MIEMSS, 2018a). Yellow Alert statuses are confirmed every two hours and may only last for a total of eight hours within a twenty-four-hour period. This twenty-four-hour period begins and ends at 12 a.m. midnight each day (MIEMSS, 2005).

Red Alert: A Red Alert is instituted when a hospital has no ECG monitored beds available for use, throughout the entire facility (MIEMSS, 2018a).

Reroute: A Reroute Alert is instituted when an advanced life support (ALS) or basic life support (BLS) unit has to be retained in the hospital ED, because there are no available beds. The Reroute Alert does not replace or interfere with a Yellow Alert (MIEMSS, 2018a).

Trauma Bypass: A Trauma Bypass Alert is instituted when a facility's capacity to operate as a trauma center has been depleted (MIEMSS, 2018a).

Mini Disaster: A Mini Disaster Alert is instituted when a hospital's emergency department conveys that their ward has temporarily ceased operation, and are unable to service any patients, due to an extreme condition such as a terrorist threat, power-failure, flooding, etc. (MIEMSS, 2018a).

Blue Alert: A Blue Alert is instituted when a regional EMS system is temporarily overloaded, impairing its ability to provide prehospital care and emergency medical transport. The alert is issued during times of severe conditions, such as flooding, heavy icing and/or snow, and additional extreme situations that may result in an excessive demand for ambulance services. Initiation of a Blue Alert triggers a provisional suspension of both Red Alerts and Yellow Alerts (MIEMSS, 2005).

It is also worth noting that CHATS Yellow Alert data are encompassed as a salient indicator in the Maryland Department of Health's syndromic surveillance programs (MIEMSS, 2017a). Public health practitioners, along with medical professionals, closely monitor Yellow Alerts to support readiness for timely response, as well as to identify historical trends (MIEMSS, 2017a). These consistent tracking efforts, paired with facilities' standard mitigation protocols for ED overload, work to assure systemwide availability of essential medical services (MIEMSS, 2017a). The primary outcome variable of this dissertation research study, EDCrowding, was constructed using Yellow Alert data extracted from the CHATS archive.

Gap Analysis

Upper-level decision makers have called for an increased focus on investigating, and refining, emerging methods of public health surveillance (Savel & FoldyAQ, 2012). Over the past decade, practitioners have begun to diversify their management of ED-based syndromic surveillance systems, to address a cadre of critical health concerns (CDC, 2017a). As modern surveillance architectures have harnessed a gamut of

unconventional tactics, and continue to evolve, it is not unreasonable to assume that ED-based syndromic surveillance systems could possibly serve as an effective approach to alleviating ED crowding. Though standard emergency department operations have been found to safeguard and bolster the capacity of public health surveillance processes, a sweeping search of the premier scientific research databases failed to identify any studies demonstrating the use of ED-based surveillance systems to address the known challenges associated with daily ED utilization (IOM, 2007). In fact, a significant portion of the publications demonstrating the utility of ED-based syndromic surveillance systems are primarily centered on the early detection and identification of infectious diseases, and these same studies have little to no mention of the functional status of the environments in which they operate. As no studies seeking to utilize ED-based syndromic surveillance systems for the detection or prevention of emergency department crowding currently exist, this dissertation research adds to the body of knowledge surrounding non-traditional uses of syndromic surveillance data, while exploring a plausible method of mitigating one of the premier public health challenges of the 21st century.

Research Question

Can ED utilization data collected and forecasted by the ESSENCE syndromic surveillance system, serve as an early indicator of emergency department crowding? This research probed the association between ED utilization trends captured and forecasted by the ESSENCE syndromic surveillance system and the reporting of hospital ED crowding, as indicated by the CHATS ambulance diversion system. Key questions to be addressed include:

1. Is there an association between reported ED crowding and days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE?
    a. Does this association vary based on facility size?
    b. Does this association vary based on year of observation?
    c. Does this association vary based on the combination of facility size and year of observation?
2. Do the odds of reported ED crowding increase on days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE?
    a. Does this increase in odds vary based on facility size?
    b. Does this increase in odds vary based on year of observation?
    c. Does this increase in odds vary based on the combination of facility size and year of observation?

Chapter 3: Methods

The following section describes, in detail, the research methodology of this dissertation study. Guided by the conceptual model of emergency department crowding, this investigative inquiry was fashioned as a retrospective, secondary data analysis. Pre-existing data extracted from the ESSENCE syndromic surveillance system and the CHATS ambulance diversion system, were cross-classified to test the principal hypotheses of this study.

Research Hypotheses

The hypothesized outcomes for each of the research questions were as follows:

$H1_A$: There is an association between reported ED crowding and days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE.

$H1_{A_a}$: The hypothesized association between ED crowding and days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE does not vary based on facility size.

$H1_{A_b}$: The hypothesized association between ED crowding and days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE does not vary based on year of observation.

$H1_{A_c}$: The hypothesized association between ED crowding and days when actual utilization counts surpass the expected utilization counts forecasted by ESSENCE does not vary based on the combination of facility size and year of observation.

$H2_A$: On days when actual ED utilization counts surpass the expected utilization counts forecasted by the ESSENCE syndromic surveillance system, hospitals will have increased odds of reporting ED crowding.

$H2_{A_a}$: The hypothesized increase in odds of reporting ED crowding on days when actual ED utilization counts surpass the expected utilization counts forecasted by the ESSENCE syndromic surveillance system does not vary based on facility size.

$H2_{A_b}$: The hypothesized increase in odds of reporting ED crowding on days when actual ED utilization counts surpass the expected utilization counts forecasted by the ESSENCE syndromic surveillance system does not vary based on year of observation.

$H2_{A_c}$: The hypothesized increase in odds of reporting ED crowding on days when actual ED utilization counts surpass the expected utilization counts forecasted by the ESSENCE syndromic surveillance system does not vary based on the combination of facility size and year of observation.

Study Design and Data Collection

In this scientific exploration, a secondary data analysis approach was employed due to its ability to properly answer the postulated research questions. Analyses were stratified by facility size, year of observation, and a combination of the two factors. Data used to drive this study's analysis were extracted from the ESSENCE and CHATS surveillance system archives. Like most ED-based syndromic surveillance systems, ESSENCE operates using chief complaint data, derived from patrons seeking care in hospital emergency departments (Lombardo, 2003a). During daily operations, ESSENCE functions following a protocol similar to the following example: Patient A visits the

emergency department due to suffering from a “runny nose and fever”. At the initial point of contact, their reason for visit, or chief complaint, is entered into the ESSENCE system by the intake personnel. These data, once entered into the local system, travels to the ESSENCE regional archive (Lombardo et al., 2004).

Upon reaching the regional archive, ESSENCE then incorporates a unique parsing process to match the patients’ ailment to the most appropriate syndrome category (Lombardo et al., 2004). This grouping procedure takes into consideration the combination of keywords that are included in the reported symptoms of the chief complaint (Lombardo et al., 2004). In this particular scenario, “runny nose and fever” is likely to be flagged by the ESSENCE system as one case of “Influenza Like Illness”. Influenza Like Illness (ILI) is one of the standardized syndrome categories used in ED-based syndromic surveillance systems around the globe (Rosenkotter et al., 2013). Lastly, all data collected and processed through the ESSENCE system are made available to public health and healthcare personnel through a secure website linked to the central archives (Lombardo et al., 2004).

