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Optimisation of clinical workflow and monitor settings safely reduces alarms in the NICU

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Abstract

Aim: To address alarm fatigue, a new alarm management system which ensures a quicker delivery of alarms together with waveform information on nurses' handheld devices was implemented and settings optimised. The effects of this clinical implementation on alarm rates and nurses' responsiveness were measured in an 18-bed single family rooms neonatal intensive care unit (NICU).

Methods: The technical implementation of the alarm management system was followed by clinical workflow optimisation. Alarms and vital parameters from October 2017 to December 2019 were analysed. Measures included monitoring alarms, nurses' response to alarms and time spent by patients in different saturation ranges. A survey among nurses was performed to evaluate changes in alarm rate and use of protocols.

Results: A significant reduction of monitoring alarms per patient days was detected after the optimisation phase (in particular for SpO2 ≤ 80%, $P < .001$). More time was spent by infants within the optimal peripheral oxygen saturation range (88% < SpO2 < 95%, $P < .001$). Results from the surveys showed that false alarms are less likely to cause an inappropriate response after the optimisation phase.

Conclusion: The implementation of an alarm management solution and an optimisation programme can safely reduce the alarm burden inside of the NICU environment.

KEYWORDS

alarm, alarm management, monitoring, neonatal intensive care unit, safety

1 | INTRODUCTION

Neonatal intensive care units (NICUs) provide high-quality care to critically ill newborn patients.[1] The majority of the patient population consists of premature infants, with immature physiological functions, at greater risk of developing serious complications, which include necrotising enterocolitis,[2] bronchopulmonary dysplasia or retinopathy of prematurity.[3,4] They often require respiratory support from ventilators and parenteral feeding and medication via infusion pumps. To detect possibly critical events, physiological signals,

Abbreviations: GA, Gestational age; HR, Heart rate; MMC, Máxima Medical Center; NICU, Neonatal intensive care unit; SpO2, Peripheral Oxygen saturation.

which often include heart rate, respiration rate, arterial blood pressure and oxygen saturation levels, are continuously monitored to detect moments in which a predefined threshold is exceeded. This leads to the generation of an alarm to alert caregivers.

Patient monitoring devices are responsible for producing a high number of alarms. One of the most common alarms in the NICU relates to peripheral oxygen saturation (SpO2), as the use of supplemental oxygen in preterm infants is common practice and patients need to be kept in a tight range to prevent harm.[5-8] However, many alarms are considered false or clinically irrelevant.[9,10] In previous studies, it was estimated that over 70% of clinical alarms do not require clinical intervention.[11] These alarms are an important concern since they both disturb patient's sleep and increase the level of stress experienced by their parents as well as the hospital personnel.[12] Alarm fatigue occurs when caregivers are exposed to large numbers of alarms, resulting in desensitisation, delayed or even no response to alarms,[13,14] which can lead to serious patient harm.[11,15] False alarms are responsible for reducing nurses' response time and trust in the alarms.[16-18] In particular, when performing Intensive Care Unit care in separate rooms per patient, alarm management is a safety concern, as caregivers are not continuously at the bedside of each patient. In that scenario, central

Key Notes

- To address alarm fatigue, a new alarm management solution, including a workflow optimisation programme was introduced in a NICU environment
- A significant reduction in the number of monitoring alarms combined with an increase in time spent within the optimal oxygen saturation range was found
- A reduction in the number of alarms in a NICU environment is feasible without compromising patient safety

TABLE 1 Implementation phases and characteristics of the populations involved in the study

