An Evidence-Based Approach to Reduce Nuisance Alarms and Alarm Fatigue

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About the Author

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To help clinicians make evidence-based decisions about where to program alarm settings, Masimo Corp. based in Irvine, CA conducted an analysis of 32 million pulse oximetry (SpO_2) data points from 10 hospital general post-surgical care areas. Each hospital was equipped with a Masimo Patient SafetyNet™ remote monitoring and clinician notification system, which continuously captures and stores time-stamped SpO_2 data with a one-second resolution. This paper reports on the results of a retrospective analysis conducted by the company to determine the incidence of alarms at various alarm threshold and delay settings.

Analysis of the Problem

Alarm hazard has been the first or second "Top 10" technology hazard named by the ECRI Institute in the last three years.[1] The high incidence of false and nuisance alarms in hospital settings has led clinicians to either ignore alarms or defeat them altogether as exemplified by a recent high-profile case in a major tertiary care hospital in Boston.[2] One emergency department (ED) study reports that less than 1% of alarms were clinically actionable, requiring bedside intervention.[3] Reducing alarm fatigue is a shared responsibility between clinicians, biomedical engineers, and industry. Strategies for addressing this hazard require optimization of the signal path, technology innovation and examination of alarm policies. Pulse oximetry is one of the most common continuous measurements. It is therefore essential to address alarm management for this life-critical vital sign. Innovations in signal processing have significantly reduced alarms by 97% due to motion artifact.[4] However, many true alarms that do not require clinician intervention contribute to nuisance alarms.

The Johns Hopkins Hospital reduced pulse oximetry alarms by 63% in a step-down unit by reducing the low SpO_2 alarm thresholds from 90% to 88%.[5] Rheineck reported a 60% reduction in low SpO_2 alarms in a post-anesthesia care unit (PACU) population by adding a 15-second delay to the 90% lower SpO_2 limit.[6] Dartmouth Hospital achieved more dramatic results by lowering the low alarm threshold to 80% with 15-second delay for continuous patient safety surveillance. Results showed a dramatic reduction in rapid response calls and ICU transfers.[7]

The tradeoffs between SpO_2 low alarm threshold and delay settings have not been described across the full range of low SpO_2 alarm settings and alarm annunciation delays. Automated SpO_2 data collection allows the study of alarm behavior retrospectively for a given patient population. The goal of this evidence-based analysis is to allow clinicians to develop internal policies that optimize alarm behavior and reduce alarm fatigue.

Factors Influencing SpO_2 Alarms

The occurrence of alarms is dependent on the integrity of each component in the signal path. A compromised or suboptimal component will result in increased nuisance alarms.

Sensor Application and Choice

Proper application of the SpO_2 sensor is critical. An improperly applied sensor is prone to weak signal strength, light interference, or the penumbra effect.[8,9] Single-patient-use sensors should be used in continuous monitoring applications, especially where low perfusion or motion is common. The lower mass and skin adhesion of single-patient-use sensors improves the coupling of the sensor to the biologic signal. Second-source recycled sensors may provide financial savings, but if not properly refurbished can deteriorate sensor performance and contribute to nuisance alarms. Sensor choices allow a hospital to meet both clinical and financial goals. A broad range of sensor configurations are available, each validated for the intended application. Biomedical personnel should be aware that using sensors outside the instruction for use may impact accuracy. Pulse oximeter manufacturers can provide a list of approved sensors.

Cable Management

All cables, regardless of application, have a finite life depending on the environment of use. High-patient-turnover areas like emergency departments and operating rooms are particularly challenging environments. Cable connectors are prone to mechanical stress resulting in intermittent failures that can generate nuisance alarms. Cables should be routinely inspected and replaced on a lifecycle schedule specific to the care area. Intermittent failures are typical of cables approaching the end of their lifecycle and a major cause of nuisance alarms.

