Novel ways to analyse and cope alert-fatigue phenomenon in intensive care units

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Abstract. In Intensive Care Units (ICUs), patient monitoring relies on many devices configured to trigger alarms when specific physiological parameters surpass pre-established thresholds, including metrics like heart rate and oxygen saturation. Nevertheless, these alerts are susceptible to fallibility and frequently contribute to a common issue called "alert fatigue," wherein healthcare practitioners become desensitized to the alarms due to their frequent occurrence, often with questionable accuracy. This research introduces an innovative model to mitigate the alert fatigue phenomenon in ICUs by diminishing the overall requirement for medical interventions. The model is developed following the system dynamics (SD) methodology framework. The initial phase of the study encompasses the development of a current-state model, which, when implemented, was validated by medical and nursing professionals in the ICU. The subsequent phase involves a simulated implementation of our novel model, resulting in a reduction in the total number of interventions, thereby, based on the common assumption, reducing the alert fatigue phenomenon. This simulated SD model lays the groundwork for the prospective design of Internet of Medical Things (IoMT) systems, which are poised to contribute significantly to mitigate alert fatigue and enhance patient safety.

1. Introduction

Individuals experiencing work overload are likelier to experience fatigue and decreased attention [1]. This phenomenon has increased over time and has accelerated in recent

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years because of the transformative shift through the advent of the Internet of Medical Things (IoMT), establishing a complex system of patient monitoring mechanisms marked by precision and accuracy [2, 3]. Within the IoMT framework, devices actively engage in the real-time collection of physiological data, enabling the meticulous analysis of intricate physiological patterns [4-9]. This process is further facilitated by integrating event processing (EP), a sophisticated analytical approach centered on meticulously examining event-related information to draw meaningful inferences. EP is underpinned by a suite of real-time computational tools designed to extract invaluable insights [10, 11], adhering to the comprehensive "4D" framework encompassing the stages of "Detect, Derive, Decide, Do" [12, 13].

The utilization of IoMT gives rise to a significant challenge characterized as "alert fatigue," a condition arising from the sheer volume of alarms generated by multiple devices. This phenomenon submerges healthcare professionals with an overwhelming influx of irrelevant information, primarily due to constraints related to time and cognitive resources [14-16]. Notably, this challenge is particularly pronounced within critical healthcare settings such as hospitals, emergency departments (EDs), and intensive care units (ICUs), where the issue of "alert fatigue" significantly impedes the efficiency and efficacy of medical decision-making processes [17, 18]. It is crucial to underscore that no universally accepted standard measurement scale exists for quantifying "alert fatigue" [19]. Consequently, the predominant approach employed to mitigate this challenge is centered on reducing the overall number of alerts, thereby attempting to alleviate the burden placed on healthcare professionals.

In our exploration of the IoMT landscape, and to understand the processes, we have employed the system dynamics (SD) methodology to assess its impact comprehensively. As a theoretical framework, system dynamics provides a robust analytical lens through which complex systems, such as IoMT, can be dissected and comprehended. By leveraging the principles of system dynamics, we aim to unravel the intricate interplay of factors within the IoMT ecosystem, shedding light on its multifaceted implications and potential avenues for enhancement and optimization.

Our proposal encompasses the development of an innovative methodology outlined within the framework of the SD mode [20]–[24]. This methodology aims to describe and simulate two distinct models. The first model is grounded in a practical case study on general patient conditions. The second simulation model serves as a manifestation of our novel approach designed to mitigate the occurrence of alert fatigue. Our innovative methodology, rooted in the 4D framework, is specifically tailored to exert its influence on the "derive" stage. Within this framework, the overall quantity of alerts generated during the "detect" stage remains constant, while the "derive" stage is meticulously structured to trim the total number of alerts through a patient-specific clustering approach. This reduction in the aggregate alert count bears direct implications on the subsequent "decide" and "do" stages, thereby resulting in a consequential alleviation of the phenomenon of alert fatigue.

This methodological approach has been subjected to validation procedures involving assessment by medical experts who have attested to its accuracy in representing the prevailing patient conditions within a specific ICU context.

2. Materials and Methods

To facilitate the 4D model, based on the IoMT in the ICU, we employed SD methodology. The operationalization of this approach necessitates a meticulous representation of all pertinent factors within the situation during the operation process. In the architecture of the systems, this operationalization entails the integration of (a) sensors and devices, (b) gateway applications, (c) data storage, (d) domain algorithms or analytical systems, and (e) mechanisms for data visualization. The proposed model integrates sensor alerts from the Internet of Medical Things (IoMT) as crucial input data. These alerts are meticulously recorded in the detect repository, denoted as stock-Detect, as depicted in Figure 1. It is essential to underscore that the medical and nursing staff have the ability to establish specific thresholds for each sensor, tailoring them to individual patient statuses.

Given the substantial volume of alerts generated by the system, it is inevitable that not all alerts indicate events requiring immediate medical intervention. All alerts, regardless of their significance, are initially directed to the main Derive stock, as illustrated in Figure 1. The Derive stock performs a comprehensive analysis of these alerts. The medical and nursing team is promptly notified of all medical issues, and the system generates detailed reports for further examination.