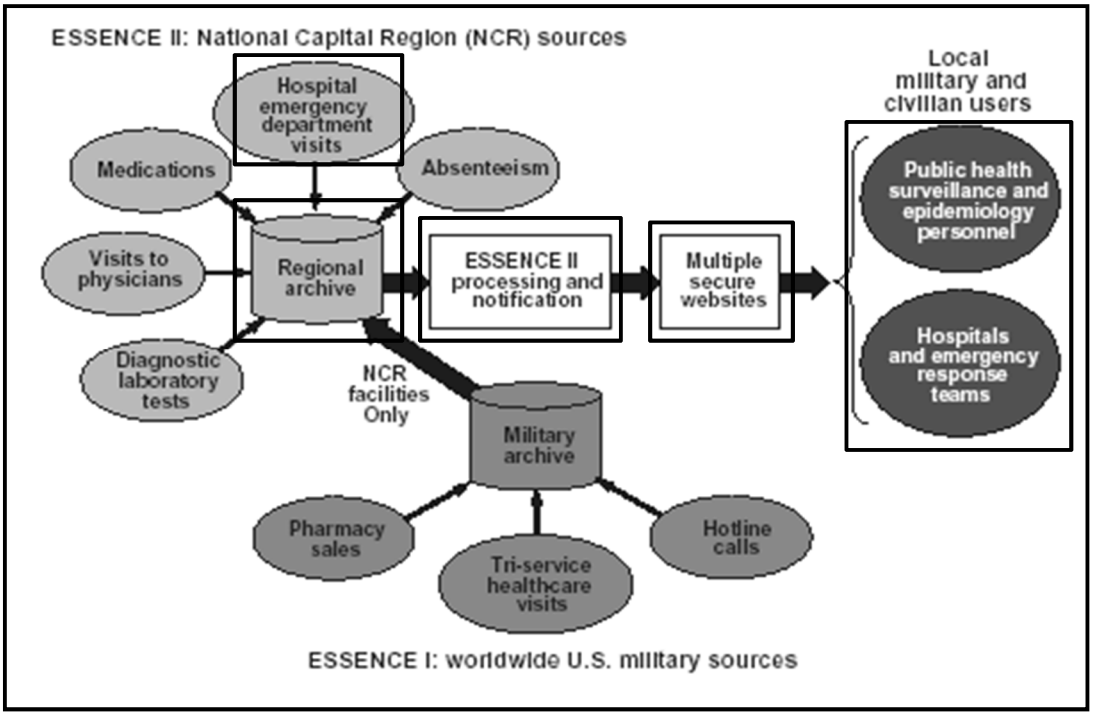

Figure 2. Data sources for the Electronic Surveillance System for the Early Notification of Community-Based Epidemics (ESSENCE). Adapted from "ESSENCE II and the Framework for Evaluating Syndromic Surveillance Systems," by Lombardo, J.S., Burkom, H., and Pavlin, J., 2004, *Morbidity and Mortality Weekly Report*, *53(Suppl)*, p.160.

Each day, ESSENCE's novel surveillance process is implemented for a multitude of care-seeking patients (Figure 2). Amidst monitoring the frequency of ailments presented in hospital emergency departments, ESSENCE consequently catalogs daily ED utilization counts, for each of its host facilities (Lombardo et al., 2004). Additionally, ESSENCE routinely produces an expected daily utilization count, based on an auto-regressive forecast built from the previous four weeks of reported utilization (Lombardo et al., 2004). This algorithm, known as the exponentially weighted moving average (EWMA) technique, has been cited to produce "low false alarm rates for both large and small daily counts" (Lombardo, 2003a, p. 38). Furthermore, this offshoot functionally

empowers ESSENCE to readily engineer a predictive analysis of utilization trends, that may possibly contribute to disfunction within EMS systems, such as ED crowding.

The CHATS Yellow Alert, signifying ED crowding, is declared on or off at the discretion of the facility's lead administrator (MIEMSS, 2005). The official reporting of the alert is made by the facility manager to the emergency medical resource center (EMRC), as a part of the MIEMSS' statewide communications system (MIEMSS, 2005). Based on this dispatched information, participating hospitals' operational status is updated every 60 seconds, and disseminated as a part of the CHATS live dashboard (MIEMSS, 2018a). All emergency department Yellow Alert recurrences are overseen at state, regional, and facility-specific levels, by virtue of this 24-hour web-based console (MIEMSS, 2017b).

CHATS supports a number of surveillance activities, including maintaining a catalog of archived alert data, dating back to 2008 (MIEMSS, 2017b; MIEMSS, 2018a). Scheduled updates to the archive are conducted regularly, and the information is made available for public consumption through the MIEMSS' central website (MIEMSS, 2018a). Researchers, practitioners, and laypersons may visit the site to generate customized reports, using a host of optional search criteria (MIEMSS, 2018a). The primary outcome variable of this dissertation research study, EDCrowding, was constructed using Yellow Alert data extracted from the CHATS archive.

As the data sets required for this investigation consisted of pre-existing records, no primary data collection activities were mandated. Advanced customized queries of the ESSENCE and CHATS archives were implemented on behalf of the investigator, to

procure the desired ED utilization and ambulance diversion records. The resulting CSV files were then imported into the STATA/IC v15 program by the lead investigator, where the data were prepared to undergo a series of statistical analyses.

Study Sample

The population from which this study sample was drawn is all hospital emergency departments, operating in the Baltimore City, Maryland. Analytic procedures of this dissertation study necessitated that to qualify for inclusion, hospitals must have fully reported ED utilization to the ESSENCE syndromic surveillance system, between the years of 2015-2017. Moreover, these same entities must have concurrently initiated "Yellow Alert" ED crowding protocols through the CHATS ambulance diversion system. Institutions that met the outlined inclusion criteria comprised the pool of facilities sanctioned for participation.

In the following stages of the participant selection process, the investigator was provided a convenience sample of three eligible Baltimore City hospitals. This technique was leveraged for ease of access to a sample of hospital EDs that met each of the study's eligibility requirements (Hulley, Newman, & Cummings, 2007). Incurred restrictions to obtaining protected ED utilization data required that the actual selection of the facilities be completed by expert staff, from the local health department. Serving as a blinding mechanism, imposed on the investigator, this external sample selection process was incorporated to protect the anonymity of the participating facilities. The masking of the facilities was necessary for the study to meet all facets of the data usage agreements;

however, this provision contributed to several research limitations. The exact limitations of this study are discussed in the culminating chapter of the manuscript.

No specified facility characteristics were included in the authorized data sets, other than facility size. Classified as small, medium, and large, these categorizations were assigned by the local health department staff who conducted the facility selection process. The actual cutoff criteria, used by these experts, were also masked from the investigator. Upon receipt of the study data, a preliminary univariate analysis revealed the following information. The small facility had a mean utilization of 53 patients per day, with a range of 0 to 87. The medium facility had a mean utilization of 147 patients per day, with a range of 0 to 203. Lastly, the large facility had a mean utilization of 269 patients per day, with a range of 0 to 375.

In the final stages of preparing the sampled data sets, ED utilization and ambulance diversion statistics, from 2015-2017, were cross-classified for an examination of the association between these two recognized constructs of ED crowding. The unit of analysis for this research study was ED utilization in Baltimore City. The unit of observation is one day (24 hours) of ED utilization, beginning at 12am.