Instrumentation and Signal Processing

Reducing alarms due to false data (false alarms) is essential to an effective alarm management strategy. Most pulse oximeters perform well with patients who are not moving and have good peripheral perfusion. However, during motion and low perfusion, conventional pulse oximetry can freeze, zero out, or falsely alarm. Freezing or zeroing out can delay the notification of true alarms when the patient may require intervention. False alarms due to motion and low perfusion can significantly increase the total number of alarms so that clinicians become desensitized to true alarms when they occur.

Masimo has developed a new technology for pulse oximeters called Signal Extraction Technology® (SET) which is designed to measure pulse oximetry accurately through motion and low-perfusion conditions. Pulse oximeters embedded in mulitparameter monitors that implement SET technology audibly alarm based on three primary factors: The displayed SpO_2 and pulse rate value

- The user-defined alarm threshold and alarm notification delay
- Alarm averaging

This means that two mulitparameter monitors with the same embedded pulse oximetry technology can have different alarm behaviors.

Effects of Settings on Alarm Frequency

A retrospective analysis was conducted to determine the incidence of alarms at various alarm threshold and delay settings. Alarm policies can be determined by collecting high-resolution parametric data that represents a patient population and retrospectively measuring the effects of alternative alarm configurations.

For example, there are instances where alarm thresholds are exceeded for clinically insignificant periods of time, necessitating alarm management strategies that provide clinician-controlled notification delays. Patients in acute care settings can have desaturation events that fall below the traditional alarm threshold of 90% but recover within a few seconds without the need for therapeutic interventions. Figure 1 shows a distribution of SpO_2 values in post-surgical patients on a 36-bed floor over an 11-month period.[10] SpO_2 values less than 90%, the most

Technology Overview

In 2005, Masimo introduced a new technology for pulse oximeters called Signal Extraction Technology® (SET). Conventional pulse oximetry assumes that arterial blood is the only blood moving (pulsating) in the measurement site. During patient motion, the venous blood also moves, which causes conventional pulse oximetry to under-read because it cannot distinguish between the arterial and venous blood. SET signal processing identifies the venous blood signal, isolates it, and using adaptive filters, cancels the noise and extracts the arterial signal, with the goal of reporting the true arterial oxygen saturation and pulse rate.

The Patient SafetyNet® (PSN) remote monitoring and clinician notification system combines this SET pulse oximetry data with acoustic respiration rate monitoring and wireless clinician notification via pager. The devices have a selectable audio alarm delay to reduce bedside noise levels. The bedside devices connect to a PSN server over an isolated biomedical network or the hospital's main information technology (IT) network, either hardwired or wireless. The PSN server communicates to both a central display as well as an optional direct clinician notification system. Additional alarm delays can be configured for the clinician notification device so that clinicians close to either the central display or the patient can respond to that alarm and avoid a notification. The technology includes a configurable alarm escalation rule set that notifies additional clinicians if the alarm persists.

common alarm threshold setting, occurred 4.4% of the entire monitoring time which equates to an average of 63 minutes per patient per day. Assuming an average desaturation event of 15 seconds, the 63 minutes of alarm condition would result in 250 separate alarms.

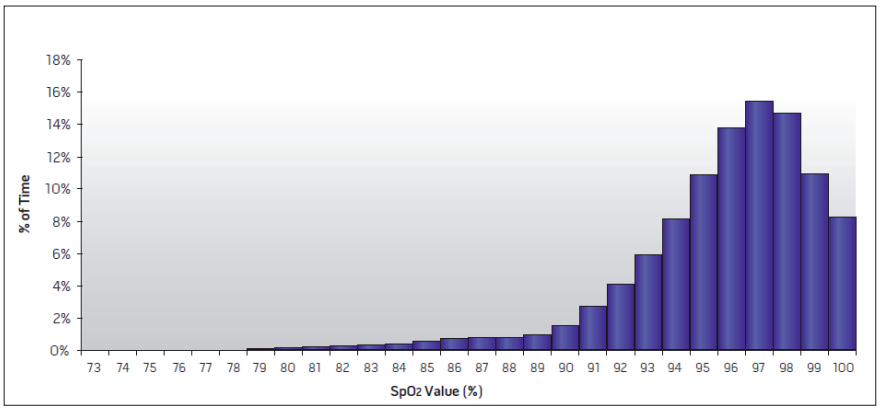

Figure 1. Frequency of SpO_2 values in post-surgical patients. Values under 90% occurred 4.4% of the time. However, very few of these alarms below 90% were actionable.