Implementation phases	Phase-0	Phase-1	Phase-2
Whole periods	October 2017-August 2018	September 2018-April 2019	May 2019-December 2019
Quarters	October 2017-December 2017	October 2018-December 2018	October 2019-December 2019
Alarm management solution	Philips emergin alert management platform	Philips CareEvent	Philips CareEvent
Other implementations	—	—	Philips mobile caregiver app (since September 2019)
Handheld devices	Ascom I62	Ascom Myco	Ascom Myco
Servers	Central + Emergin Server	CareEvent server	CareEvent server
Integration	Alarms delivered to handhelds	No configuration changes/ accept-reject alarms possible	Improved configuration, workflow and processes
Visualisation from handhelds	Alarms as notifications on handhelds	Alarms and waveforms on handhelds	Optimised alarms and waveforms on handhelds
Survey for nurses' evaluation	—	First survey (November 2018)	Second survey (November 2019)
Populations (Whole periods)	**Phase-0**	**Phase-1**	**Phase-2**
Days	336	230	225
Patients days	11.93 ± 2.32	11.03 ± 2.34	11.11 ± 1.98
Gestational age	29.05 ± 1.18	29.15 ± 1.02	29.05 ± 1.31
Postmenstrual age	32.43 ± 1.34	31.93 ± 1.47	31.84 ± 1.33
Populations (Quarters)	**Phase-0**	**Phase-1**	**Phase-2**
Days	92	85	90
Patients days	11.93 ± 2.32	11.03 ± 2.34	12.11 ± 1.87
Gestational age	29.09 ± 1.00	29.20 ± 1.12	28.58 ± 1.02
Postmenstrual age	32.81 ± 1.00	32.06 ± 1.38	31.45 ± 1.03

monitoring and mobile alerting solutions would need to deliver alarms to the caregiver wherever they are.[19]

To reduce the alarm burden and improve alarm handling in a single family room NICU, a new alarm management solution that displays waveform information on nurses' handhelds was introduced. In a next phase, an optimisation programme was performed.

The aim of this study is to evaluate the effects of the implementation of an alarm management solution followed by an optimisation programme on the alarm rates and nurses' responsiveness to alarms over time. Since reducing alarms could result in an unsafe situation, the time spent by patients within the optimal saturation target range is also evaluated to determine the impact of this implementation on patient safety.

2 | METHODS

2.1 | Architecture of the NICU and study population

The NICU of Máxima Medical Center (MMC, Veldhoven, The Netherlands) includes a total of nine single infant rooms, five rooms for twins and one room for a triplet, with a total of 22 beds of which 18 are typically in use, for an admission rate of approximately 380 newborn patients per year.[19] During the study period, on average 90 per cent of the patients admitted in the NICU were born prematurely with a gestational age (GA) below 32 weeks. Patient population characteristics are specified in Table 1. A waiver for this study was provided by the medical ethical committee in accordance with the Dutch law on medical research with humans (WMO). More details about the organisation of the NICU and the equipment provided in each room can also be found in other works.[19-21]

In the unit, patient monitors are connected to a network, displaying alarms both on the central monitor and other bedside monitors. When a patient is admitted to the NICU, a patient profile is chosen depending on GA as shown in Table 2 which also includes the alarm limits that are currently used. Alarms in MMC NICU are classified into three different levels of priority, which include red (critical), yellow (alerting) and blue (technical) alarms.[19] Red alarms, being associated with a potentially life-threatening situation, have the highest priority and are characterised by a loud and high-frequency high repetition rate sound. Red alarms are relayed to nurses' handhelds, and in case of no response for 45 seconds, are forwarded to a pre-determined buddy nurse. Yellow alarms sound on the monitor with a

TABLE 2 Alarm settings (thresholds and delays) assigned to patients with different gestational ages (GA) in MMC NICU

