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Multilevel control chart and fuzzy set theory to monitor inpatient falls☆

Chih-Ming Chang [a,b], Chi-Hung Kao [b], Wei-Shun Sha [b], Wen-Hsiang Wu [c], Juei-Chao Chen [b,*]

[a] MacKay Memorial Hospital, HsinChu, Taiwan
[b] Fu Jen Catholic University, New Taipei City, Taiwan
[c] Yuanpei University of Medical Technology, HsinChu, Taiwan

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ABSTRACT

Monitoring hospital adverse events ensures the patient's safety. This study aims to develop a multilevel control chart and to apply fuzzy set theory and warning lines concept to monitor inpatient adverse events. This study uses a *u* chart to monitor the adverse events relating to falls. This study also considers the severity of fall injuries to develop multilevel control charts, and applies fuzzy set theory to determine the severity of falls. The final analysis of this study is a combination of multilevel control charts, fuzzy set theory, and warning lines concept. The findings of this study show that traditional control charts do not consider the severity of fall injury, whereas multilevel control charts can make up for the deficiencies of traditional control charts through the establishment of fuzzy rules and warning lines, thus reducing the shortcomings of traditional control charts, which cause error and low sensitivity.

1. Introduction

Issues in patient safety are a global health care problem (Baker, Morton, Gatton, Tong, & Clements, 2009; Patel & Wu, 2014). Some of the most common adverse events in health care settings are medication errors, inpatient falls, catheter dislodgements, and transfusion-related adverse events. Of all, inpatient fall is the most frequent as well as the most serious adverse event, constituting 24%–84% of global health care adverse events (Akihito, 2006; Haines, Hill, Walsh, & Osborne, 2007; Tzeng & Yin, 2008). Taiwan Joint Commission on Hospital Accreditation implements in Taiwan a patient-safety reporting system, which reports 60,739 adverse events in 2013, of which 16,173 are inpatient falls; thus, inpatient falls rank second in the list of most common adverse events (Taiwan, 2013).

Inpatient falls not only lead to accidental injury but also have a direct impact on psychological status, which consequently may lead to alterations in the initial treatment plan, prolongation of hospitalization, and reduction in patient and family's life quality (Albert et al., 2014; Spoelstra, Given, & Given, 2012). Inpatient falls during hospitalization not only increase hospital cost but they also may lead to medical dispute. Therefore, patient-safety quality indicators are necessary in every medical institution.

Monitoring hospital adverse events helps to ensure patient safety (Baker et al., 2009). In addition, because adverse events are increasing, monitoring these events can help to decrease the incidences by examining the causes. To do so, the monitoring systems should consider not only the rate in which the events happen but also the severity of those events.

This study aims to examine the indicators of inpatient falls through *u* control charts to find a way of reducing these falls. Traditional control charts only consider the number of abnormal events but do not take into account the severity of these events. Using multilevel control charts allows distinguishing and classifying the severity of the adverse events. Fall severity judgment has fuzzy, subjective characteristics; thus, applying fuzzy set theory and the concept of warning lines could draw out the real problems and improve the traditional classification of inpatient fall severity.

After this introductory section, Section 2 presents the theoretical background for his research. Section 3 offers the study's design and method, Section 4 presents the results, and Section 5 provides the conclusions for this study.

2. Theoretical background

During 1920s, Shewart is the first to propose the use of control charts, an important tool for statistical process control (SPC). Control charts are useful in quality control to analyze and process variables, determine process capabilities, and to monitor the effects of the variables on performance (Sabegh, Mirzazadeha, Salehian, & Weberb, 2014). When the process of the control chart is on a stable status, that process is capable to predict the ability of the process to produce a

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* Corresponding author at: Department of Statistics and Information Science, College of Management, Fu Jen Catholic University, No.510 Zhongzheng Road, Xinzhuang Dist., New Taipei City 24205, Taiwan.
E-mail address: 006884@mail.fju.edu.tw (J.-C. Chen).

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Table 1
NSW Health Complaints Commission risk severity assessment matrix, NSH, Australia.

Severity	Criteria	Financial loss
Serious	Patients suffering death unrelated to the natural course of their illness and not an expected patient management outcome, and also not involving suspected suicide or any sentinel events.	$10,000,000
Major	Patients suffering a major permanent function loss (sensory, motor, physiologic, or psychological) unrelated to the natural course of their illness and not an expected patient management outcome.	$1,000,000
Moderate	Patients suffering permanent reduction in function (sensory, motor, physiologic, or psychological) unrelated to the natural course of their illness and not an expected patient management outcome.	$100,000
Minor	Patients requiring increased level of care, including: Review and evaluation, additional investigations, or referral to another clinician.	$50,000
Minimum	Patients with no injury or need for increased level of care or length of stay.	1

Note. Source: New South Wales Health Department (2011).

particular statistical model. Therefore, a control chart provides a quick and easy way to identify critical variables that lead to an outcome (Zarandi, Turksen, & Kashan, 2006).

