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Research Article

# Alert Fatigue and Alert Override Significance in Relation to CDSS Success

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## Abstract

**Introduction/Background/Significance:** Clinical decision support systems (CDSS) use information and communication technologies developed through evidenced-based methodologies such as algorithms and logical regression to provide relevant knowledge and information to providers to assist with the decision making process to support the health care and clinical outcomes of the patient. Common formats of CDSS include alerts and 'pop-up' messages. The overall success of the CDSS depends on five stages. Each stage builds on the previous stage and the lowest two factors impacting success include firing rates and override rates. This literature review seeks to evaluate the relationship between the two factors of alert fatigue and alert overrides to the success of CDSS.

**Problem/Purpose Statements:** The problem is that electronic medical record (EMR) systems which actively depend on CDSS generally have a large quantity of alerts and these alerts have been shown to create alert fatigue for providers. Given the significance of alert fatigue and the potential negative outcomes that result from alert overrides, the aim of this systematic literature review is to answer three questions: Does the use of CDSS when used in the care of a patient improve clinical outcomes?, Is there a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue?, Is there a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?

**Methods:** The literature search focused on two databases using key search terms and Boolean operators. Sixteen articles (n = 16) were utilized after the inclusion and exclusion criteria were applied, abstract and full-text reviews were assessed for significance to the research purpose and quality assessments were completed. A data collection matrix was used to organize the data.

**Results/Findings:** Several benefits were found to support the use of CDSS to support clinical outcomes. Precautions and possible consequences were also identified. Several theories were identified which explain the alert fatigue phenomenon. Several recommendations for both CDSS and alert design and implementation were identified.

**Discussion/Conclusions:** Subgroup analysis did not provide enough evidence at this time to conclude that quantity alone can explain the relationship between CDSS alert messages presentations and the frequency of alert overrides. Best practice guidelines and recommendations are provided for CDSS and alert design and implementation as well as recommendations for the use of CDSS in conjunction with health information technologies (HITs) to support decision making processes. This literature review has implications for designers, implementation specialists, system analysts and additional health informatics (HI) professionals. Additionally, it adds value to the existing knowledge base surrounding CDSS while presenting areas for further research to examine additional heterogeneous factors which may impact the success of CDSS.

**Keywords:** Alert Fatigue; Alert Override; Clinical Decision Support (CDS); EMR Alerts

## Introduction

Clinical decision support (CDS) can be defined as "the use of information and communication technologies to bring relevant knowledge to bear on the health care and well-being of a patient" [12]. Within this definition lies several key features of clinical decision support systems (CDSS). Within the terminology, "information and communication technologies" [12], the reference is made for the use of some computer-based application. In 2020, this reference generally means the electronic medical record (EMR) but can be expanded to mean multiple health information technologies (HITs). The goal of the CDSS is to use these technologies to provide a method for sharing the information generated from the CDS model with the user and allow for the user to in turn interact with the system appropriately based on the information provided. The terminology, "relevant knowledge" [12], implies that the CDSS is designed with logic to provide accurate information which is deemed to be relevant to the care for the patient or the necessary decision to be made by the provider. Another important realization within this concept is that these systems are designed to support the end-user in their decision-making process, not make the decision for the end-user. Finally, "to bear on the health care and well-being of a patient" [12], indicates that the goal is to utilize these systems to provide quality care for the patient.

Delivering quality care for the patient has multiple facets. As such, depending on the provider, the patient and the service delivery mechanism, the purpose of the specific CDSS can vary. Depending on the specific purpose of the CDSS, the design of the CDSS will vary to choose the appropriate methodology which best supports the purpose for the CDSS. One purpose of a CDSS is to answer questions. For example, given a lab value, the clinician may question how this specific value relates to normal ranges or even more so information about the sensitivity of the lab test or medications and factors that may affect the lab value. One methodology used for this purpose is a hyperlink. Strategic placement of the hyperlink can guide the end-user towards seeking further information and an easy method for obtaining the information. More complex methodologies for accomplishing this purpose may include "bots" or "information brokers" [12] which link to outside mechanisms which retrieve information. The link to such tools may be in the form of an information button, hyperlink or additional icon.

Another purpose of a CDSS includes gathering and analyzing data to assist the provider in making decisions and additionally providing recommendations for the provider. One key decision is the patient's diagnosis. A differential diagnosis helps trigger a series of decisions related to the chosen diagnosis. Other providers utilize this to formulate their need for additional tests and their treatment plan, further education is provided to the patient based on this diagnosis and even financial implications stem from this decision such as length of stay predictions and resource allocation. Diagnoses are often made over time and evolve as more and more information is gathered. Bayes' theorem is a key methodology used in the design of CDSS. The basis for this theorem is that the hypothesis is obtained using probability and statistics for that hypothesis to hold true based on prior knowledge and as information becomes available. Additional methods used for the CDSS purpose of making a diagnosis decision include "algorithmic computation, heuristic reasoning, and statistical data mining/ pattern recognition methods" [12].

