Operations Research for Health Care 3 (2014) 168–175

Contents lists available at ScienceDirect

Operations Research for Health Care

journal homepage: www.elsevier.com/locate/orhc

Intensive care unit discharge policies prior to treatment completion

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ARTICLE INFO

Article history:
Received 2 January 2014
Accepted 26 June 2014
Available online 2 July 2014

Keywords:
Intensive care unit
Hospital readmission
Dynamic programming
Simulation–optimization

ABSTRACT

In this study we explore a model to optimize the Intensive Care Unit (ICU) discharging decisions prior to service completion as a result of capacity-constrained situation under uncertainty. Discharging prior to service completion, which is called demand-driven discharge or premature discharging, increases the chance that a patient to be readmitted to the ICU in the near future. Since readmission imposes an additional load on ICUs, the cost of demand-driven discharge is pertained to the surge of readmission chance and the length of stay (LOS) in the ICU after readmission. Hence, the problem is how to select a current patient in the ICU for demand-driven discharge to accommodate a new critically ill patient. In essence, the problem is formulated as a stochastic dynamic programming model. However, even in the deterministic form i.e. knowing the arrival and treatment times in advance, solving the dynamic programming model is almost unaffordable for a sizable problem. This is illustrated by formulating the problem by an integer programming model. The uncertainties and difficulties in the problem are convincing reasons to use the optimization–simulation approach. Thus, using simulations, we evaluate various scenarios by considering Weibull distribution for the LOS. While it is known that selecting a patient with the lowest readmission risk is optimum under certain conditions and supposing a memory-less distribution for LOS; we remark that when LOS is non-memory-less, considering readmission risk and remaining LOS rather than just readmission risk leads to better results.

1. Introduction

The intensive care unit (ICU) is designed to provide special services with a high level of care for unstable patients in a hospital. ICUs are equipped with high technology and expensive medical equipment and have higher medical staff-to-patient ratio compared to other units in hospitals. The number of beds in an ICU is very limited due to the high costs associated with ICU operations.[1] Therefore, ICUs often have a high level of occupancy. The average occupancy rate in ICUs is 90% in the United States [2]. Health Department figures in Australia also reveal a scarcity in the number of available ICU beds, for instance in Victoria there are less than 5.4 beds per 100,000 people and in public hospitals an ICU with 11 beds has approximately 1000 admissions each year. If we assume that the average length of stay (LOS) in an ICU is 3.8 days, the occupancy level would be around 95%. This limitation on ICUs causes an increase in situations where there is no available bed for an incoming patient. This is called "access block" in the literature. A 95% occupancy level in an ICU with 10 beds implies that ($0.95^{10} \approx 0.6$) 60% of times the ICU faces access block and there is only a 40% chance that a bed is available for a newly arrived patient. Duke et al. [3] indicate that all hospitals reported ICU access block in Melbourne, which resulted in 4368 additional hospital bed-days each year. These features show that the ICU is a bottleneck to patient flow and may limit a hospital's responsiveness to new emergencies. Moreover, Hall [4], Duke et al. [3] and Halpern and Pastores [5] show that ICU occupancy levels and access block rates are increasing. These figures (as also stressed by Howell [6]) demonstrate that optimal utilization of the ICU is a critical issue in hospital management.

Chalfin et al. [7] show that there is a crucial negative impact associated with any delay in providing ICU service to an arriving patient. Therefore, as discussed by Chan et al. [8] hospitals may exercise a policy of immediately admitting a newly arrived patient into the ICU even if it requires discharging one of the existing patients in the ICU before the completion of his/her treatment. This is called "bumping" or "demand-driven discharge" or "premature discharging" in the literature. ICUs in Australia and New Zealand exercise four polices when faced with access block, which are:

1. Refusing to admit and possibly transferring the newly arrived patient to another hospital with an available intensive care bed.

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[1] "The cost of caring for patients in ICUs in the United States has been estimated to account for 1%–2% of the gross national product" quoted from Gruenberg et al. [1].

http://dx.doi.org/10.1016/j.orhc.2014.06.001
2211-6923/

2. Keeping the patient in the emergency department (ED) until an intensive care bed becomes available.
3. Canceling or postponing an elective major surgery.
4. Demand-driven discharge or transferring one of the existing patients to a low-acuity (standard care) ward. (ANZICS [9] and the Australian Council on Healthcare Standards (ACHS) [10–12].)

In Australia, 3.4% of patients were refused admissions in ICUs due to inadequate resources (either beds or staff) in 2007. This rate varies from hospital to hospital with the maximum admission refusal as a result of limitations in ICU resources being 25.3% [10,11]. These figures relate to the first policy in the above list. Also the data show that there was 2.8% cancellation of surgery due to unavailability of intensive care beds in 2007 [10,11]; this is related to the third policy in the above list. In 2007, out of hours discharging was 15.8% of total discharges; this figure relates to the last policy in the above list as discharging normally occurs in day working hours. However, the true value of demand-driven discharge is likely to be higher as some demand-driven discharge occurs in day working hours.