Alarm	Parameter	GA < 26 wks	GA 26-36 wks	GA ≥ 37 wks
SpO2 ≤ 80%	Threshold (%)	80	80	80
	Averaging time (s)	10->4	10->4	10->4
	Delay (s)	10->20 (total delay 20->24)	10->20 (total delay 20->24)	10->20 (total delay 20->24)
80% < SpO2 ≤ 88%	Threshold (%)	88	88	92
	Averaging time (s)	10	10	10
	Delay (s)	10	10	10
SPO2 ≥ 95%	Threshold (%)	95	95	95
	Averaging time (s)	10	10	10
	Delay (s)	10	10	10
SpO2 smart alarm	Threshold (min)	SpO2 yellow alarms lasting ≥ 5 min		
	Averaging time (s)	No averaging		
	Delay (s)	No delay		
Bradycardia	Threshold (bpm)	80	80	60
	Averaging time (heart beats)	Last 12 (HR ≥ 80 beats/min) Last 4 (HR < 80 beats/min)	Last 12 (HR ≥ 80 beats/min) Last 4 (HR < 80 beats/min)	Last 12 (HR ≥ 80 beats/min) Last 4 (HR < 80 beats/min)
	Delay (s)	No delay	No delay	No delay
Heart rate (HR) low	Threshold (bpm)	100	100	100
	Averaging time (heart beats)	Last 12 (HR ≥ 80 beats/min)	Last 12 (HR ≥ 80 beats/min)	Last 12 (HR ≥ 80 beats/min)
	Delay (s)	No delay	No delay	No delay
Heart rate (HR) high	Threshold (bpm)	200	200	200
	Averaging time (heart beats)	Last 12 (HR ≥ 80 beats/min)	Last 12 (HR ≥ 80 beats/min)	Last 12 (HR ≥ 80 beats/min)
	Delay (s)	No delay	No delay	No delay

Note: Alarms and values indicated with a -> were introduced during phase-2 (available from May 2019).

softer sound and a lower repetition rate, but are not communicated to the nurses' handhelds. Blue alarms are notifications of technical problems, that sound with low repetition rate, and some are relayed to the handheld in case the monitor cannot measure or detect vital signals reliably.

Nurses also have the option to silence or pause an alarm at the bedside or from the central monitor. This is usually the first action performed in MMC upon entering the room as the alarm sounds are considered a nuisance for both patients and caregivers. Silencing stops a specific alarm for 60 seconds. On the other hand, an alarm pause stops all alarms generated by a patient for 180 seconds but can be manually terminated in case a patient handling is ended earlier. Alarm pause is typically used during nurse handling like feeding or diaper change.

2.2 | Study phases

Alarm handling architecture and modifications in the study period are presented in Table 1. In phase-0, monitoring alarms were sent as messages through the central monitor to an Emergin server (Philips Medical Systems), then to the central server of the messaging system (Ascom, Sweden) and from there alarms were distributed to handheld devices (Ascom i62). In phase-1, a new alarm management system, Philips CareEvent, was implemented without changing alarm settings. This solution requires just one server for alarm handling and allows for quicker delivery of alarms. It also allows the display of waveform information of all monitor signals on handhelds, for which the Ascom Myco handheld is used. In phase-2, direct access to real-time monitoring signals was implemented and alarm settings and workflow were optimised.

2.3 | Workflow optimisation

A multidisciplinary team of clinicians, nurses and engineers were engaged in an optimisation programme to optimise workflow and alarm settings. A literature study, an analysis of the current situation and nurse shadowing were performed to collect information about alarm pressure, nurses' behaviour and policies to improve alarm handling. Next, in several work sessions, 5 areas for improvement were determined, in accordance to literature [22]: standardisation of protocols, revision of alarms settings, workflow upon patient handling, training of nurses and a definition of guideline rules for alarm handling. Finally, the following changes were chosen and implemented:

1. Protocols for application, positioning and replacement of electrodes and sensors and protocol for the patients' admission and discharge from system were standardised.
2. Delay time for saturation-related alarms was increased from 10 to 20 seconds based on the findings from.[7,23,24] Averaging time was decreased from 10 to 4 seconds as suggested in.[21,25] An additional red 'smart alarm' was introduced to indicate yellow alarms lasting for more than 5 minutes. All modification to alarms are summarised in Table 2.
3. Nurses were instructed to pause alarms before starting to handle the patients to avoid generating alarms during caregiving. Additional training sessions were organised.
4. With regards to training, key users were made responsible for checking alarm management policy regularly. Nurses were trained on the new standard protocols, alarm policy and evaluation of alarm settings.
5. Nurses participated in three brainstorm sessions. The nursing group established guidelines on handling the alarms and made a '5 golden rules' poster for instruction. This was introduced with the aim of standardising responses to alarms and improving the workflow considering the recent changes introduced by the new alarm management solution. Explanations on how to delegate alarms to buddy nurse and rules for choosing the right patient profile or changing it according to the needs are included in the poster. The need for the verification of the alarm limits at the beginning of each nursing rounds and response to alarms before handing the patient is addressed. Finally, guidelines on how to handle communication with the rest of the hospital personnel and patients' relatives are described.