Additional key decisions include test selection and recommended treatments. Once again, algorithmic models and additional logic design are key methodologies. These decisions have a tremendous impact on the patient. As such, it is important to ensure that the algorithm and logic within the model is accurate, consistent, thorough and that ample testing has been accomplished to ensure integrity within the chosen methodology. Adverse events related to errors within these methods could lead to inappropriate ordering of tests which can be costly and also burdensome to the patient. Adverse drug events could result from inappropriate treatment decisions. Contrarily, there is a lot of potential gain from using the CDSS to support medication selection such as choosing a more affordable medication for the patient or one which may offer less side effects or potential for drug to drug interactions.

The final key decision includes assigning a prognosis for the patient. With or without the assistance of CDSS, this decision is an estimation or forecast made by the provider with consideration of all available evidence. Key methodologies used for the purpose of prognosis include "[l]ogistic regression, Markov modeling, survival analysis models, and quality of life assessment scoring methods" [12]. Logical regression is best utilized when the variables can be categorized especially the dependent variable leading to a prognosis of two possible outcomes, generally positive ("no") or negative ("yes") outcomes. For example, the patient's tumor is malignant or not malignant. This method is often used for decisions involving presence or absence of disease as well as prognosis regarding time or probability of an event occurring. Markov modeling is a methodology used to determine the prognosis for future events of a diagnosis based on current factors. One can visualize this model as a decision tree in which the patient is at a given health state at various points in time and based on treatments provided and/or additional events the patient transitions through the states resulting in a prognosis based on the transition and position on the tree. In this model, each of the health states are called Markov states. This type of methodology is often used for chronic conditions and those in which risk continues to exist over a given time period. Scoring method methodology assigns probability for events and prognosis based off of a combination of factors with scores assigned to each factor based off of evidenced based practice. These factors can be both structured and unstructured data. Structured data includes objective data such as lab values, medication dosage and vital signs as some examples. Unstructured data includes subjective data such as qualitative descriptions found during exams, patient history and clinical judgements as examples. This methodology is very context specific, and the amount and type of variables included in the scoring method can vary considerably. As such, the structure of the scoring method methodology can range from a simple mathematical equation to complex algorithmic equations.

These key methodologies can also be used for additional purposes such as optimizing process flow and workflow, monitoring actions and focusing the user's attention and visualization to key areas to encourage a behavior or guide the user to more easily see and utilize the data. In addition to any combination of the key methodologies described, other CDSS methodologies include rules and alerts, data display and reporting capabilities and additional visualization methods such as dashboards, trending displays and additional graphing capabilities. With such a wide variance in methodologies, the chosen design must take into account many factors such as the specific purpose of the CDS, the context of use, end user capabilities and needs in order to select the most optimal methodology to match the specific CDS purpose.

## Background and Significance

Unfortunately, while the benefits to CDSS and the standards supporting the functionality are highly beneficial, currently CDSS are under-utilized. If CDSS are not appropriately utilized or are ignored, then they have no benefit and in fact could result in a context of creating adverse consequences for the patient. The challenges encountered with the CDSS which ultimately led to the failure fit into three main categories; false negative classifications, excessive alerts and incomplete physician response to alerts [27].

Clinical alerts are one main form of CDSS. Overall success in response to alerts depends on five stages[6], firing rates or frequency of alerts, override rates, response to the alert, intermediate process goals and outcomes achieved. The lowest two levels of response are determined by the firing rates and override rates. Each stage builds on the previous stage to determine the overall success of the CDSS.

While these alerts can have a wide variety of formats, two common alert types can be conceived by considering a 'pop-up box' which serves the purpose of two broad functions of either alerting the user to perform a task or suggest an action or alerting the user of the potential consequences for not performing the task or taking a particular course of action [5]. As such, if these alerts are ignored, one could see the potential problem or risk that may occur regarding the care of the patient.

Alert fatigue is a phenomenon whereby clinicians are prompted in an overwhelming fashion which leads to an excessive cognitive load within the working environment and results in a failure to engage with the alerts[1]. Alert overrides occur when this excessive cognitive load creates a scenario whereby, the user or clinician inadvertently disables the alert or otherwise ignores the alert. As such, this process negates the effectiveness of the alert and more specifically negatively impacts the CDSS outcome [1]. A more significant impact could be the affect that this alert fatigue and alert override has on patient care and clinical outcomes. "Although little discussed prior to the widespread use of electronic medical records, alert fatigue is now recognized as a major unintended consequence of the computerization of health care and a significant patient safety hazard" [1].

## Problem statement

The problem is that EMR systems which actively depend on CDSS generally have a large quantity of alerts and these alerts have been shown to create alert fatigue for providers.