Delay Settings

Adding a time delay between event detection and the resulting alarm is one of the simplest and most effective methods to reduce alarm occurrence. Separation of events between short-duration and longer-duration alarms can be realized by modest alarm delays. Most desaturations below 90% recover within a short period of time. These self-correcting desaturations represent the vast majority of alarms. Audio delays provide two benefits: They quiet the beside environment, and reduce alarms caused by short desaturation events.

Figure 2 shows the impact of 5, 10, and 15-second delays on the number of alarms at a low SpO_2 threshold setting of 90%. An alarm delay of 15 seconds reduces alarm frequency by 70%.

Threshold Settings

The low SpO_2 alarm threshold can also have a significant effect on the number of alarms generated. Ideally, alarm thresholds should be set to the individual patient condition. Modest lowering of the alarm threshold in the absence of any alarm delay can help reduce the total number of alarms generated. Figure 3 shows that lowering the low SpO_2 alarm threshold from 90% to 88% reduces alarms by 45%. Reducing the low SpO_2 alarm threshold from 90 % to 85% decreases alarms by 75%.

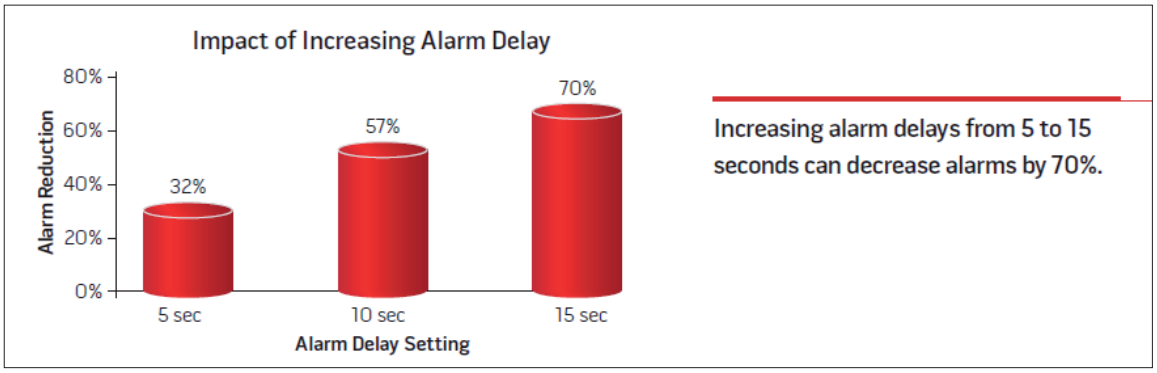

Figure 2. Longer alarm delays can greatly reduce nuisance alarms, assuming such short-duration events are clinically nonactionable.