Sample Size Calculation

The required sample size for this study was 221 days of observed emergency department utilization. This number includes 132 days of observation from Population 1, and 89 days of observation from Population 2. Population 1 represented days on which actual hospital emergency department utilization exceeded the expected utilization counts forecasted by the ESSENCE syndromic surveillance system. Population 2 represented

days on which actual hospital emergency department utilization did not exceed the expected utilization counts forecasted by the ESSENCE syndromic surveillance system. Estimated sample size was calculated at standard levels of significance (.05) and statistical power (.8), using the STATA statistical software package. Furthermore, hypothesized proportions of the outcome variable, EDCrowding, were projected based on the researcher's review of published literature on the subject matter.

The sampled data for this analysis were comprised of 3288 days of ED utilization occurring from 2015-2017, at three Baltimore City hospitals. For each individual facility, there were 365 days of ED utilization occurring in 2015, 366 days of ED utilization occurring in 2016 (leap year), and 365 days occurring 2017. In total there were 1096 days of ED utilization extracted from each of the sampled facilities, yielding a grand total of 3288 days of observation.

Variable Definitions

EDCrowding, the primary outcome variable, was constructed from ambulance diversion data obtained from the County Hospital Alert Tracking System (CHATS). According to alert descriptions, delineated on the CHATS' website, "a Yellow Alert is initiated because the emergency department is experiencing a temporary overwhelming overload such that some patients may not be managed safely, at which time the emergency department temporarily requests that it receive absolutely no patients in need of urgent medical care" (MIEMSS, 2018b). For the purpose of this study EDCrowding for a given facility was represented by the occurrence of a Yellow Alert within a 24-hour reporting period. The EDCrowding variable was coded dichotomously.

AboveExpected, the main predictor variable of this study, was constructed from two forms of ED utilization counts obtained from ESSENCE query reports. This investigator-created variable was crafted as a novel means of utilizing standard ED-based syndromic surveillance data. The structuring of the AboveExpected variable signifies whether actual ED utilization counts recorded by ESSENCE exceeded the expected utilization counts forecasted by ESSENCE's temporal algorithm. Coded dichotomously, each observation under AboveExpected was assigned a value of either 0 "No" or 1 "Yes". Supplementary predictor variables for this investigation included, facility size (size), year of observation (year), month of observation (month), day of observation (day), and the occurrence of an ESSENCE alert in addition to the CHATS Yellow Alert (essencealert).

Data Analysis

In effort to meticulously characterize the association between ED utilization and ED crowding, this examination employed a multilevel analytic model. Specific procedures included a regimen of univariate, bivariate, and multivariate statistical assessments. Most notably, the principal method of analysis used to test this investigation's primary research hypotheses was a multiple predictor logistic regression. Among its many advantages, multivariate regression models possess the ability to account for potential confounders, through statistical adjustment.

Additionally, this study examined the sampled data within various layers of stratification. Stratum included facility size, year of observation, and a combination of the two factors. Featured in this segment of the planned analysis were the chi-square test of

independence, the two-sample test of proportions, the univariate logistic regression, along with the Mantel-Haenszel and Breslow-Day statistical tests. The chi-square test was used to assess whether the primary variables of interest were independent of each other. Additionally, the Cramer's V was encompassed to examine the effect size of the chi-square test results. The two-sample test of proportions served as an additional indicator of the relationship between the two primary variables of interest. More specifically, the test for independent proportions allowed for the actual size of the difference in the proportions of the outcome to be observed. The univariate logistic regressions produced odds ratios for the relationship between ED crowding and the ED utilization trend being analyzed. And lastly, the Mantel-Haenszel test was used to compute a single-point estimate of risk to describe the relationship between ED utilization and ED crowding, across the specified strata. This weighted estimate was reported in the form of a common odds ratio (COR). As a complementary analysis, the Breslow-Day test, for homogeneity of the odds ratios, was used to assess the validity of reporting the weighted risk estimate, produced by the Mantel-Haenszel test. When the findings of the Breslow-Day test are statistically significant, this requires that individual ORs be reported for each level of a given stratum, whereas a statistically insignificant finding lends itself to the validity of reporting a single-point estimate of risk, such as the COR generated by the Mantel-Haenszel test.

Example Statistical Model

Logistic regression models are used to measure the relationship between a categorical outcome variable (DV), and one or more predictor variables (IV). The logistic regression model, in logit form, to test the hypothesis of this proposed research study follows the following format: $\mathbf{logit[pr(Y=1)] = ß_0 + ß_1X_1 + ß_2X_2 \ldots ß_kX_k}$. After plugging in for the specific variables being used in this study, the formula will be $\mathbf{logit[pr(Y=1)] = ß_0 + ß_1(}\boldsymbol{AboveExpected}\mathbf{) + ß_2(}\boldsymbol{Size}\mathbf{)}$. In this format Y denotes *EDCrowding* (0=No, 1=Yes), X_1 represents *AboveExpected* (0=No, 1=Yes), and X_2 represents *Size* (0=small, 1=medium, 2=large). Each predictor variable (X_k) was plugged in with the number corresponding to that variable and the association being examined. For example, the equation $\mathbf{logit[pr(Y=1)] = ß_0 + ß_1(1) + ß_2(2)}$ was used to represent the association between emergency department crowding on days when actual utilization was above expected utilization, at the large sized facility. The ß coefficients, produced in the logistic regression models, further characterized the predictor variables' association with the outcome. Logistic regressions performed in this study also produced odds ratios, which estimated the strength of association between each of the predictor variables and the outcome being studied.

Chapter 4: Results

Outcomes of this investigation were evaluated as a mode of characterizing the association between emergency department crowding and ED utilization trends. Analytic results were communicated through a mixture of tables, graphs, and interpretive writings. The detailed reporting included in this section was restricted to the most salient points. All other atypical discoveries were noted for possible exploration in future research activities. In respect to the investigative premise of this dissertation, the overarching purpose of the following statistical examination was to probe a previously unexplored aptitude of ED-based syndromic surveillance systems.

Emergency Department Crowding: EDCrowding

Amongst the three sampled Baltimore City hospitals, emergency department crowding was reported on 772 (23.48%) of the 3288 days that ED utilization was observed. The observational period in which these data were collected spanned from 2015-2017. When stratified by facility size, the percentages of reported ED crowding for the small, medium, and large facilities were 1.64%, 23.45%, and 45.26%, respectively. These figures demonstrated a relative variation from the mean percentage of 23.48% that was observed in the aggregated analysis. When stratified by year of observation, the percentages of reported ED crowding, from 2015-2017, were 21.74%, 23.95%, and 24.75%. In contrast to the facility stratified results, these figures held relatively constant compared to the mean percentage observed in the aggregated analysis. Lastly, when stratified by facility size and year of observation, the percentages of reported ED crowding were as follows. The small sized facility reported percentages of 2.19%, 1.09%,

and 1.64%, from 2015-2017. The medium sized facility reported percentages of 23.01%, 23.77%, and 23.84%, from 2015-2017. And lastly, the large sized facility reported percentages of 40.00%, 46.99%, and 48.77%, from 2015-2017. From these figures we were able to garner that the highest percentages of ED Crowding occurred at the large and medium sized facilities. Table 2 provides an overview of emergency department frequencies and percentages, stratified by facility size and year of observation.