### Purpose statement

Given the significance of alert fatigue and the potential negative outcomes that result from alert overrides, the aim of this systematic literature synthesis is to answer three questions:

- Does the use of CDSS when used in the care of a patient improve clinical outcomes?
- Is there a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue?
- Is there a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?

The null hypothesis for this last question is that there is no relationship between the number of alerts presented and the frequency rate of alert overrides. Alternatively, the alternative hypothesis is that there is a relationship between the number of alerts presented and the frequency rate of alert overrides.

## Results and Findings

### Does the use of CDSS when used in the care of a patient improve clinical outcomes?

To answer the first question, Does the use of CDSS when used in the care of a patient improve clinical outcomes?, the literature review retrieved five articles which directly addressed the potential benefits and possible drawbacks related to clinical outcomes when providers use CDSS to support patient care. Three of these studies used qualitative methodology and systematic review research design. These articles included [19,21,25]. One article [10] provided and outlined the government policies supporting CDSS use. Finally, one article [13] used quantitative methodology which supported a cluster-randomized trial research design which assessed before and after clinical outcomes for diabetic patients in which providers within the intervention group utilized CDSS and providers in the control group did not use CDSS. This study sought to provide quantitative clinical outcome measurements to measure the effects of CDSS use within this diagnostic group.

The systematic review articles [19,21,25] provided nine benefits and six possible drawbacks to CDSS use. Benefits to CDSS use can be divided into broad categories of patient safety, clinical management, cost containment, administrative, diagnostic support, patient decision support, improved documentation and workflow improvements [25]. If CDSS are ignored or not used correctly, then adverse effects could include adverse drug events, overreliance on the presented information, decreased patient care time and other adverse events which compromise patient safety and lead to unintended clinical outcomes [19,21,25]. These benefits included:

- Supporting patient safety [19]
- Meeting meaningful use requirements [19]
- Providing dosing guidance for medications [19]
- Potential to prevent adverse drug events (ADEs) [19]
- Augmenting clinicians in their complex decision-making processes [21,25]
- Providing targeted clinical knowledge, patient information, and other health information [25]
- Providing education to providers and clinical staff [25]
- Reducing medical errors [21]
- Increasing health care quality and efficiency [21]

These possible drawbacks included:

- Alert overrides can hinder improved patient outcomes (guidance not accepted) [19,21]
- Providers may start to dismiss them regardless of importance [25]
- Reliance on, or excessive trust in the accuracy of the information [25]
- May lead to decreased face-to-face time with patients [25]
- Can create an impression that verifying the accuracy of an order in unnecessary or automatic [25]
- Interoperability issues as the patient transitions through the levels of care [25]

The government policy outline [10] revealed benefits which aligned with those described in the systematic review articles and described two additional benefits. Additionally, the use of CDSS aligns organizations with compliance to Medicare and Medicaid EHR Incentive and required programs [10].

These additional benefits included:

- Reducing healthcare costs [10]
- Enhanced provider and patient satisfaction [10]

Finally, the quantitative study found no significant primary or secondary clinical outcomes between the intervention and control group at six and twelve month follow-up visits indicating that the CDSS did not contribute to improved patient care for the diabetic patient group [13]. Despite these findings, there were some limitations to this study. These limitations included a 43% dropout rate across both groups and the study was conducted for physician groups and practices in Belgium [13]. There may be specific cultural, organizational and technological infrastructure differences within this country that prevent generalizing the outcomes from this study.

In addition to the findings within these articles describing the possible benefits and possible drawbacks to CDSS use to support patient care, the literature review also retrieved six articles which provided specific recommendations for CDSS alert design and recommendations for end-user preparedness and implementation guidance for CDSS to support these benefits and minimize drawbacks for CDSS use and implementation. Three of these articles use qualitative methodology and systematic review research design. These articles included [19,21,25]. One article[10] provided and outlined the government policies supporting CDSS use. An additional article[18] used qualitative methodology and qualitative survey research design. Finally, one article[13] used quantitative methodology which supported a cluster-randomized trial research design which assessed before and after clinical outcomes for diabetic patients in which providers within the intervention group utilized CDSS and providers in the control group did not use CDSS. This study sought to provide quantitative clinical outcome measurements to measure the effect of CDSS use within this diagnostic group.

The systematic review articles [19,21,25] provided twelve specific recommendations for CDSS alert design and ten recommendations for end-user preparedness and implementation guidance. Common themes related to CDSS alert design could be broadly categorized by interface factors [21] which include presentation, placement, positioning and tiering strategies[25] to incorporate alert sensitivity and address overall alert quantities. Common themes related to CDSS implementation guidance could be broadly categorized by incorporating interaction features for preferred design and recommendations [21] and 'think-aloud' methods to incorporate provider workflow into implementation strategies [25]. Additional overarching themes and recommendations for alert design and end-user preparedness guidance have a foundation in human factors [21], incorporate predictive models [19], and there is also recommendations for continuous evaluation, training, obtaining feedback [25] and customization whenever possible [21].