2.4 | Alarm analysis

Alarm load was measured by the count and duration of monitoring alarms and separated for red and yellow alarms, as used in our previous study[20] and as reviewed by Johnson et al.[22] Analyses were performed on different alarm clusters (eg, all red monitoring alarms), to try to identify a possible general effect of changes occurred to the NICU, and on specific alarm types (eg, SpO2 ≤ 80%), to allow for a more specific interpretation of results. Alarms were counted for each day and normalised for the number of patients present in the NICU.

The time spent in target oxygen saturation range was evaluated per day by considering time spent in various ranges: below red (SpO2 ≤ 80%), below target (80% < SpO2 ≤ 88%), within target (88% < SpO2 < 95%), above target (95% ≤ SpO2 < 98%), above red (SpO2 ≥ 98%).

Analysis of nurses' responses included percentages of alarms that were silenced and the count of autoterminated and manually terminated (non-autoterminated) alarm pauses.

One important problem that characterises each NICU is that multiple alarms can appear in the NICU at the same time, causing an increase in nurses' workload in specific daily hours. In order to provide an estimation for this problem, we introduced a new measure: seconds of parallel alarms. This was computed (for red alarms only) by considering for each hour all seconds in which a superposition between at least two alarms generated by different patients assigned to any nurse was found. All seconds of parallel alarms found within each hour were then summed and normalised considering the

number of patients present in the unit. 24 values for each day (1 value per hour) included in the analysis were therefore extracted.

All the analyses were performed in Matlab (The MathWorks, Natick, United States).

2.5 | Survey

A survey was distributed among all NICU nurses to evaluate the perception of changes occurred during phase-1 and phase-2. Part of the questions in the survey came from our previous study.[26] Surveys were made available online to all nurses on November 2018 (n = 101) and November 2019 (n = 99), a few months after the beginning of each study period. Both surveys included the same statements that they could disagree or agree with based on a five-point Likert scale. The questions aimed at identifying nurses' perceptions about alarm rate and occurrence of false alarms (28 questions), use of protocols and settings (5 questions) and training (3 questions). The survey was conducted in Dutch, native language of all nurses, and results were translated to English. No personal information was collected in the surveys. All questions delivered with survey are available in Figure S1.

2.6 | Statistical analysis

Three quarter periods of the same seasons (October-December, 2017-2019) were used as a representative sample of each of the three phases to compute statistical comparisons. The same quarters were chosen in order to avoid seasonal effects. Differences between phase-0 (reference) and both phase-1 and phase-2 were analysed. Pairwise comparisons can be affected by multiplicity as the result of multiple testing.[27] However, no correction for multiplicity was included in this work since correction for type I error is not required in case multiple primary endpoints have to be verified together.[28]

Natural logarithmic transformation was applied on the count of alarms and alarm pauses. A linear regression model created considering phase as the only categorical independent variable was then fitted to the log-transformed outcome. Normality assumptions of the residuals were assessed. Wilcoxon rank sum test was applied for the analysis of alarm durations to test differences between the periods.

Hotelling's T-squared test, a generalisation of Student's *t* test, was used to compare percentages of silenced alarms and the time spent within different saturation ranges.

Seconds of parallel alarms were inflated by substantial amount of zeros since in multiple occasions no superimposed alarms were found during a daily hour. A lognormal statistical model was fitted to non-zero seconds of parallel alarms normalised using the number of patients present during that hour in the NICU. For the zero part, logistic regression was instead used to assess the proportion of zeros between different periods.

Statistical analysis was performed using R (R Core Team, Vienna, Austria).