Figures that relate to the second policy in the above list are not available. But there is some research showing that this policy may eventually result in demand-driven discharge. Most of the research to date assumes that service time is exogenous to system congestion, but there is some research showing that a high level of utilization leads to a reduction in patient flow and service time in hospitals. This is associated with an increase in risk of mortality and an increase of readmission rate [13]. For ICUs, Anderson et al. [14] show that when occupancy rate increases the LOS decreases even by excluding prematurely discharged patients. This shows that keeping the patients in the ED before allocating an intensive care bed may reduce the LOS (in other words reduce the standard of ward care) of the current patients in the ICU. However, they are counted in the normal discharging category.

The above findings demonstrate that ICUs often confront decisions in which one of their current patients must be selected for demand-driven discharge to make a bed available for another critically ill patient. The potential impact of these demand-driven discharge decisions on patient welfare presents ethical issues for the hospital. These ethical problems require further attention and elaboration that lie beyond the scope of this work. The patients who are discharged prematurely will be transferred to other units such as the transitional care unit (TCU). Demand-driven discharge can be seen as a part of the treatment phase in the patient flow, as it is applied to patients who could be retained in the ICU if there was no demand pressure, and in cases of patient discharge and transfer to another ward there is often no (or very minimal) negative impacts on their care (for more discussion we refer to Anderson et al. [14]). However, such discharges are undesirable and may escalate mortality rates [15]. As indicated by Chan et al. [8], clinicians make the decision to discharge a patient from the ICU based on their clinical judgment, as predictive models of patient dynamics are not readily available. When a patient is discharged from the ICU or the hospital, there is a chance of readmission due to several possible reasons. Elliott [16] provides a literature survey on readmission in ICUs. Australian readmission rates have been reported from 3.9% to 10.5%, which omits readmissions later than 48 h after initial ICU discharge [17]. Patient readmission significantly reduces the capacity of hospitals and imposes additional costs to hospitals and patients. Readmission has crucial adverse impacts on limited resources such as ICUs. Hence, ICU readmission within 72 h of discharge is a performance indicator for ICUs according to the Australian Council on Health Care standard. Elliott et al. [18] show that readmitted patients in the ICU have higher mortality rates than those not readmitted. Kc and Terwiesch [13] indicate that readmission markedly reduces the ICU capacity and places additional stress on the ICU. Readmitted patients generally need a longer LOS thus placing an extra load on the ICU. Kc and Terwiesch [13] demonstrate that a readmitted patient requires a significantly longer stay in the ICU compared to his/her first visit. As a corollary, an overcrowded ICU results in more readmissions.

Bearing in mind the crucial consequences of readmissions, it has been reported that patients who are discharged from an ICU prematurely are more likely to be readmitted than those discharged maturely [19,20]. Therefore, when a decision is required on discharging a patient prior to treatment completion, the concomitant impacts of the decision on the load of ICU should be considered. This problem is linked to the general capacity planning problem as studied by Asaduzzaman and Chaussalet [21]. Chan et al. [8] use the probability of readmission and length of stay after readmission (LOS^r) to outline an ICU demand-driven discharge policy. Their model assumes LOS is a memory-less random variable. This assumption allows the securing optimal solutions in certain regimes. However, according to Dobson et al. [22] “in ICU operations, a complete system description requires knowing the status of every patient in the ICU and is not really memory-less”.

In this study by assuming (based on statistical evidence) that a demand-driven discharge policy is practiced by ICUs, we shed some light on the required decision making for selecting the patient to be discharged from the ICU before completion of his/her treatment.

We outline some scenarios considering the probability of readmission, length of stay after readmission (LOS^r) and also the remaining length of stay (LOS^t) to select a patient who can be discharged prematurely so that his/her bed may be given to a newly arrived patient. We compare various polices by using an extensive simulation study to nominate a patient for demand-driven discharge. Instead of a geometric distribution (used in [8]) we use a Weibull distribution which covers a wide range of distribution shapes and is not necessarily memory-less. The model in this study is a stochastic dynamic programming problem. In the case where one assumes full knowledge of the arrival times and LOS's for each patient, the problem turns into a dynamic programming model with a large state domain. We show that even in this case solving a real sized problem is almost undoable in any reasonable time frame by formulating the problem as a linear integer program.

In the next section we present a review of the related literature. In Section 3, we explore the problem and its complexity. Section 4 formulates the problem as a stochastic dynamic program as well as a linear integer program for deterministic situations. Section 5 explains different discharge scenarios. In Section 6, we carry out an extensive simulation study considering different LOS distributions, different level of occupancy and scenarios discussed in Section 5. In Section 7, we summarize the result of simulation study. Finally, Section 8 concludes the paper.

2. Literature review on demand-driven discharge in ICUs

In the literature, operational demand-driven discharge models consider alleviating overcrowding in ICUs and keeping the mortality rate as low as possible. Iapichino et al. [23] show that a higher occupancy level leads to a higher mortality. Swenson [24] applies a ranking strategy, based on the amount of care required for each patient as well as the risk of complications, to allocate a limited number of beds in ICUs to patients. Swenson [24] does not consider demand-driven discharge. Dobson et al. [25] model the ICU as a Markov chain and define states as the remaining length of stay (LOS^t) for each patient. Then, they use the expected remaining length of stay in deciding which patient should be discharged. They developed an aggregation–disaggregation technique to reduce the size of the state space and compute the stationary probability distribution, which requires an affordable computing time for high dimensional problems. In addition, they investigate how the surgical schedule, a factor under the control of the hospital (the third