Specific recommendations for CDSS alert design included:

- Identifying which alerts are clinically relevant [19]
- Identifying which overrides are justifiable [19]
- Utilize an interactive dashboard with 2 views, one for evaluating CDS and clinician alert and response [19]
- Incorporate predictive models [19]
- Prioritize critical alerts [25]
- Minimize use of disruptive alerts for non-critical indicators [25]
- Avoid prescriptiveness in system design [25]
- Reference expert knowledge in messages where appropriate [25]
- Disruptive alerts should be limited to more life-threatening or consequential contraindications (ex: serious allergies) [25]
- Consider interface presentation, placement, positioning and provision of multiple presentation layers [21]
- Incorporate information features such as clean, concise, content guidance and consistency of information [21]
- Establish basic design standards with a foundation in human factors [21]

Recommendations for end-user preparedness and implementation guidance included:

- Using an interactive dashboard for identifying successes, justifiable overrides, provider non-adherence and unintended consequences [18,19]
- Incorporate predictive models [19]
- Evaluate system impact on an ongoing basis [25]
- Implement new knowledge, physician feedback [18,25]
- Train users on why certain data entry and standardization of data entry practices [18,25]

- Usability evaluation [21,25]
- Workflow modeling [25]
- Use 'think-aloud' methods to model practitioners' workflow [25]
- Consider interaction features of speed, fit, feedback, forgiveness and flexibility in design [21]
- Foundation in human factors to guide the design, development, implementation and customization [21]

The qualitative survey article expanded on these recommendations to include additional specifics to these recommendations. The overarching theme from this research suggested utilizing various tiering and categorizing strategies for both the design and implementation of CDSS [18].

Specific recommendations for CDSS alert design included:

- Classifying alerts into three main levels (severe, moderate, minor) [18]
- Develop a list of a core set of critical drug to drug interactions, use colors for these critical alerts [18]
- Classify alerts into active (interruptive, critical alerts) and passive (non-interruptive, less critical) groups [18]
- Provide systems with automated feedback and learning mechanisms where frequent, ignored and justified alerts could be moved automatically from the active interruptive to the passive non-interruptive model [18]

Recommendations for end-user preparedness and implementation guidance concurred with the systematic review recommendation and additionally included:

- Meet and interview CDSS users to evaluate and eliminate or adjust the severity level of certain alerts [18]
- Form an expert panel to rate the alerts and interactions [18]

The government policy outline provides best practice recommendations for CDSS alert design which incorporates the 'Five Rights' concept. "The "Five Rights" concept provides a best practice framework that providers may consider in considering CDS options appropriate for their practice" [10].

'Five Rights' recommendations for CDSS alert design include:

- Incorporate the right information [10]
- Ensure the information is provided to the right people [10]
- Ensure the information is accessed through the right channels [10]
- Incorporate the right intervention formats [10]
- Ensure the information is presented at the right points in workflow [10]

Finally, the quantitative article provided additional recommendations for CDSS alert design and end-user preparedness and implementation guidance.

Specific recommendations for CDSS alert design included:

- Incorporate clinical practice design [13]
- Ensure high quality of data [13]

Recommendations for end-user preparedness and implementation guidance concurred with the systematic review recommendation and additionally included:

- Incorporate proactive processes [13]
- Utilize CDSS to support clinical practice but not as a standalone tool [13]
- Consider multifaceted strategies such as CDSS systems in combination with continuing education, feedback mechanisms, organizational changes and patient-oriented strategies [13]

## Is there a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue?

To answer the second question, Is there a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue?, the literature review retrieved five articles which theorized the reasons why alert fatigue occurs. "Alert fatigue, the mental state resulting from alert overload, is a frequent unintended consequence of clinical decision support implementation" [7]. Three of these articles used qualitative methodology and systematic review research design. These articles included [7,17,22]. Additionally, two articles used mixed-methods research methodology. The first mixed-methods article [20] utilized an exploratory analysis research design to provide qualitative theories explaining the reasons supporting alert fatigue and a quantitative metric, alert dwell time, to measure alert response. Finally, the second mixed-methods article [23] provided results from a single-site retrospective pre-post study which attempted to measure alert frequencies, types and responses after an alert re-categorization process took place.