Table 2

Emergency Department Crowding Frequencies and Percentages: Stratified by Facility Size and Year of Observation

	2015		2016[b]		2017		All Years	
Variable	Freq.	%	Freq.	%	Freq.	%	Freq.	%
EDCrowding (S[a])								
Yes	8	2.19	4	1.09	6	1.64	18	1.64
No	357	97.81	362	98.91	359	98.36	1078	98.36
EDCrowding (M[a])								
Yes	84	23.01	87	23.77	87	23.84	258	23.54
No	281	76.99	279	76.23	278	76.16	838	76.46
EDCrowding (L[a])								
Yes	146	40.00	172	46.99	178	48.77	496	45.26
No	219	60.00	194	53.01	187	51.23	600	54.74
All Facilities								
Yes	238	21.74	263	23.95	271	24.75	772	23.48
No	857	78.26	835	76.05	824	75.25	2516	76.52

Note. Freq. = frequency of days that emergency department utilization was observed; % = percentage of days that emergency department utilization was observed;
[a]n = 1. [b]Denotes one additional day of observation per facility due to leap year.

Actual and Forecasted ED Utilization: AboveExpected

Amongst the three sampled Baltimore City hospitals, actual ED utilization counts surpassed the expected utilization counts forecasted by the ESSENCE system on 1614 (49.09%) of the 3288 days that ED utilization was observed. The observational period in which these data were collected spanned from 2015-2017 (See Table 3). When stratified by facility size, these percentages for the small, medium, and large sized facilities were 49.54%, 49.64%, and 48.08%, respectively. These figures demonstrated relatively little variation from the mean percentage of 49.09% that was observed in the aggregated analysis. When stratified by year of observation, the percentages of actual utilization surpassing the forecasted utilization counts, from 2015-2017, were 48.58%, 48.54%, and 50.14%. Similar to the facility stratified results, these figures demonstrated relatively little variation from the mean percentage observed in the aggregated analysis.

Lastly, when stratified by facility size and year of observation, the percentages of actual utilization surpassing the forecasted utilization frequencies were as follows. The small sized facility reported percentages of 49.32%, 50.00%, and 49.32%, from 2015-2017. The medium sized facility reported percentages of 45.75%, 51.37%, and 51.78%, from 2015-2017. And lastly, the large sized facility reported percentages of 50.68%, 44.26%, and 49.32%, from 2015-2017. Table 3 provides an overview of emergency department utilization trend frequencies and percentages, stratified by facility size and year of observation.

Table 3

Emergency Department Utilization Trend Frequencies and Percentages: Stratified by Facility Size and Year of Observation

	2015		2016[b]		2017		All Years	
Variable	Freq.	%	Freq.	%	Freq.	%	Freq.	%
AboveExp. (S[a])								
Yes	180	49.32	183	50.00	180	49.32	543	49.54
No	185	50.68	183	50.00	185	50.68	553	50.46
AboveExp. (M[a])								
Yes	167	45.75	188	51.37	189	51.78	544	49.64
No	198	54.25	178	48.63	176	48.22	552	50.36
AboveExp. (L[a])								
Yes	185	50.68	162	44.26	180	49.32	527	48.08
No	180	49.32	204	55.74	185	50.68	569	51.92
All Facilities								
Yes	532	48.58	533	48.54	549	50.14	1614	49.09
No	563	51.42	565	51.46	546	49.86	1674	50.91

Note. Freq. = frequency of days that emergency department utilization was observed; % = percentage of days that emergency department utilization was observed;
[a]n = 1. [b]Denotes one additional day of observation per facility due to leap year.

Chi-Square Analyses

According to chi-square test of independence, the main predictor variable was found not to be independent of the primary outcome variable of this study. This was demonstrated by a p-value of less than .001 for the calculated chi-square test statistic, $\chi^2 = 76.17$. However, the Cramer's V ($\Phi = .1522$) for the effects size of the chi-square test indicated that the strength of association between the EDCrowding and AboveExpected research variables was relatively weak. Table 4 displays the results of the chi-square test results from the combined sample. When the study data were stratified by facility size,

the main predictor variable was found not to be independent of the primary outcome variable of this study, at two of the three sampled facilities. For the medium and large sized facilities, this lack of independence was demonstrated by p-values of less than .001 for their respective chi-square test statistics, $\chi^2 = 39.15$ and $\chi^2 = 55.81$. However, the Cramer's V quantifying the effects size of the chi-square tests, at the respective facilities, ($\Phi = .1890$, $\Phi = .2256$) indicated that the strength of these associations was moderate at best. At the small sized facility, the computed chi-square was $\chi^2 = 03.77$. This test statistic had an associated p-value of .052, which indicated that at this facility the two primary variables interest were independent of each other. The calculated Cramer's V ($\Phi = .0586$) further supported the notion that the strength of association between the EDCrowding and AboveExpected research variables, at the small sized facility, was extremely weak.

When stratified by year of observation, the main predictor variable was found not to be independent of the primary outcome variable of this study, each year from 2015-2017. This was demonstrated by p-values of less than .001 for each of their respective chi-square test statistics ($\chi^2 = 16.10$, $\chi^2 = 22.24$, and $\chi^2 = 39.95$). However, the Cramer's V across each year of observation ($\Phi = .1213$, $\Phi = .1423$, and $\Phi = .1910$) indicated that the strength of these associations was relatively weak. Lastly, when the data were stratified by both facility size and year of observation, the results of the chi-square tests were as follows. At the small sized facility, the chi-square test statistics ($\chi^2 = .0015$, $\chi^2 = 4.044$, and $\chi^2 = 2.824$), yielded p-values of .969, .044, and .000. These findings spanned between the years of 2015-2017, respectively. In this same analysis, the Cramer's V

across each year of observation (Φ = .0021, Φ = .1051, and Φ = .0880) indicated a weak strength of association between the primary variables of interest, in addition to the observed variation in statistical significance.

Similarly, the chi-square test of independence at the medium sized facility (χ^2 = .7928, χ^2 = 22.24, and χ^2 = 31.84), produced a mixture of statiscally significant test results. This was indicated by their p-values of .373, .000, and .000, from 2015-2017 respectively. Additionally, the Cramer's V across each year of observation (Φ = .0466, Φ = .1423, and Φ = .2953) indicated that the strength of these associations were relatively weak. Results from the chi-square test of independence at the large sized facility (χ^2 = 24.16, χ^2 = 15.83, and χ^2 = 17.93) were found to be statistically significant. This finding was supported by a p-values of less than .001 for each of the calculated chi-square test statistics. Also, the Cramer's V across each year of observation (Φ = .2573, Φ = .2080, and Φ = .2217) indicated that there was a moderate strength of association between the primary research variables.

Table 4

Crosstabulation of Reported Emergency Department Crowding and Emergency Department Utilization Trends: All Facilities (2015-2017)

	AboveExp.			
EDCrowding	Yes	No	χ^2	Φ
Yes	485	287	76.17*	.1522
No	1,129	1,387		

Note. *= $p \leq .001$

Two-Sample Tests of Proportions

According to the two-sample test of proportions, the proportion of reported ED crowding was significantly higher on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE syndromic surveillance system. This was demonstrated by a p-value of less than .001 for the calculated z test statistic, $z = 8.73$. When the study data were stratified by facility size, the proportion of ED crowding was found to be significantly higher on days when actual utilization counts surpassed the forecasted utilization counts, at two of the three sampled facilities. The p-values of less than .001 for the calculated z test statistics ($z = 6.26$, $z = 7.47$), at the medium and large sized facilities, indicated statistically significant findings. The proportion of ED crowding at the small sized facility was found to be higher on days when actual utilization counts surpassed expected utilization counts forecasted by the ESSENCE system. This was demonstrated by the calculated z test statistic, $z = 1.94$; however, the associated p-value of .052 for this test statistic indicated that the observed difference was not statistically significant. When the study data were stratified by year of observation, the proportion of ED crowding was significantly higher on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE system. This was demonstrated by p-values of less than .001 for each of the calculated z test statistics ($z = 4.01$, $z = 4.72$, and $z = 6.32$), from 2015-2017. Lastly, Table 5 provides the two-sample test of proportion results for the primary variables of interest, when the data were stratified by both facility size and year of observation.