The health care industry increasingly uses control charts to monitor performance, thus improving the quality and enhancing the safety of patient care (Benneyan, Lloyd, & Plsek, 2003; Montgomery, 2007). Control charts can monitor, for example, in detecting infections rate, inpatient falls, patient waiting time, and medication errors (William, 2003).

In 1965, Zadeh proposes the fuzzy set theory (Sabegh et al., 2014). Classical set theory assesses the membership of elements in a set in binary terms: An element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set. Fuzzy set theory is useful to describe difficult to articulate semantics (Kvist, 2007; Sabegh et al., 2014). Fuzzy set theory is useful in health issues; Wu (2015) uses fuzzy set theory to deal with food safety issues. In addition, according to Faraz and Moghadam (2007), control charts in combination with fuzzy numbers can improve control chart detection results and allow the easier detection of changes in the process under control.

Although traditional control charts can detect problems, this method has difficulties in determining variables such as the severity of the falls. According to the Safety Assessment Codes (SACs) for adverse events (New South Wales Health Department, 2011), five categories of severity for inpatient fall injuries exist: severe, major, moderate, minor, and minimum (Middleton, Chapman, Griffiths, & Chester, 2007). The determination of the severity of fall injuries has fuzzy, subjective characteristics. Therefore, using fuzzy set theory to improve the sensitivity of the traditional control chart is necessary to detect abnormal events. Table 1 shows the monetary equivalence of these falls and offers the specific characteristics of each type of fall injury.

3. Design and method

The study uses as sample those inpatients with fall-related injuries. First, by using a u chart, the study determined that the number of inpatient fall-related adverse events obeys a Poisson distribution by using u chart to monitor. Second, the study analyzes the incidence of falls with a multilevel control chart to achieve the best results. Third, the study applied fuzzy set theory to determine the severity of falls. Finally, combining fuzzy set theory, the multilevel control chart, and warning lines concept, the study analyzed the fall-related adverse events in Taiwan's Patient-safety Reporting System for the period 2011–2014. The analysis involved seven steps.

3.1. Data collecting

The study collected the inpatient fall-related adverse events data from Taiwan Patient-safety Reporting System for the period 2011–2014. In addition to the number of falls, the severity of the fall, and the time of occurrence, the study also recorded the patient's basic information: gender, age, disease diagnosis, drug administration, whether the patient went through surgery, the surgery site, and other important variables. This study constructs a fishbone diagram with these variables.

3.2. Monitoring indicators

This study uses attribute control charts, which include p control charts, np control charts, c control charts, and u control charts (Amirzadeh, Mashinchi, & Yaghoobi, 2008). As a calculation method to construct the u control chart, this study uses inpatient fall events. The study chose this adverse event because inpatient falls is the most common hospital adverse event, and one of the important indicators of Taiwan Clinical Performance Indicator (TCPI).

After collecting the data from inpatient fall-related adverse events, the study applied the TCPI's formula (Taiwan, 2013), where the definition of numerator is the total number of fall-related incidents and the definition of denominator is the days of stay. The study has created the attribute control chart of u control chart in (3) and (5) to show the limits of the attribute control chart that the study developed by using the Minitab 15 software.

(1) $\overline{f} = \frac{\sum f_i}{\sum n_i}$, that is, the average number of inpatient fall-related adverse events and the center line of the control chart.
(2) Standard deviation $\sigma_f = \sqrt{\frac{\overline{f}}{N}}$.
(3) Upper control limit $UCL = \overline{f} + 3\sigma_f$.
(4) Center line $CL = \overline{f}$.
(5) Lower control limit $LCL = \overline{f} - 3\sigma_f$.

In these formulas, f_i = the ith month of total number of fall-related incidents, n_i = is the ith month of total number hospitalized patients in days of stay and N = the total number of days a patient stays in the hospital.

3.3. Interpretation the results of u chart

While monitoring the fall-related adverse event in u control chart, inpatient fall-related incidents fall within the upper and lower control limit, which shows that the event is in a stable status and indicates that no changes or intervention are necessary at this point. However, if the fall-related adverse events were to fall on the UCL, this result would mean that the process is probably out of control and that an investigation is necessary to find and eliminate the cause.

Table 2
Fuzzy grading of severity.

Linguistics	*L*	*M*	*U*	*Fi*
Minimum	0	0	0.25	0.08
Minor	0	0.25	0.5	0.25
Moderate	0.25	0.75	0.5	0.5
Major	0.5	0.75	1	0.75
Serious	0.75	1	1	0.92