Kane-Gill., *et al*. (2017) theorized that alert fatigue was associated with the desensitization concept. As such, as the quantity of alerts increases, the provider becomes desensitized to recognizing these alert presentations [17]. Olakotan and Yusof, (2020) proposed that alert fatigue was related to alert quantity, timing and sensitivity. Consequently, Olakotan and Yusof, (2020) proposed that the alert response could be modified by adjusting the quantity of alerts through discerning between relevant and irrelevant alerts. Additionally, they proposed adjusting the alert trigger to fire optimally within the clinicians' workflow to provide valuable information without disrupting the workflow [22]. Also, they suggested improving alert specificity to decrease excessive false positive (FP) alerts [22]. Finally, Baysari., *et al*. (2016) theorized that alert fatigue is related to habitual behavior and occurs without conscious intention. "For habits to form, the context must be stable, the behavior must be repeated frequently, and the outcome of the behavior must be reinforcing (i.e., satisfying)" [7]. These antecedents commonly exist when the frequency of alerts is high within the EMR context and the prescriber's decision to override or ignore the alert is not accompanied by any immediate negative consequence [7].

In addition to the reasoning behind the alert fatigue phenomenon, a common theme within these articles [7,17,22] included strategies to improve alert effectiveness and minimize alert fatigue. Overriding themes amongst these strategies included alert management strategies [17] to assess alert quantity, timing and sensitivity[22] and customization of alert interface and design when this option is possible [7,17].

Additional strategies to improve alert effectiveness and minimize alert fatigue included:

- Prioritizing alerts [17]
- Developing sophisticated alerts [7,17]
- Including end user opinion in alert selection [17]
- Consider workflow within the interface design phase [7,22]
- Concise language, large font size, minimal text to enhance readability [22]
- Using signal words such as critical, danger, high risk, warnings and caution to indicate severity [22]
- Tiering alerts and presenting only high-level (severe) alerts to clinicians [7]

McDaniel., *et al*. (2015) introduced a metric to measure and quantify alert responses. According to McDaniel., *et al*. (2015), alert dwell time is defined as the "time elapsed from the generation of an interruptive alert to dismissal of the alert window by adhering to the instructions of the alert or overriding" [20]. Within this exploratory analysis an expert team composed of physicians and pharmacists met to categorize alerts by severity ratings, limit interruptive alerts to those rated as "major" or "major contraindicated", disabling duplicate alerts and requiring prescribers to document override reasons [20]. These modifications decreased the final alert dataset from 106,019 total alerts to 25, 965 total alerts which included 777 unique drug-drug interaction (DDI) alerts within the review period [20]. The alert dwell time for these alerts was measured and the results indicated "the median dwell time of these infrequent alerts was 11 s versus 7 s for the top 10 most frequent alerts" [20]. From these results, McDaniel., *et al*. (2015) associated alert dwell time with alert fatigue by proposing that infrequent alerts had longer dwell time than frequent alerts indicating that providers spent more time processing the information for infrequent alerts versus 'quickly' responding to frequent alerts. Limitations to this review included that the exploratory analysis occurred at a single research facility and the expert panel was limited to physicians and pharmacists.

Another mixed-method review included results from a single-site retrospective pre-post study[23]. In this study, Parke., *et al*. (2015) theorized that alert fatigue is experienced when there is an abundance of alerts triggered that are not actionable. As such, an initial quantity of DDI alerts (n = 8023) was measured in a pre- categorization baseline period. An expert panel met to re-categorize the alerts by severity rankings. "The expert panel was composed of three clinical pharmacists, two informatics pharmacists, and two physicians" [23]. The re-categorization decreased the DDI alert quantity to 7,270 alerts [23]. Additionally, "a 6% reduction was seen in the total number of alerts viewed during the order-entry process" [23]. Key limitations to this study include the limited structure and size of the expert panel which introduced subjectivity into the research and an additional factor in which additional alert types were also visible during this period for the provider group which may have skewed the results which measured only the single alert type, DDIs [23].

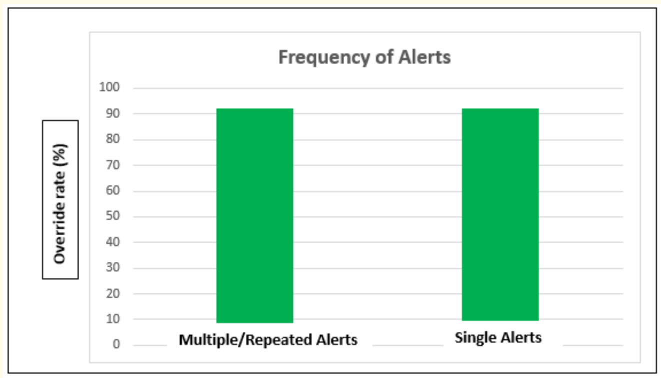
### Is there a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?

To answer the third question, Is there a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?, the literature review retrieved six quantitative studies which provided quantitative data showing relationships between alert presentations and alert overrides. These articles included [2,8,9,20,24,26].

Topaz., *et al*. (2016), Bryant., *et al*. (2014), Slight., *et al*. (2013) and Ancker., *et al*. (2017) performed their studies using a retrospective observational design. These studies first looked at the alert overrides trends over time. These studies found that over a decade of research revealed override rates which increased despite attempts to improve CDSS and health information technology (HIT) use [9]. These studies revealed an override rate range from 83.3% in 2004 to 93% in 2014 [26].