3 | RESULTS

3.1 | Alarm analysis

3.1.1 | Alarm count and duration

An overview of the median monthly alarm count per patient per day over three years of different implementation steps is reported in Figure 1. A decrease is observed in the number of alarms in phase-2, mainly for the number of SpO2 ≤ 80% alarms, but also seasonal fluctuations, related to severeness of illness, are noticeable. The statistical analysis shown in Table 3 for the quarters October to December in 2017, 2018 and 2019 showed a significant reduction in the number of all red monitoring alarms from phase-0 to phase-1 and a further decrease in phase-2. The largest decrease is seen in SpO2 ≤ 80% alarms comparing phase-0 and phase-2 (alarms per patient days 27.71 vs 13.11, $P < .001$). However, an increase in the number of 80% < SpO2 ≤ 88% alarms is found over time, indicating that though critical desaturation stages are not reached, lower SpO2 values do occur. Conversely, SpO2 ≥ 95% alarms showed a significant reduction in phase-2. A small increase in the number of bradycardia and heart rate (HR) alarms was noticed in phase-2. However, these values remained much lower compared to those found for SpO2 alarms. Reduced alarm duration was found for red and yellow monitoring alarms and SpO2-related alarms, with the most significant results found in phase-2. Duration of bradycardia and HR alarms remained instead rather similar during all phases.

3.1.2 | Time within SpO2 target range

Boxplots for the time spent in 5 different SpO2 ranges are displayed in Figure 2. The percentage of time spent within SpO2 target range (88% < SpO2 < 95%) was found to be significantly larger in phase-2 compared to phase-0 (44.9% vs 33.2%, $P < .001$). Significant reduction in time spent in critical ranges outside target was found in phase-2 compared to phase-0. An important reduction was especially found for the most critical conditions, namely below red alarm limit (1.4% vs 2.2%, $P < .001$) and above red alarm limit (13.7% vs 19.7%, $P < .001$).

3.1.3 | Nurse response to alarms

The percentage of silenced alarms (shown in Table S1) shows no difference between the 3 phases. However, the count of alarm pauses shows an increase in phase-2. In addition, more alarms were silenced in months where alarm pressure was higher.