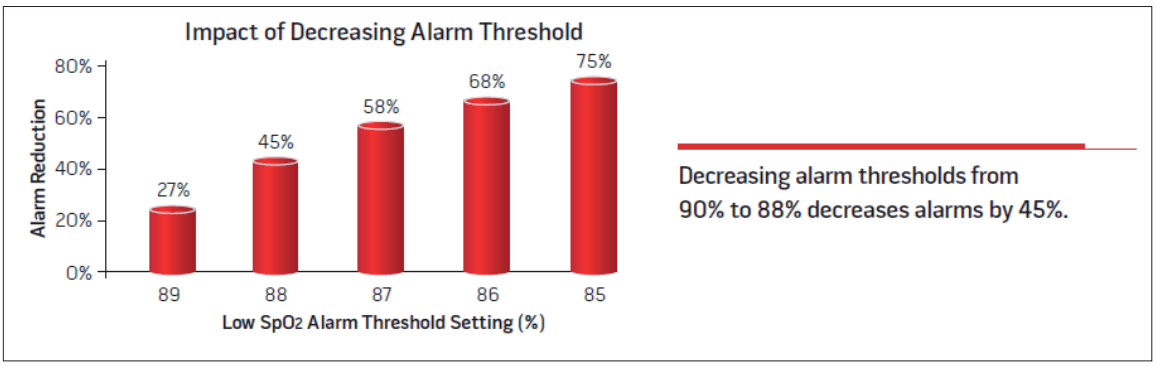

Figure 3. Lower alarm thresholds significantly reduce the occurrence of alarms and should be set according to the severity and risk of the patient population.

Combining Alarm Delay and Threshold Settings

Combining both alarm delays and lower threshold produces the greatest reduction in alarms, as shown in Figure 4. Lowering alarm limits to 88% with a 15-second delay reduces alarms by over 85%. These two settings offer significant alarm reduction while preserving actionable alarms. Using the previous example of 250 alarms per day, setting the low SpO_2 threshold to 88% with a 15-second delay would reduce alarm frequency to 38 alarms per patient per day, a six-fold reduction. Lowering the low SpO_2 alarm threshold to 85% with a 15-second delay would reduce the alarms even further to 15 alarms per patient per day.

Table 1 shows the full range of alarm reductions possible by lowering alarm thresholds and increasing alarm delays, compared to a 90% low SpO_2 threshold at a zero-second delay. Alarm delays have a diminishing effect on alarm reduction as alarm thresholds are lowered from 89% to 85%. This table demonstrates that alarm occurrences can be managed through the combination of low alarm and audio delays.

Alarm Averaging

The responsiveness of the numeric display to beat-to-beat changes in SpO_2 can be smoothed by averaging the current measured values with previous values. This filtering reduces the low SpO_2 data points of short duration desaturation events. Modest changes in SpO_2 averaging times have a small impact compared to alarm

Key Terms

Actionable Alarms: Alarms that require a response to bedside and therapeutic intervention to avoid an adverse event.

Alarm Fatigue: Failure to recognize and respond to true alarms that require bedside clinical intervention as a result of high occurrence of alarms.

False Alarms: Alarms due to artifact that produce false data.

Nonactionable Alarms: True alarms that do not require patient therapeutic intervention.

Nuisance Alarms: The high occurrence of clinically nonactionable alarms.