**Graph 1**

An additional relationship found within these studies looked at the relationship between frequency of alerts and override rates. Specifically, these studies compared the override rates between singularly occurring or infrequent alerts and repeated alerts. Overall, the findings within this relationship revealed an insignificant difference between override rates for multiple alerts to single alerts with a mode value of 92% (range 77.4% to 92%) [9,26]. Additionally, the study by Ancker., *et al*. (2017) failed to prove the desensitization hypothesis, finding no evidence of override rate relationship with repeated alerts or overall quantity of alerts across providers' caseload levels.




**Graph 2**

McDaniel., *et al*. (2015) and Baysari., *et al*. (2020) performed their studies using experimental analysis design. These studies utilized alert dwell time as a metric to measure response to alerts. Using alert dwell time, infrequent alerts were compared with frequent alerts [8,20]. The average dwell time for infrequent alerts was 13.2 seconds (range 11s-15.6s) compared to an average dwell time for frequent alerts equaling 8.6 seconds (range 7s-10.2s) [8,20]. The standard deviation for these alert dwell time values was 2.78 with a 68.3% confidence level and variance of 7.72 [8,20]. McDaniel., *et al*. (2015) found a variance of 9 seconds for accepted alerts versus 8 seconds for overridden alerts. From these results, McDaniel., *et al*. (2015) concluded that it was possible to measure the length of time for which an alert is present before being dismissed by a provider which they termed 'alert dwell time'.

## Discussions, Conclusions and Implications

### Discussing the relationship between CDSS use and clinical outcomes

In analyzing the first question, Does the use of CDSS when used in the care of a patient improve clinical outcomes?, the literature review found several positive benefits for using CDSS to support patient care. These broad categories of benefits includes patient safety, clinical management, cost containment, administrative, diagnostic support, patient decision support, improved documentation and workflow improvements [25]. Additionally, the Centers for Medicare and Medicaid Services (CMS), the governing body for healthcare policy in this area, positively defines clinical decision support (CDS) as "health information technology functionality that builds upon the foundation of an electronic health record (EHR) to provide persons involved in care processes with general and person-specific information, intelligently filtered and organized, at appropriate times, to enhance health and health care" [11]. Ultimately, the answer to this first research question is yes, CDSS does contribute to improved clinical outcomes and even contributes to saving lives.

However, if providers solely depend on CDSS for their clinical decision making, consequences to utilizing these tools could occur. Additionally, unintended consequences can occur when CDSS are ignored which can occur from an overabundance of CDSS presentations, a phenomenon known as alert fatigue. More so, adverse events are possible when CDSS are not used correctly such as overriding a CDSS presentation. A worst case scenario is a drug-to-drug interaction (DDI) or drug-to-allergy interaction (DAI), two common forms of CDSS, which is ignored or overridden leading to the administration of a drug which then leads to an adverse drug event (ADE) and possibly even death.

The data supports and cites both positive benefits and negative drawbacks from utilizing CDSS in clinical practice. There are many knowledge-based and non-knowledge based tools which are used in day to day healthcare functions which if used incorrectly lead to unintended consequences. As such, the research was taken a step further than just acquiring a list of potential benefits and cautionary drawbacks to CDSS use; additionally, gathered recommendations for design and implementation which provided the greatest potential for CDSS success were gathered. The thought behind identifying these recommendations is such that organizations which employ these strategies are providing their providers and their organization with the greatest potential for success and improved clinical outcomes through the use of CDSS.

When considering alert design, considerations should include presentation, placement, positioning and tiering strategies [25]. Tiering and classification strategies are utilized to address alert quantities and promote only the most critical alerts as causing an interruption to clinician workflow. Colors and placement strategies are utilized to promote visibility to these significant alerts. Finally, continued training and evaluation of CDSS should occur on an ongoing basis so providers know how to utilize the CDSS and the knowledge base that the models and algorithms are built off of to instill trust in these decision support tools.

### Discussing the relationship between the level or quantity of alerts and provider alert fatigue?

In analyzing the second research question, Is there a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue?, common theories were discovered which help to explain this phenomenon. These theories support the relationship between a level or quantity of alerts and alert fatigue; however, also introduce additional factors beyond quantity which leads to alert fatigue. While no single theory ultimately explained the reason for this phenomenon, all the theories found within the research held some value in promoting alert fatigue and could not be ruled out as potential reasons to explain this occurrence. These theories related alert fatigue to quantity [17], timing and sensitivity [22]. Therefore, it is concluded that there is a threshold with the level or quantity of alerts that has been shown to create provider alert fatigue. However, a single quantity or specific level could not be determined from the research at this time.

