An Evaluation of the Risk Impact of Device Heterogeneity on Critical Care Delivery

Mohamed Khedr Saad
Social Network Research Group,
John Jay College, CUNY
New York, USA

Bilal Khan
Dept. of Math &Comp. Science,
John Jay College, CUNY
New York, USA

Ghassen Ben Brahim
Computer Science Department,
Prince Mohamed University,
Al-Khobar, Saudi Arabia

***Abstract*—Hospital care facilities often make use of non-interoperable devices produced by many different vendors to monitor the state of patients. The heterogeneity of these devices makes it difficult to synthesize multivariate monitoring data into a unified array of real-time information regarding the state of patients in a care unit. Without an infrastructure for data integration, the assignment of caregivers to patients cannot be optimized to reflect the relative urgency of patient needs. This is an especially serious issue in critical care units (CCU). In this work, we evaluate the hypothesis that the integration of vital sign data can yield a significant positive impact on the efficiency and outcomes of critical care delivery, via a computer simulation of a CCU. Within our simulated CCU, an infinitely replenishable finite set of patients are being monitored, while a small set of caregivers is addressing patient alarm conditions. Patients who experience an alarm accumulate injury exponentially during the time that they are without care. Once a caregiver arrives at a patient, the time it takes to treat the underlying disturbance is assumed linear in the patient's accumulated injury. If a patient accumulates more than a threshold level of injury, a fatality occurs. Fatalities require the execution of close out procedures, which take a specified period of time (and must be given precedence over living patients).**

Through simulation we compare the current defacto scheduling processes in use within CCUs, against a new scheduling algorithm that makes use of an integrated array of patient information collected by a hypothetical vital sign integration infrastructure. Our simulation study provides quantitative evidence from which we can measure the extent to which such an infrastructure reduces risk to CCU patients and lowers operational personnel costs.

I. Introduction

Medical related errors, occurring frequently in hospitals may result in catastrophic consequences. Some studies [13] found that in the United States, medical errors resulted in between 100,000 and 200,000 of deaths that could have been prevented. In [19] Schroeder described a case of patient fatality linked to a nurse delayed response to a cardio alarm. This catastrophic loss could have been prevented if the nurse have postponed stabilizing a patient with a less critical alarm and handled a more severe cardio alarm. In the effort of determining the causes of this breakdown, the Joint Commission, a non-profit organization seeking to improve safety through healthcare accreditations recently released a report that investigated incidents of serious injuries related to ventilation [10]. It was found that approximately 20-35% of these incidents were associated with a delayed response to an alarm; none of the cases were found to be related to a hardware malfunction.

In order to assess the human body functions, health professionals need to monitor the state of the patient *vital signs* such as body temperature, pulse rate, blood pressure, and respiratory rate [22]. In CCU, these are collected and monitored through a set of sophisticated *heterogeneous* devices produced by a number of distinct vendors with, often proprietary system of cabling, data protocols, etc. The heterogeneity of these devices has added more challenges to caregivers to monitor, integrate, aggregate, and more important prioritize the multivariate alarms reporting the patient's overall health which has a direct impact on the health professional response time.

The extent to which we can mitigate patient risks caused by delayed responses rests on addressing the problem of effective caregiver scheduling. Caregiver scheduling has received considerable attention in recent years. Researchers have proposed different approaches on how to tackle this problem. The first major approach suggests to start with data from existing facilities and analyze the data to build a model and determine how it responds to various stresses. For instance, McManus et al [17] and Zai et al [25] have used queuing theory to model the operation of existing healthcare facilities and admission procedures. The existing practices of "manpower allocation" in respiratory care is considered Matthews et al. in their 2006 study [16], while Gajc et al. examine the effects of having 24-hour (mandatory) versus on-demand critical care specialists on staff. The second major approach suggests using data mining techniques to improve workflow and decision making processes (e.g. Gallivan et al [8] and Shahani et al. [21]).

The third major approach consists of standardizing medical device interfaces, so as to allow for easier integration in both critical care and operating rooms. Most of these efforts (e.g. COSMOS [11]) have sought to define data standards for interconnectivity between heterogeneous systems in healthcare [7]. A recent RFID-based effort to device integration was demonstrated in pilot project in a Taiwan hospital [24]. Such ongoing efforts aim at developing an infrastructure capable of integrating vital sign data streams, thereby providing a unified view of a collection of patients, synthesized from a diverse collection of medical devices. Proponents of such infrastructures claim they would yield great positive impacts on the delivery of critical care. Here we seek to verify such claims, quantitatively.

The remainder of the paper is organized as follows. We begin in Section II with a description of the system model. Then, in Section III we define the proposed simulation frame-

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