In this process, some alerts may be deemed irrelevant and can be disregarded, while others undergo a discerning decision-making phase, as illustrated in Figure 1, referred to as the Decide phase. During this phase, the system conducts a thorough analysis to determine the appropriate course of action for each alert. This decision-making process involves evaluating the context and relevance of the alert to ascertain whether medical intervention is necessary.

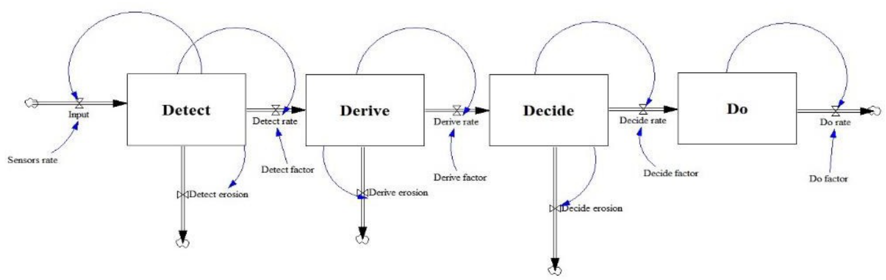

Fig 1. ICU single-bed model

The alerts generated by the IoMT sensors play a pivotal role in shaping the available medical activity options within the proposed model. These alerts serve as a fundamental foundation for identifying potential medical events and irregularities in patient parameters. The subsequent course of action is then deliberated and decided upon by the medical and nursing team, a process encapsulated in the Do stock.

As depicted in the model, the Do stock represents the phase where the medical and nursing professionals assess the alerts and determine the appropriate measures to be taken. This involves a dynamic decision-making process where the team considers the context, severity, and relevance of each alert. The information derived from the alerts serves as a valuable resource for the medical team to formulate effective strategies and interventions.

The proposed System Dynamics (SD) model was developed with a focus on a particular Intensive Care Unit (ICU). Its validation was conducted through interviews and questionnaires with medical practitioners. While initially developed within a specific Intensive Care Unit (ICU) setting, the model is engineered to encompass the broader concept of a patient bed within any ICU, leveraging various IoMT infrastructures. The versatility of the model lies in its ability to interpret a wide range of alerts. It is essential to note that the model operates under the assumption that the IoMT alert inputs remain the same. However, the proposed methodology advocates for intervention in the next stages, i.e., Derive, Decide and Do. This adaptability is facilitated by the flexibility to modify the IoMT configurations and relevant parameters. Consequently, the tool can be tailored to suit the characteristics of any ICU patient bed by adjusting the configuration and parameters based on the specific data of that particular ICU.

3. Results

The SD model simulation was initiated by employing the existing state definitions alongside the proposed model framework. The simulation outcomes are visually depicted in Figure 2. In this representation, the red line corresponds to the current state definitions, whereas the blue line signifies the anticipated future state. Both states exhibit an equivalent detection rate, as evidenced by the detection ("Detect") box. However, upon closer inspection of the Derive box, it becomes apparent that the current state definition stabilizes at approximately 49 alerts per hour. In contrast, the proposed model stabilizes at a slightly reduced rate of approximately 34 alerts per hour, the reduction process hinges on deriving meaning from combinations of alerts rather than relying solely on individual direct alerts. This reduction in alert frequency exerts discernible influence on the subsequent stages, namely Decide and Do, as evidenced by the data presented in Fig. 2. The effect on the Decide and Do stages is a reduction of about 45%.

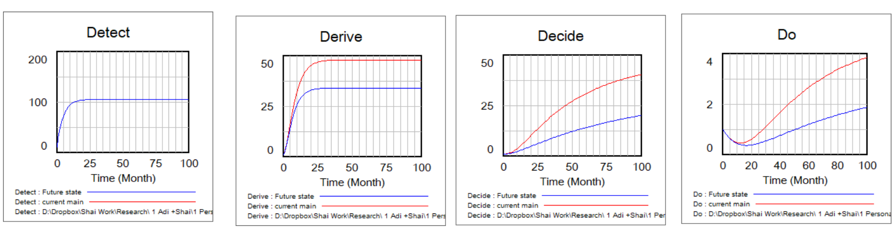

Fig. 2 Current state and future state

4. Conclusions

This study introduced an innovative model designed to mitigate alert fatigue within ICUs. The research endeavor entailed the creation of a novel model, using the SD methodology, to represent the current state. Findings emanating from the SD model developed in this research reveal a marked reduction in the requisite intensity of medical interventions when employing our innovative model, which effectively mitigates the "derive" stage within the 4D framework, and reduces the Decide and Do stages, in contrast to the current static model. The discovery suggests a plausible decrease in the overall amount associated with the "Decide" and "Do" stages, contingent upon the foundational assumption that reducing the aggregate number of necessary interventions will alleviate the alert fatigue phenomenon.

Future investigations should consider the potential extension of this methodology to other domains within the realm of healthcare and explore its diverse applications in fields such as agriculture, finance, and manufacturing.

The presented simulated SD model serves as a foundational framework that has the potential to catalyze the future development of IoMT systems. These forthcoming IoMT systems are strategically positioned to play a pivotal role in addressing the pervasive issue of alert fatigue, which, in turn, promises substantial improvements in the realm of patient safety.

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