Additionally, an inverse relationship between alert fatigue and CDSS success was found through the research. As such, additional conclusions from this research were a summarization of specific recommendations for alert design which were shown to decrease the alert fatigue phenomenon and improve alert effectiveness. These recommendations target the reasons behind alert fatigue such that they include design features to address quantity, timing and sensitivity. Furthermore, customization should be considered whenever possible to adjust the interface and design specific to the intended clinician [7,17]. An additional interesting summary was that several of the design recommendations for alerts concurred with the design recommendations for CDSS. This concept makes sense such that alerts and 'pop-ups' are a common presentation of CDS. Consequently, this concept may have been hypothesized prior to conducting the research but was additionally supported by the research.

### Discussing the relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?

Finally, to analyze the third question, Is there a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides?, a general trend could be seen between these two factors. First, over a time span of a decade, overall override rate percentage increased. During this same time frame, there was an overall increase in the quantity of CDSS alerts as more organizations implemented EMRs. Additionally, government policy continued to support the required use of CDS which overall contributed to more CDSS alerts.

Another relationship considered the concept that alerts which fired more frequently would equate to a larger quantity of alerts. An interesting finding indicated that the override rates were exactly equal between single and infrequent alerts and recurring frequent alerts [9,26]. One limitation to these findings were the limited number of studies found within this literature review that specifically measured these values. However, the desensitization hypothesis was additionally disproved in an additional study by Ancker., *et al*. (2017), finding no evidence of override rate relationship with repeated alerts or overall quantity of alerts.

Another form of analysis for the relationship of CDSS alert presentations and override rate percentage included using 'alert dwell time' as a measurement tool to measure response to alerts. McDaniel., *et al*. 2015 and Baysari., *et al*. 2020 used this measurement to attempt to also establish a relationship between frequencies of alerts and override rate percentage. These studies showed an inverse relationship between 'alert dwell time' and frequency of alerts such that infrequent alerts showed a longer 'alert dwell time' and as this frequency increased the 'alert dwell time' decreased. This relationship may lend support towards the alternative hypothesis that there is a relationship between the number of alerts presented and the frequency of alert overrides. However, this relationship is assuming that the increased duration of time is spent analyzing the alerts and actually considering the message presented within the alert. This measurement tool has potential for future research supporting its validity in measuring this relationship, but at this time this assumption cannot lead to these conclusions.

As such, ultimately these subgroup analyses did not provide enough evidence at this time to conclude that quantity alone can explain the relationship between CDSS alert messages presentations and the frequency of alert overrides. Additionally, this research shed light on possible heterogeneous factors such as drug class, provider groups, tier groups such as 'minimal', 'moderate' and 'severe' alert presentations and alert types such as DDI, DAI and non-medication based alerts which are areas of additional research required to ultimately determine the optimal alert presentation make-up which aligns with positive benefits from CDSS use. At this time, to finalize the answer to the third question, quantity alone cannot explain alert overrides. Consequently, the null hypothesis is accepted as there is no relationship between the number of alerts presented and the frequency rate of alert overrides.

## Conclusions

This research provided several recommendations for CDSS and alert design, implementation recommendations and ongoing maintenance which have linked CDSS use to positive clinical outcomes. When CDSS is used in coordination with additional clinical tools as well as to support decision making processes, there is significant potential for positive clinical outcomes. Using CDSS solely without using it in coordination with additional health information technologies (HIT) and in isolation of the clinician's own decision making process would not support best practice guidelines and could equate to less favorable clinical outcomes.

Additionally, alert fatigue is a real phenomenon and can occur when CDSS are over utilized and/or the alert design does not fit the needs of the provider or organization. Alert fatigue can lead to CDSS being ignored which additionally leads to adverse effects and the potential to negatively impact clinical outcomes. While a specific quantity of alerts has not been determined, great care and caution should be taken when designing and implementing alerts to represent CDS messages which optimally fit the needs of the provider and organization. Health informatics professionals and healthcare providers should be vigilant in recognizing alert fatigue and implement strategies and efforts to minimize this occurrence in relation to CDS to promote CDSS success.

Furthermore, adverse events are possible when CDSS are not used correctly such as overriding a CDSS presentation. While a one size fits all strategy does not apply to CDSS alert messages presentations and a relationship between the number of CDSS alert messages presentations and the frequency rate of alert overrides could not be determined, this research supports several factors which should be considered for utilizing CDSS.

**Appendix A:** PRISMA Diagram

## Implications

The findings in this research can provide guidance for design and implementation strategies for organizations seeking to initiate utilization of CDSS or improvement strategies for those organizations which are already using CDSS. This research has implications for EMR vendors, health informatics professionals, system analysts and designers as it offers several recommendations for optimal CDSS and alert design and implementation.