Table 5

Difference in Proportion of Reported Emergency Department Crowding on Days When Actual Utilization Counts Surpassed Expected Utilization

Variable	Prop.	z
AboveExp. (Small, 2015[a])		
Yes	.022	
No	.022	
Diff prop (Yes) – prop (No)	.001	.04*
AboveExp. (Small, 2016[ab])		
Yes	.022	
No	.000	
Diff prop (Yes) – prop (No)	.022	2.01*
AboveExp. (Small, 2017[a])		
Yes	.028	
No	.005	
Diff prop (Yes) – prop (No)	.022	1.68*
AboveExp. (Medium, 2015[a])		
Yes	.251	
No	.212	
Diff prop (Yes) – prop (No)	.039	.89*
AboveExp. (Medium, 2016[ab])		
Yes	.330	
No	.140	
Diff prop (Yes) – prop (No)	.189	4.25*
AboveExp. (Medium, 2017[a])		
Yes	.360	
No	.180	
Diff prop (Yes) – prop (No)	.252	5.64*

(continued)

Table 5 (continued)

Difference in Proportion of Reported Emergency Department Crowding on Days When Actual Utilization Counts Surpassed Expected Utilization

Variable	Prop.	z
AboveExp. (Large, 2015[a])		
Yes	.524	
No	.272	
Diff prop (Yes) – prop (No)	.252	4.92*
AboveExp. (Large, 2016[ab])		
Yes	.586	
No	.377	
Diff prop (Yes) – prop (No)	.209	3.98*
AboveExp. (Large, 2017[a])		
Yes	.600	
No	.378	
Diff prop (Yes) – prop (No)	.222	4.23*

Note. Prop. = proportion of days on which emergency department crowding was reported at a specific facility.; z = percentage of days that emergency department utilization was observed;
[a]n = 1. [b]Denotes one additional day of observation per facility due to leap year.
*= $p \leq .001$

Simple Logistic Regressions

Table 6 illustrates the results from the logistic model of the relationship between the primary research variables. Crude findings showed that the odds of reported ED crowding were 2.076 times higher on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE syndromic surveillance system. This association was found to be statistically significant (OR = 2.076; 95% CI = [1.759,

2.450]). An alternative method of describing this increase in odds is as follows: on days when actual utilization counts surpassed the expected utilization counts, the odds of reported ED crowding increased by 107.6%. This same analysis, when the data were stratified by facility size, yielded slightly different results. At the medium and large sized facilities, the odds of reported ED crowding were significantly higher on days when actual utilization counts surpassed the expected utilization counts (OR = 2.505; 95% CI = [1.870, 3.357] and OR = 2.515; 95% CI = [1.970, 3.211]). However, the observed increase in odds at the small sized facility was not found to be statistically significant (OR = 2.688; 95% CI = [.9518, 7.593]).

Results of the simple logistic regression, when the study data were stratified by year of observation, indicated that the odds of reported ED crowding increased on days when actual utilization counts surpassed the ESSENCE forecasted utilization counts. This relationship was found to be statistically significant for 2015 (OR = 1.811; 95% CI = [1.352, 2.426]), 2016 (OR = 1.965; 95% CI = [1.480, 2.607]), and 2017 (OR = 2.492; 95% CI = [1.869, 3.323]). Lastly, when the study data were stratified by both facility size and year of observation, results of the simple logistic regressions were as follows. At the small sized facility, the odds of ED crowding increased on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE system. Yet, the observed increase in odds were not found to be statistically significant in 2015 (OR = 1.028; 95% CI = [.2533, 4.176]), 2016 (OR = 1; 95% CI = [omitted due to collinearity]), or 2017 (OR = 5.257; 95% CI = [.6081, 45.45]). At the medium sized facility, the odds of reported ED crowding increased on days when actual utilization

counts surpassed the forecasted utilization counts. This observed increase in odds was found to be statistically significant in 2016 (OR = 3.011; 95% CI = [1.789, 5.069]) and 2017 (OR = 4.644; 95% CI = [2.650, 8.139]). Contrarily, the results from 2015 (OR = 1.248; 95% CI = [.7660, 2.033]) were not found to be statistically significant. Lastly, the odds of reported ED crowding, at the large sized facility, increased on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE system. This relationship was found to be statistically significant for 2015 (OR = 2.947; 95% CI = [1.904, 4.562]), 2016 (OR = 2.339; 95% CI = [1.534, 3.566]), and 2017 (OR = 2.464; 95% CI = [1.618, 3.754]).

Table 6

Logistic Model for Odds of Reporting ED Crowding

Variable	OR	95% CI	% Change
AboveExp			
Yes	2.076	[1.759 to 2.450]	107.6%
Constant	0.2069	[.1822 to .2350]	

Note. OR = odds ratio; CI = confidence interval; % Change = percent change in odds of emergency department crowding per unit increase in x.

Mantel-Haenszel and Breslow-Day Tests

When combining the stratified odds ratios, from the small, medium, and large sized facilities, the odds of reported ED crowding increased significantly on days when actual utilization counts surpassed the expected counts forecasted by the ESSENCE system. This observed increase in odds was demonstrated by the computed Mantel-Haenszel Common Odds Ratio (MH-COR = 2.517; 95% CI = [2.093, 3.027]). Moreover, analytic findings from the Breslow-Day Test of Homogeneity (χ^2 = .02; p = .9918)

indicated a homogeneous association between the size specific odds ratios. This conclusion supported the validity of utilizing the weighted MH-COR as a single point estimate of risk, to describe the relationship between the EDCrowding and AboveExpected research variables, across the given stratum (facility size).

When combining the stratified odds ratios, from each year of observation between 2015-2017, the odds of reported ED crowding increased significantly on days when actual utilization counts surpassed the expected counts forecasted by ESSENCE. This observed increase in odds was demonstrated by the computed Mantel-Haenszel Common Odds Ratio (MH-COR = 2.074; 95% CI = [1.757, 2.448]), displayed in Figure 3. Results of the Breslow-Day Test of Homogeneity ($\chi^2 = 2.54$; $p = .2814$) indicated a homogeneous association between the year specific odds ratios, included in this analysis. This conclusion supported the validity of reporting the weighted MH-COR as a single point estimate of risk, to describe the relationship between the EDCrowding and AboveExpected research variables, across the given stratum (year of observation).