True Alarms: Alarms that represent true and accurate physiologic data

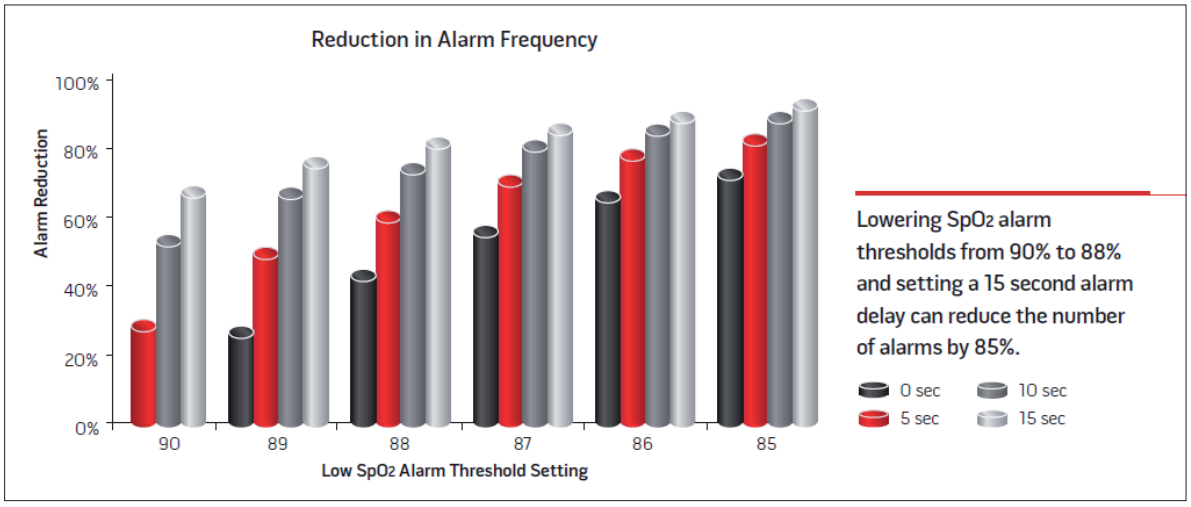

Figure 4. Impact of combining alarm delay and lower threshold settings. The combined effect of adjusting both settings significantly reduces nuisance alarms in this data set.

Reduction in Alarm Frequency

Low SpO2 Alarm Threshold (%)	Alarm Delay			
	0 sec	5 sec	10 sec	15 sec
90	Reference	32%	57%	70%
89	27%	51%	69%	79%
88	45%	64%	78%	85%
87	58%	74%	84%	89%
86	68%	80%	87%	91%
85	75%	85%	87%	91%
84	80%	89%	93%	95%
83	84%	91%	95%	97%
82	87%	93%	96%	97%
81	89%	95%	97%	98%
80	90%	96%	97%	98%

Table 1. Percent reduction in alarms at various low SpO_2 alarm thresholds and alarm notification delays, compared to a 90% low SpO_2 threshold at a zero-second delay.

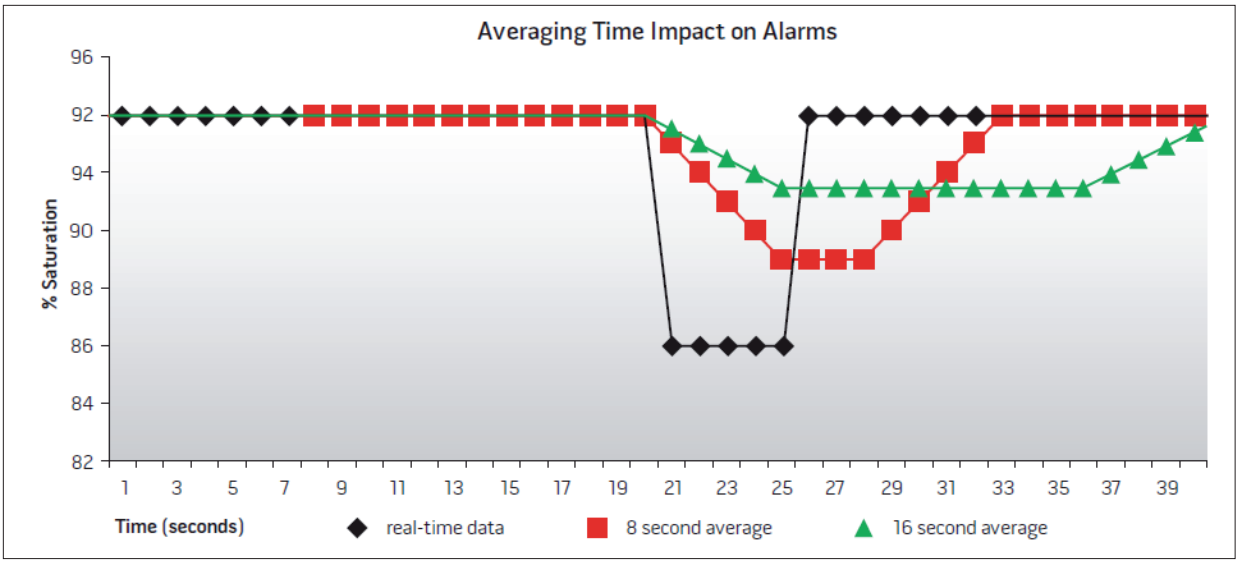

Figure 5. Longer averaging times can filter the actual changes in saturation such that alarm thresholds may not be crossed for short duration desaturation events.