Additionally, findings in this research indicated that there are potentially heterogeneous factors which may explain override frequency. Heterogeneous analysis could include further research for clinical position relationship, drug class relationship and alert type relationship to override rates. The literature review introduced these concepts and provided quantitative findings for these relationships but there was not enough data to make conclusions for these relationships. As such, these areas could be starting points for further research. Additionally, further research could be done to answer these three questions building on this research as a framework and starting point. In particular, the researcher had hoped to find a quantitative recommendation or proportion of time spent within an EMR which showed a correlation to increased override rates. However, the limited number of studies did not find an outcome that explicitly stated these values. Nor, did the quantitative findings lead to inferential statistics that could be used to propose a value or formula that organizations could use to establish this value. This question would be an additional opportunity for further research.

This program included a class which focused on CDSS and many other classes which reviewed this topic. Furthermore, health informatics programs and certifications are on the rise. This research has implications to support education and instruction on this topic within academic institutions and certification processes.

Finally, CDS is a key component of existing policy within the Meaningful Use Program which is part of the 2009 Health Information Technology for Economic and Clinical Health (HITECH) Act [3]. The most current stage of this program, Meaningful Use Stage 3, Promoting Interoperability (PI) Program, and the objective for goal three of this program is to "implement clinical decision support (CDS) interventions focused on improving performance on high-priority health conditions"[11]. Despite this recognition of the importance of CDS, this policy does not provide specifications or recommendations in design or implementation to promote success. As such, this research has the potential to serve as an amendment, addition or measurement standard added to existing policy which provides guidance for CDSS and alert design and implementation to promote success and improved clinical outcomes.

## Bibliography


1. Agency for Healthcare Research and Quality. Alert fatigue (2019).
2. Ancker JS., *et al*. "Effects of workload, work complexity and repeated alerts on alert fatigue in a clinical decision support system" (2017).
3. Athena Health. "What is meaningful use?" (2020).
4. Athena Health. "What is meaningful use stage 2" (2020).
5. Backman R., *et al*. "Clinical reminder alert fatigue in healthcare: A systematic literature review protocol using qualitative evidence" (2017).
6. Basit M., *et al*. "Agile clinical decision support development and implementation [Powerpoint presentation]". AMIA Informatics Summit, UT Southwestern Medical Center (2018).
7. Baysari MT., *et al*. "Alert override as a habitual behavior-a new perspective on a persistent problem" (2016).
8. Baysari MT., *et al*. "An experimental investigation of the impact of alert frequency and relevance on alert dwell time" (2020).
9. Bryant AD., *et al*. "Drug interaction alert override rates in the meaningful use era" (2014).
10. Center for Medicare and Medicaid Services (CMS). "Clinical decision support: More than just 'alerts' tipsheet" (2014).
11. Centers for Medicare and Medicaid Services (CMS). "Promoting interoperability programs" (2020).
12. Greenes R A. "Clinical decision support: The road to broad adoption (2nd ed.)". Oxford, UK: Elsevier, Inc (2014).
13. Heselmans A., *et al*. "Computerized clinical decision support system for diabetes in primary care does not improve quality of care: A cluster-randomized controlled trial" (2020).
14. Higgins JPT., *et al*. "Systematic reviews and meta-analyses: Eligibility criteria" (2020).
15. Joanna Briggs International. "Checklist for cohort studies" (2020).
16. Joanna Briggs International. "Checklist for systematic reviews and research syntheses" (2020).

17. Kane-Gill SL., *et al*. "Technologic distractions (Part 1): Summary of approaches to manage alert quantity with intent to reduce alert fatigue and suggestions for alert fatigue metrics". (2017).

18. Khalifa M and Zabani I. "Improving utilization of clinical decision support systems by reducing alert fatigue: Strategies and recommendations". (2016).

19. McCoy AB., *et al*. "Clinical decision support alert appropriateness: A review and proposal for improvement". (2014).

20. McDaniel RB., *et al*. "Alert dwell time: Introduction of a measure to evaluate interruptive clinical decision support alerts" (2015).

21. Miller K., *et al*. "Interface, information, interaction: A narrative review of design and functional requirements for clinical decision support" (2018).

22. Olakotan OO and Yusof MM. "Evaluating the alert appropriateness of clinical decision support systems in supporting clinical workflow" (2015).

23. Parke C., *et al*. "Reduction of clinical support warnings through recategorization of severity levels" (2015).

24. Slight SP., *et al*. "Are we heeding the warning signs? Examining providers' overrides of computerized drug-drug interaction alerts in primary care" (2013).

25. Sutton RT., *et al*. "An overview of clinical decision support systems: Benefits, risks, and strategies for success" (2020).

26. Topaz M., *et al*. "Rising drug allergy alert overrides in electronic health records: An observational retrospective study of a decade of experience" (2016).

27. Wadhwa R., *et al*. "Analysis of a failed clinical decision support system for management of congestive heart failure" (2008).