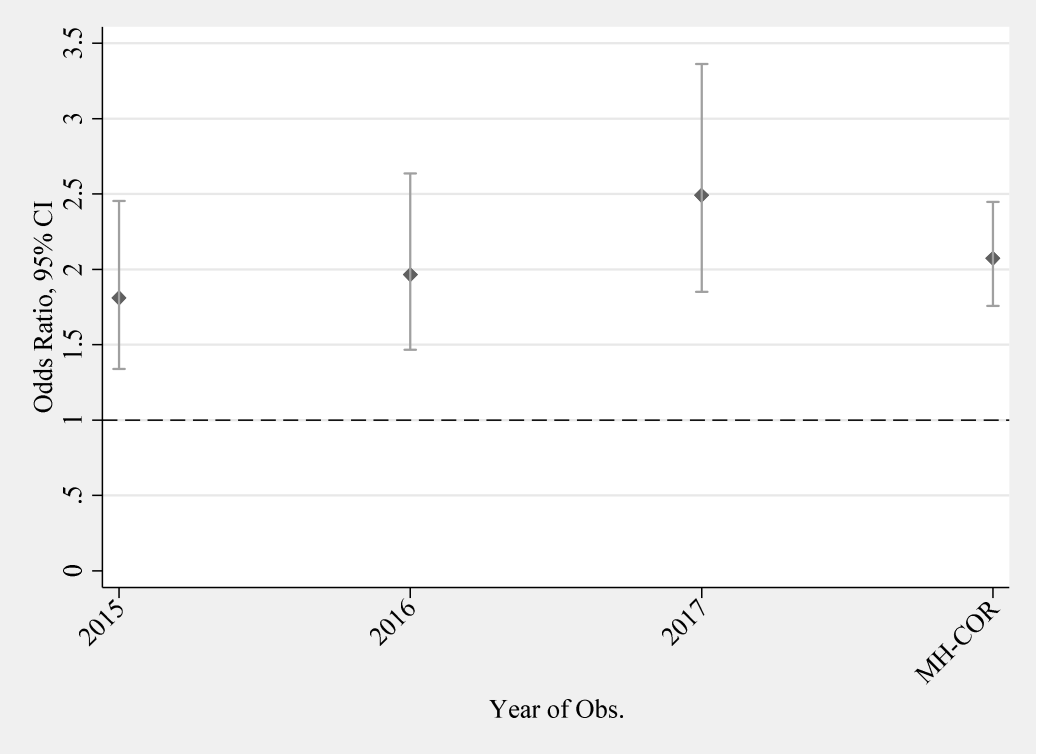

Figure 3 – Mantel-Haenszel Estimator of the Common Odds Ratio by Year

Multiple Logistic Regression

From Table 7 we can see the results of the multiple predictor model for the odds of reported ED crowding. Analytic findings showed that the odds of reported ED crowding were 2.377 times higher on days when actual utilization counts surpassed the expected counts forecasted by the ESSENCE system, holding constant all covariates included in the model. This observed increase in odds was found to be statistically significant (OR = 2.377; 95% CI = [1.954, 2.892]). Covariates factored into this regression model included facility size, year of observation, month of observation, day of observation, and the occurrence of an ESSENCE alert. An alternative method of describing the increase in odds revealed through this analysis is as follows: on days when

actual utilization counts surpassed the expected utilization counts, the odds of reported ED crowding increased by 137.7%, when adjusting for facility size, year of observation, and ESSENCE alerts.

Table 7

Multiple Logistic Model for Odds of Reporting ED Crowding

Variable	OR	95% CI	*p*
AboveExp			
Yes	2.076	[1.759 to 2.450]	≤ .001
Facility Size			
Small		Reference	
Medium	20.36	[12.46 to 33.26]	≤ .001
Large	58.91	[36.21 to 95.85]	≤ .001
Year of Obs.			
2015		Reference	
2016	1.195	[.9521 to 1.499]	.125
2017	1.219	[.9717 to 1.529]	.087
ESSENCE Alert			
Yes	1.657	[1.155 to 2.376]	.006
Constant	0.2069	[.1822 to .2350]	≤ .001

Note. Month of observation and day of observation variables excluded from table.
OR = odds ratio; CI = confidence interval;

Interpretation of Analytic Findings

In reviewing the results from the univariate analysis of the primary outcome variable of this study, we found that ED crowding occurred regularly, in the combined sample. On average, nearly one out of every four days of operation a facility could expect to report an episode of ED crowding. These figures did however slightly deviate in the results of the stratified analyses. The variation in ED crowding frequencies and percentages, whenever the study data were stratified by facility, showed the impact that the individual facility characteristics may have had on the frequency of hospital EDs experiencing ED crowding. One paramount example of a key facility characteristic that seemed to play a critical role in the frequency of reported ED crowding in this analysis is facility size. This notion is also supported by the lack of variation in ED crowding frequencies and percentages, when the study data were stratified by year of observation. Additionally, more specifics regarding the known facility characteristics may be needed to fully understand factors the contributed to the observed frequency of ED crowding.

Examination of the primary predictor variable revealed that actual ED utilization counts surpassed the expected utilization counts roughly every other day of operation. This finding was true in the analysis of the combined sample, as well as the analyses across all levels of stratification. In interpreting these results, one important factor to consider is the process by which ESSENCE produces its forecasts of expected ED utilization. For each hospital ED, the expected utilization count is generated based on a sophisticated algorithm that takes into consideration the previous 28 days of actual ED utilization. This means that because the forecasts are specific to each facility, the

individual facility characteristics, such as facility size, are already being controlled for in ESSENCE's statistical model. Unlike the AboveExpected variable which was constructed using data from the ESSENCE system, the EDCrowding variable was constructed using data from the County Hospital Alert Tracking System. CHATS alerts are declared on or off at the discretion of the individual facility managers which may be one of the contributing factors to the variation seen in the frequency of ED crowding at the facility level. CHATS data, unlike the data extracted from the ESSENCE syndromic surveillance system, are not equipped with any statistical adjustments, and seems to be fairly dependent on individual facility protocols.

Strength of Relationship Between The Primary Variables of Interest

Statistical tests assessing the relationship between the primary study variables indicated that the proportion of ED crowding was higher on days when actual utilization counts surpassed the expected utilization counts forecasted by the ESSENCE system. As these results were found to be statistically significant, additional analytic probing revealed that though there was an association between the variables, the strength of that association was relatively weak. This lack of a strong correlation between the variables was observed in the combined and stratified analyses, ultimately signifying that there may have been significant determinants that led to the reporting of ED crowding to the CHATS system, other than utilization trends.

Odds ratios extracted from the simple logistic regressions indicated that on days when actual counts surpassed the expected utilization counts produced by ESSENCE, hospitals did in fact have increased odds of reporting ED crowding. Results were found

to be statistically significant in the combined analysis, as well as in a majority of the stratified analyses. The Mantel-Haenszel Common Odds Ratio was computed to produce a properly weighted single point estimate of risk across the various levels of stratification, incorporated in the analytic plan. When proper weights were taken into consideration the odds of ED crowding were still found to increase significantly on days when actual counts surpassed the expected counts.

The final method of statistical adjustment included in this study's analysis was incorporated through the multivariate logistic regression. Similar to the manner in which the MCH-COR was able to apply proper analytic weights across a single level of stratification, the multiple logistic regression was able to produce an odds ratio that adjusted for a variety of factors that may have had a significant influence on the relationship between the primary variables of interest. By controlling for a host of covariates, the multiple logistic regression was able to produce a more accurate representation of the association being examined. This specific analytic method was not only used to test the primary hypothesis of the study, but it also produced one of the most interesting findings included in the analysis.