thresholds and alarm delays at reducing alarm frequency. Modest extensions in averaging times (e.g., from 8 to 16 seconds) can filter out some short duration saturation dips that rebound in a few seconds. Figure 5 illustrates the impact of longer averaging times based on a controlled reference signal. Masimo does not recommend averaging time greater than 16 seconds because it can mask clinically significant desaturations and delay the notification of actionable alarms.

Adaptive Alarms

New alarm technologies hold promise to further reduce unnecessary alarms. Setting alarm thresholds has historically been a one-size-fits-all endeavor. As a result, the alarm behavior of a patient with a normal baseline SpO_2 of 98% is treated by oximeters the same as a patient with a baseline of 93%. In each case, a drop below a low-alarm threshold of 90% will generate an alarm event, though the former case may be a more clinically significant event. This limitation contributes to the number of nonactionable alarms because the same alarm rule is applied to all patients in a given care area.

Setting individual alarms is the recommended practice to reduce alarms, but this effort burdens nursing staff work load. A new alarm concept addresses this challenge by adjusting the audio alarm threshold based on a continuously updating SpO_2 baseline calculation.

Clinicians still set the traditional low SpO_2 alarm threshold and selectively activate the adaptive alarm feature. The algorithm compares the current value against the patient baseline value, the low alarm threshold setting, and a low safety value determined by a configurable setting. If the new SpO_2 value falls significantly from the baseline value an audio alarm activates. If the patient's baseline drifts towards the low alarm threshold value, the tolerance for audio annunciation narrows.

The benefit of this approach is that audio alarms, which are the major cause of alarm fatigue, automatically adjust to the patient's baseline value. The sensitivity of the alarm can be increased by lowering the rapid desaturation value.

Table 2 compares the percent reduction in false alarms achieved using the adaptive alarm setting as compared to that achieved with conventional alarm settings using a 15-second delay.

Low Alarm Setting	Standard (15 sec delay)	Adaptive Alarm
90	68%	86%
88	83%	92%
85	94%	96%

Table 2. A comparison of the percent reduction in false alarms achieved using the adaptive alarm setting as compared to that achieved with conventional alarm settings using a 15-second delay.

Case Study

A recent study conducted on a post-surgical orthopedic floor at Dartmouth-Hitchcock Medical Center in Lebanon, NH and published in *Anesthesiology* demonstrated significant improvements in patient outcomes. The monitoring system reported a 68% reduction in rapid response activations and a 50% reduction in ICU transfers as compared to the previous year. These improvements saved an annual estimated 135 ICU days from this single 36-bed post-surgical unit.[7]

Dartmouth implemented the use model where alarms are sent directly to a clinician pager. The bedside low SpO_2 alarm was set to 80% with the audio delay set to 15 seconds at the bedside and 15 seconds before an alarm notification was sent to the clinician device. These settings represent an extreme case compared to the analysis summarized in Table 1.

During the implementation phase, careful attention was focused on selecting the right sensor and optimizing every element in the signal chain including the information technology (IT) wireless infrastructure. Alarms were connected to the assigned nurse through a dedicated paging system. No additional personnel were hired to support the system.

The key to this success was a thoughtful alarm management protocol that consistently achieved a performance level of four alarms per patient per day. Approximately half of these alarms were due to sensor removal for patient ambulation. The Dartmouth cross-functional team (which included nurses, physicians, biomed, and IT) were awarded the ECRI Technology Achievement Award for this remarkable achievement. The financial benefits of this pilot project justified extending the system in the hospital to other general care patient populations.