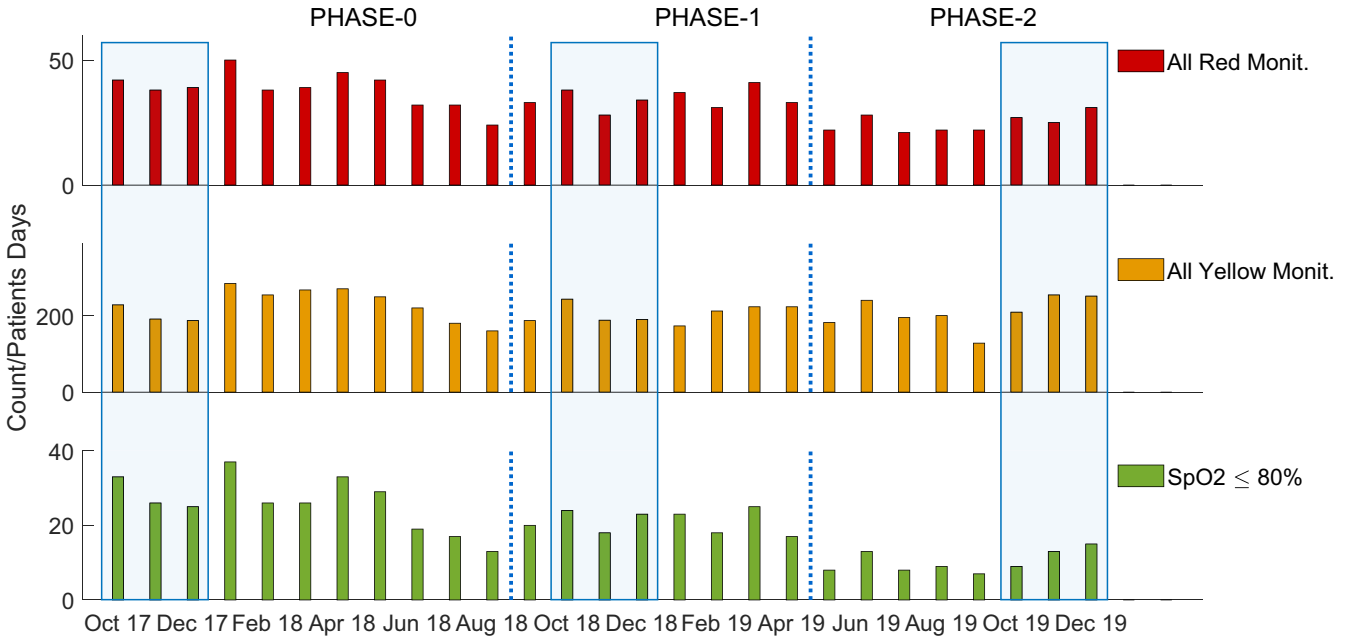

FIGURE 1 Median count of alarms/patients days for each month. Alarms for each type are counted during each day and divided by the number of patients present in the NICU on that day. Median values for each month are represented to avoid considering outliers. Dotted lines indicate the beginning and end of each phase included in this work. While this figure shows a general overview of the median values for each month, the statistical analyses for comparison between phases were performed in the same quarters highlighted in light-blue (October-December, 2017-2019)

3.1.4 | Seconds of parallel alarms

Periodicity can be observed in the seconds of parallel red alarms per patient per daily hour with a 2 to 3 hours period, in correspondence with the nursing rounds. Lower values for parallel alarms were noticed in both phase-1 and phase-2 (statistically significant).

3.2 | Survey

Thirty three nurses (32.7%) completed the survey in phase-1 and 31 nurses (31.3%) in phase-2. All questions reported in the surveys together with nurses' responses can be found in Figure S1. Since both surveys showed high variability in responses we chose to report only those items in which the average difference in Likert scale between pre- and post- was more than 0.5. Statistical analyses could not be performed due to the relatively low number of responses.

The main differences were perceived in the questions,[3,4,8,15] as shown in Figure 3. After phase-2 less nurses indicated that false alarms could reduce trust in alarms and cause an inappropriate alarm turn off. More nurses also reported that after phase-2 identification of which device is generating an alarm is more straightforward. In addition, architectural setup of the unit does not influence the way alarms are perceived and managed. Finally, in the second survey more nurses indicated that they know that in MMC NICU it is requested to document that appropriate alarms are set for each patient. For all other questions, the differences between phase-1 and 2 were smaller, though nurses reported that according to their opinion the rate of false alarms decreased over time. According to their responses, this reduction was associated with an improved interpretation of the alarm sources, an improvement in application of protocols and the use of clinical guidelines and less likelihood in missing responses to alarms. Surveys also indicated that red alarms are currently perceived as less stressful. With respect to training, the majority of nurses considered themselves well-trained in the use of handhelds. Boxplots for key results are reported in Figure 3.

4 | DISCUSSION

This study shows that the implementation of a new alarm management solution in combination with workflow optimisation can significantly reduce the number of alarms in a NICU environment, while keeping patients better into target range (saturation).

4.1 | Alarm count and duration

SpO2 ≤ 80% alarms (red alarms) were reduced the most, particularly in phase-2, at the expense of an increase in 80% < SpO2 ≤ 88% alarms (yellow alarms). These results indicate that all changes

TABLE 3 Results and statistical analysis for alarm counts and durations and time spent within different SpO2 ranges

Alarm counts	Phase-0	Phase-1	Phase-2
All red monitoring	39.50	33.38***	27.76***
All yellow monitoring	203.48	195.10	243.50***
SpO2 ≤ 80%	27.71	20.25***	13.11***
80% < SpO2 ≤ 88%	118.95	113.71	160.04***
SpO2 ≥ 95%	51.97	56.31	39.69***
Bradycardia	7.37	7.67	8.87**
Heart rate (HR) low	14.72	14.90	19.08***
Heart rate (HR) high	11	12	19.25***
Alarm durations	**Phase-0**	**Phase-1**	**Phase-2**
All red monitoring	9	9	8***
All yellow monitoring	16	18***	13***
SpO2 ≤ 80%	9	11***	9
80% < SpO2 ≤ 88%	18	20***	14***
SpO2 ≥ 95%	23	24	19***
Bradycardia	5	5	5
Heart rate (HR) lOW	5	5	5
Heart rate (HR) high	8	9*	9*
Time spent in target SpO2 range	**Phase-0**	**Phase-1**	**Phase-2**
Below red (80 ≤ SpO2)	2.2%	1.9%	1.4%***
Below target (80 < SpO2 ≤ 88)	9.3%	8.8%	7.5%***
Within target (88 < SpO2 < 95)	33.2%	35.9% *	44.9%***
Above target (95 ≤ SpO2 < 98)	35.6%	35.1%	32.5%***
Above red (SpO2 ≥ 98)	19.7%	18.3%	13.7%***