Results of the multiple logistic regression showed that the odds of ED crowding did in fact increase on days when actual counts surpassed the expected utilization counts when controlling for facility size, year of observation, and several other keys variables. An equally, if not more, interesting finding of this same analysis was that when holding constant all covariates included in the model, the odds of reporting ED crowding were 59 times higher for the large sized facility, compared to the odds of reporting ED crowding

at the small sized facility. From this statistic when can see a consistency in the observed impact that individual facility characteristics may have had in our analyses. We say individual facility characteristics instead of facility size because the other characteristics of the facilities are unknown to the researcher. These may include whether the institutions are public or private, their accepted methods of payment, staffing schedules, and a host of other factors that may impact optimal functioning in the respective EDs.

Chapter 5: Discussion

This study's statistical examination suggests that ED utilization data, collected and forecasted by the ESSENCE syndromic surveillance system, may be able to serve as an early indicator of emergency department crowding. The increased odds observed in the multiple logistic regression supports our primary research hypothesis and warrants further exploration into the matter. When seeking to assess the utility of ED-based syndromic surveillance data as an early indicator of ED crowding the findings from this dissertation can be of great use. One prime example would be to consider using a method similar to the one modeled in this study in the creation of a gauge or meter for "heightened awareness" or increased risk. This concept, along with other practical and theoretical implications of this work, is discussed in greater detail in the following passages.

Practical and Theoretical Implications

This dissertation study serves as an impetus for further research probing the creation of a custom syndrome category that can be incorporated into the ESSENCE system, for the early detection of ED crowding. The pilot study structure of this examination was tailored for its use as a foundational piece, to drive a series of studies to follow. The ultimate goal being the development as a standardized mechanism for capacity management, within the ED setting. In the featured analysis, the increased odds of ED crowding were softly linked to the AboveExpected variable. The actual data used to create the AboveExpected variable have the ability to be constructed in a way that allows the information to be wielded in more advance statistical and mathematical

models, such as those that emphasize prediction and forecasting. For example, the difference between actual and expected counts being either positive or negative, allowed for the creation of the binary AboveExpected variable. Were this difference in utilization counts simply used as a continuous variable, it could possibly be implemented in an ARIMA forecasting model, or possibly examined at various cutoff points that indicated levels of severity in the odds. Considering these realities, it is not unreasonable to assume that the same difference in utilization data produced and recorded by the ESSENCE system could be molded for effective use within ESSENCE's very own forecasting models.

As stated in the earlier in this manuscript, there is dire need to increase the amount of scientific research studies that probe the expanded utilities of syndromic surveillance systems. As surveillance methods continue to evolve, more empirical studies demonstrating the novel used of syndromic surveillance data could increase the notoriety and recognized values of these existing systems. An increased understanding and acknowledgment of the many capabilities that these systems possess could easily result in the development of innovative solutions to a great number of challenges within the healthcare and healthcare worlds, through both individual practitioners and larger organizational efforts. For example, currently the expansion of the CDC's National Syndromic Surveillance Program, and its onboarding of thousands of facilities across the country creates a very ripe atmosphere for syndromic surveillance usage to drastically increase in the years to come. The NSSP has an active Community of Practice led by some of the most cutting-edge practitioners and researchers in existence. Within this

nation-wide congregation of syndromic surveillance enthusiast, many new techniques are regularly shared and exchanged amongst the group, including custom syndrome categories.

Value To Public Health and Healthcare Institutions

The potential benefits of this dissertation research to both public health and healthcare institutions are numerous; however, in order to cultivate the desired returns, there must be continued investments on behalf of all stakeholders seeking to benefit from the concept being modeled in this study. The most urgent need is an extensive amount of fine-tuning applied to this study's current analytic methods, by the principle investigator. Secondly, in support of this ongoing research initiative the investigator should pursue the formation of a collaborative agreement, which would begin by engaging leadership within the core public health institutions, as well as upper-level decision makers in the healthcare sector. Such an agreement would support a series of studies, guided by an iterative process, that resulted in constant improvements to our nation's current mechanisms of detecting and reporting ED crowding. In time, the final product could heavily influence the way ESSENCE is used by health departments to inform and impact operational efficiency within hospital emergency departments locally in Baltimore City, throughout the state of Maryland, and across the nation.

For example, local syndromic surveillance practitioners may opt to phone into facilities, being monitored within their jurisdiction, during both emergent and non-emergent situations. These provisional calls could be used to offer various support services when the ED crowding syndrome indicator appears to be trending towards an

increased odds of a particular facility reporting crowding. The same provisional call could also serve to advise the facility manager's decision-making process, on whether or not to declare Yellow Alert crowding status to the CHATS system. These types of proactive solutions would be of great use in efforts to extract the greatest utility from the thousands of ED-based syndromic surveillance systems operating in the United States.

Another major benefit that this study provides to healthcare institutions is a platform to catalyze increased profitability and sustainability from an economic standpoint. When considering the negative economic impact that ED crowding has been proven to have on healthcare facilities, many local and statewide hospital associations may be interested in being presented with more detailed information about pragmatic solutions to the costly problem. A major selling point for the concept presented in this study is the high probability that the association members currently own and operate ED-based syndromic surveillance systems on a daily basis. This means that little to no expenditures would be incurred to implement a viable cost-saving measure. A reduction in occurrences of ED crowding, using the proposed methods, would save the member institutions money from avoiding the implementation of more expensive mitigation options.

Furthermore, member institutions could expect enlarged financial compensations from the additional volume of care seekers being serviced via optimal functioning unhindered by ED crowding. Research has shown that each patient who walks out of the ED without being treated equates to nearly $800 in lost revenue (Salway, 2017). In addition to the aforementioned financial incentives, further cost savings could result from

the restructuring of their current ED capacity management practices. This could be accomplished by incorporating syndromic surveillance data in the development of strategic plans and protocols, that optimize staffing schedules according to utilization trends. Within the MIEMSS, staffing shortages were identified a primary contributor to crowding in the ED setting (MIESS, 2017b).

Results from this study could also support the procurement of funds designed to bolster the efficacy within public health and healthcare systems. Federal legislation, such and the HITECH act, incentivize the use of electronic health records, syndromic surveillance systems, and other health-related technologies in U.S. hospitals (Lenert, 2012). Thus, reimbursements obtained from the HITECT act would offset any financial expenditures the hospital association members would suffer by adopting the recommended upgrades, suggested by the primary investigator of this study. Ideally, these funds would be leveraged as a cost-free avenue of equipping any subsidiary establishments, governed by the association, with the ESSENCE system. Upon informing major stakeholders of these spectrum-wide advantages, the formation of a meaningful partnership agreement is a realistic goal of this study's dissemination plan. As leadership in the public health and healthcare fields continue to work towards systemic improvements, the benefits that could be realized through the novel concept modeled in this study is an endeavor well worth the sought-after investment.

Community Health and Underserved Populations

The concept modeled in this manuscript has posited many potential upsides, but at its core the slated investigative agenda commands an intensified recognition of ESSENCE's ability to improve health outcomes on a broader scale. As this particular examination touts ESSENCE's functional adroitness within hospital emergency departments, forthcoming studies may seek to probe the system's efficacy in an assortment of healthcare settings. In acknowledging that hospitals represent only one avenue of obtaining healthcare, for millions of citizens living in our nation, such a consideration must be factored into future research agendas. Bearing this in mind, there are several aspects of this dissertation document that support the adoption of ESSENCE within smaller community-based facilities.