Discussion and Recommendations

Eliminating alarm fatigue is a shared responsibility between clinicians, clinical/biomedical engineers and industry. Clinicians determine policies regarding which patients are monitored and what alarms are set. Biomedical professionals support clinicians by selecting, implementing, and maintaining the best and most cost-effective technology solutions. Both depend on industry to provide technology solutions.

A limitation of the analysis summarized in Table 1 is that true alarms requiring clinical intervention were not captured in this data set. The definition of an "actionable alarm" is subject to hospital definition, but in its simplest form is any alarm that requires a bedside intervention. In this analysis, the worst-case actionable event would be a desaturation to 85% lasting more than 15 seconds. If the low alarm threshold is set to 85% and 15 seconds, then sustained desaturations above 85% would not result in an alarm event. Whether these desaturation events that never cross the low SpO_2 threshold setting of 85% are actionable is subject to clinical agreement for the intended patient population. The adaptive alarm technology discussed earlier addresses this at low alarm threshold setting of 90%, which will maintain sensitivity to desaturation events between 85% and 90% but with similar nuisance alarm reduction benefits.

Alarm management extends beyond how the bedside device functions. Alarm management solutions in intensive care areas (where 1:1 patient to nurse ratios are common) differ from those in general medical-surgical wards (where patient to nurse ratios often exceed 6:1). Pulse oximetry solutions in the ICU often involve the selection of a pulse oximetry option provided by an OEM source. The implementation of alarms is the responsibility of the bedside monitor manufacturer and may not necessarily include the same capabilities provided in OEM end-user devices. This is especially true with selectable alarm delays. Biomedical departments should be vigilant in understanding alarm management capabilities when selecting mulitparameter monitors.

General care areas require more of a systems approach to alarm management because nurses are typically not at the bedside when an alarm occurs. Patients are more active in the general care area and thus the need for measure-through-motion and low perfusion technologies is greater. Frequent audio alarms at the bedside disrupts the rest cycle of recovering patients. Modest audio delays filter short- duration desaturation events, which reduces nuisance alarms at the bedside without masking the visual alarm indicator should a clinician be in the vicinity.

When an actionable alarm occurs, the assigned nurse needs to be notified so he or she

can respond before the patient further deteriorates. Two systems architectures have emerged:

- Route all physiologic signals back to a remote central surveillance location
- Communicate alarms wirelessly and directly to the assigned nurse

The former has the advantage of using monitoring technicians to interpret alarms and only notify nurses to actionable events. The limitation of this architecture is increased capital and operational cost to sustain the system. If such investments have already been made, adding SpO_2 has merit if the SpO_2 technology is reliable in high-motion environments.

The alternative architecture directly distributes alarms to the assigned nurse. This option avoids the requirement for monitoring techs to continuously view a central station. However, in this use model, direct notification requires an advanced alarm management capability; otherwise, nuisance alarms are likely to result in system abandonment or user desensitization.

Several companies have introduced wireless "secondary" alarm systems that connect beside devices to wireless devices. The success of these systems has been limited by the alarm fatigue challenge. Regardless of chosen use model, alarm management strategies are imperative in order to realize any clinical benefit.

Conclusion

Optimizing alarm behavior is a shared responsibility. The analysis in this article provides an example on how to reduce nuisance alarms when implementing Masimo continuous pulse oximetry technology; however the methodology may be applicable to other continuous monitoring technologies. Clinicians can make evidence-based decisions about where to configure SpO_2 alarm settings based on the information presented in this analysis for similar patient populations. Optimizing alarm frequency while maintaining notification of actionable alarms can be accomplished with the following alarm settings for the post-surgical general care ward:

- Use single patient use sensors for continuous monitoring applications
- Ensure the integrity of all cables and connectors in the measurement system
- Lowering alarm limits to 88% with a 15-second delay reduces alarms by up to 85%.
- Maintain fixed averaging at 8 seconds

As always, clinicians must ensure proper application of the SpO_2 sensor and set alarm thresholds to the individual patient and care setting. ■

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