Note: All information reported here refers to quarters (October-December) for each phase. Median values and significance are reported. Significance codes include: 0***, .001**, .01*, .05'. For alarm counts, the unit of measure is alarms per patient per day and the statistical method is a lognormal model. For alarm duration, the unit of measure is seconds and the statistical method is Wilcoxon rank sum. For time spent in target SpO2 range, the unit of measure is percentages and the statistical method is Hotelling's T-squared test.

brought to the NICU prevented patients from reaching critical state and kept them in a safer condition where the risk of developing severe complications is significantly lower. This is also supported by results for time spent within target SpO2 range (88%-95%), which showed a significant increase in the phase-2 compared phase-0. In addition to the safer range, both patients and their parents experience less noise since yellow alarms in MMC have lower repetition times, lower frequency and a much lower volume than that of red alarms. Although a very small increase in the number of bradycardia and other HR alarms has been found in this work, we believe this would not add a lot to the alarm load. The contribution of bradycardia alarms is smaller compared to SpO2 ≤ 80% alarms (ratio 1:3, as shown in phase-0 of this work) and response to these alarms is much faster. Nurses' fast response to bradycardia alarms is indicated by the duration of HR-related alarms, which is always much shorter than for SpO2 ≤ 80% alarms. In addition, alarm durations for both red and yellow alarms decreased significantly over time, suggesting overall faster alarm response and further noise reduction.

4.2 | Time within SpO2 target range

We observed a higher percentage of time spent within target range (88% < SpO2 < 95%) in phase-1 but this percentage increases even further in phase-2, following optimisation. This indicates that both implementation of the alarm management system and an optimisation programme led to increasing the time patients spent within target range, from 33% in phase 0 to 45% in phase 2, indicating improved patient safety. As the most important change was the delivery of both alarms and corresponding waveforms to nurses' handhelds, we speculate that this additional information helped nurses to adjust oxygen therapy and provide better care to patients.

4.3 | Nurse response to alarms

The significant increase in the use of alarm pauses in phase-2 suggests that the intervention affected nurses' habits with regard to alarm handling. We assume this an effect of training.