In recent years, ambulatory treatment centers, such as urgent care and community health clinics, have gained substantial notoriety. If the need for public health and healthcare services in our nation continues to rise, historic trends suggest that these alternatives to mainstream medical establishments will inevitably be confronted with accommodating a higher volume of care seekers. Subsequently, capacity management issues, such as crowding, may become more prevalent as the demand for care begins to surmount the availability of healthcare resources. Though hospitals have struggled with ED crowding for decades, these smaller community-based medical centers may be able to address this looming concern with greater effectiveness, by being proactive and incorporating ESSENCE into their daily operations. Similar to larger healthcare organizations, federal legislation, such and the HITECH act, could serve as a cost-free

mechanism by which these types of smaller entities could adopt the use of electronic health records and syndromic surveillance systems. Moreover, such facilities would undoubtedly benefit from a direct linkage to the local, state, and federal public health agencies that monitor and analyze the syndromic surveillance data on a consistent basis.

More importantly, if the ESSENCE system operated within urgent care and community health facilities, the real-time data could be used to actively refer patients to more appropriate care options. Ancillary services such as chronic disease management programs, subsidized access to primary care physicians, low-cost oral healthcare plans, affordable housing vouchers, and other need-based resources are essential to achieving optimal health within underserved populations. When left uncontrolled and/or neglected, these underlying factors have been found to promote the improper utilization of emergency medical services (Morley, 2018). Thus, increasing access to adequate treatment outside of the emergency medical setting, would ultimately lead to a reduction in the overwhelming demand for care that causes crowding.

Lastly, a community-based ESSENCE network could be used in a collaborative effort by public health researchers, neighborhood improvement associations, and other altruistic community-based organizations for the identification of priority health needs. A concerted taskforce of this sort could launch an ongoing mission, dedicated to conducting in-depth analyses of healthcare utilization trends, extracted from ESSENCE and other pertinent data sources. By understanding the historical and speculated service needs, a collection of robust community profiles could be constructed within an ambispective framework.

These data-driven community profiles would enable devoted stakeholders to accurately address the overarching health and human service challenges, within specific communities. In effort to expand the scope of this newly formed conglomerate, the community profile database could even be structured as an open-access web-based resource. This would allow the taskforce to reach a larger audience and fuel the development of targeted interventions from a vast assortment of established entities. Any assemblage embodying a vested interest in improving community health outcomes would stand to benefit from the shared analyses. For example, non-profit organizations may be interested in gaining access to the community profiles for the development of philanthropic activities, as a means of maintaining their tax-exempt status. Overall, these strategies exemplify the true purpose of this dissertation research study, which is to promote the reduction of adverse health outcomes through the novel utility of syndromic surveillance data.

Study Limitations

Limitations regarding this study's sampling methods stemmed from regulations associated with patient privacy and protection. The de-identification of the study data led to many of the individual facility characteristics being unknown to the researcher. The actual impact of this constraint on the analytic conclusions was most pronounced in the multivariate analysis. The multiple logistic regression, employed to test the principal hypothesis of the study, was confined to a limited number of control variables. The lack of meaningful covariates included in the model was a direct result of the restricted nature of the study data. As the regression model failed to include a host of factors that could

have heavily influenced the observed relationship between the two primary variables of interest, this deficiency of statistical controls must be taken into consideration when interpreting the statistical results.

An additional limitation associated with this study's sampling methods is the small number of sampled facilities. Though the number of observations included in the primary analysis was exponentially more than required for the desired statistical power, these observations were extracted from three facilities. In lieu of this fact, the external validity of this study was compromised, as well as the ability to generalize analytic findings to all hospital EDs operating in the state of Maryland. This investigation would have benefited from the inclusion of more facilities. The final limitation regarding the study's sampling methods, is the inclusion of only data from Baltimore City. As Baltimore City is a highly populated metropolitan area, this may hamper the ability to generalize the analytic findings other environmental and community settings. Both the ESSENCE and CHATS systems operate state-wide, allowing for the inclusion of facilities from urban, suburban, and rural areas alike. However, failing to include any facilities to represent these additional operational settings is an issue to be addressed in future investigations.

Inconsistencies in the data source used to construct the primary outcome variable was another identified limitation of this study. CHATS Yellow Alerts have no official protocol by which the reporting is based upon; therefore, this lack of uniformity unquestionably influences variations in the observed frequencies of ED crowding across facilities. Yellow Alerts, signifying ED crowding, are reported to the CHATS system at

the discretion of the facility managers. As "ED Crowding" is based on an individual's perception of current operational conditions, this deems the CHATS Yellow Alerts an unreliable indicator of the true functional status hospital EDs (MIESS, 2017b). A less noticeable limitation of this study is that in assessing the relationship between utilization trends and the reporting of ED crowding, the investigator fails to acknowledge that utilization is only a single factor contributing to the occurrence ED crowding. Known causes of ED crowding are much more complex, and include issues such as the low-acuity of care seekers, inadequate services administered outside of ED, and other systemic impediments (Morley, 2018).

Future Research

In effort to improve upon the identified limitations, future research agendas should seek to replicate this study using a large nation-wide sample. In using a nation-wide sample, future investigations would be able to strengthen the external validity the current study. Though data use restrictions may pose a challenge for independent researchers, the proposed endeavor could be achieved through initiating a partnership with the CDC's National Syndromic Surveillance Program. Working in collaboration with the NSSP would not only allow open access to ESSENCE data from thousands of facilities across the country, but it would also bypass many obstructions associated with data use agreements. The only lingering concern would be the need to establish a standardized indicator of EDCrowding for the newly sampled facilities, as the CHATS Yellow Alert is specific to the state of Maryland.

The next recommendation for future studies would be to incorporate the ESSENCE utilization data used in this investigation into a traditional statistical forecasting model. Using retrospective data, these forecasts could then be verified against actual reported occurrences of ED crowding. This would allow the examination of whether the statistical forecasts were a valid detector of ED crowding, and enable the calibration of the customized "ED Crowding" syndrome category modeled in this study. Additionally, such a study may benefit from the inclusion of permutated variations of the sampled data sets, in effort to replicate a larger sample size. This would bypass the need for additional data use agreements, and also address issues associated with identifying a standardized indicator of ED crowding that would accompany sampling hospitals EDs outside of the state of Maryland.

The final recommendation for future research would be centered on fine-tuning the customized "ED Crowding" syndrome category through multiple trial runs in real-world ED settings. Ideally, this is the desired outcome of the concept modeled in this dissertation study. Real-world application is the only way to truly assess how valuable a custom syndrome category would be to the improvement public health and healthcare practices. As many surveillance practitioners across the country are known to create and share their own customized syndrome categories for use across jurisdictions, collaborating with an organization such as the International Society for Disease Surveillance (ISDS) would create the perfect opportunity to implement this pilot-study across a broad range of facilities. This would allow the investigator to expand the scope of the current research agenda and receive performance measurements from a wider

variety of operational conditions and geographic locations. However, the final recommendation would only serve useful after the investigator has devoted a substantial amount of time into strengthening the current methods demonstrated this study.

The Future of Public Health Surveillance

Syndromic surveillance initiatives have begun and will continue to establish their place within the time-honored foundations of applied epidemiology. Though mainstay surveillance methods have demonstrated the ability to subsist the ever-changing landscape of public health practice in our nation, practitioners' perpetual search for trailblazing resolutions will continue to support the construction of unorthodox surveillance architectures. It is due to this fact that the future of public health surveillance will be characterized by the novel usage of health-related data. This sets the stage for the increased utility of syndromic surveillance systems, such as ESSENCE.

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