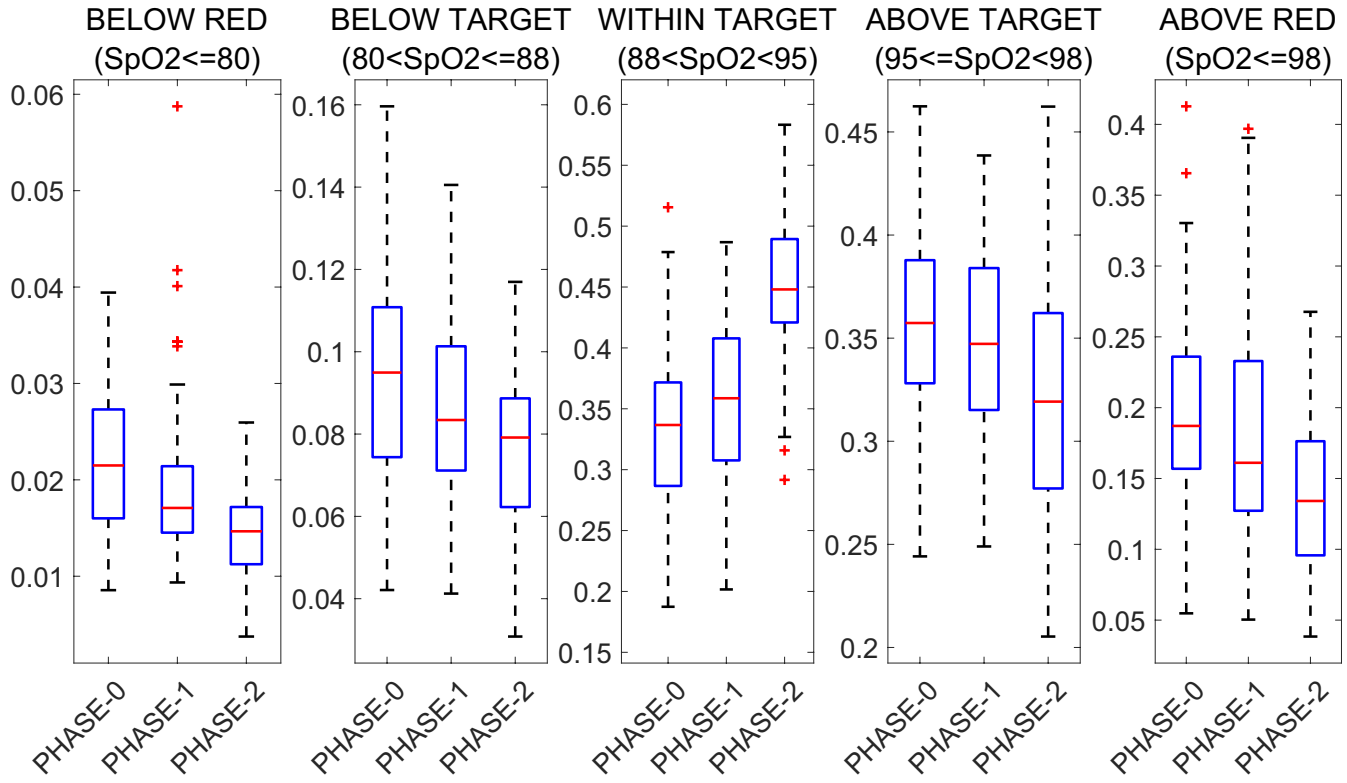

FIGURE 2 Boxplots for percentages of time spent by patients within different SpO2 target ranges: below red (SpO2 ≤ 80), below target (80 < SpO2 ≤ 88), within target (88 < SpO2 < 95), above target (95 ≤ SpO2 < 98), above red (SpO2 ≥ 98). Data reported in this figure refer to quarters that include months October-December included in each phase as for the statistical analyses

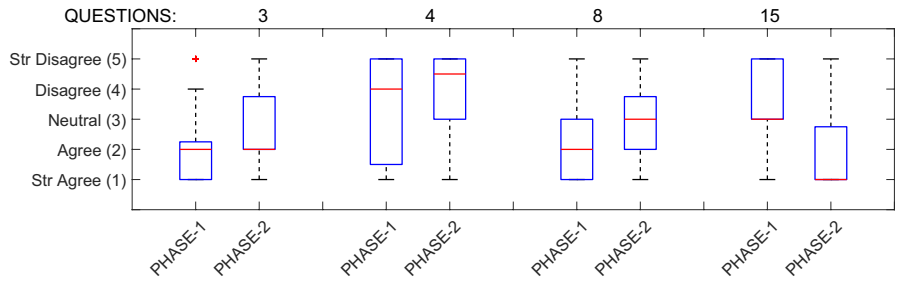

FIGURE 3 Boxplots for the surveys delivered to nurses. Nurses' responses have been analysed and questions showing the biggest difference between the two periods have been represented. These questions are the following[3]: False alarms reduce trust in alarms and cause care givers to inappropriately turn alarms off at times other than during setup or procedures, [4] When multiple medical devices are used in a patient, it can be confusing to determine which device is in an alarm condition,[8] The architectural setup of the unit influences the way alarms are perceived and managed,[15] In my unit, there is a requirement to document that the alarms are set and are appropriate for each patient

4.4 | Seconds of parallel alarms

A novel measure proposed in this study is the measure of seconds of parallel alarms. Seconds of parallel alarms computed per daily hour showed that alarm pressure shows a 2-hours periodicity which corresponds to the feeding and caregiving times planned for the patients. A reduction of these high-alarm-burden periods for the different daily hours was found in phase-2, after optimisation, indicating a decrease of alarm burden in MMC NICU.

4.5 | Survey

The survey among nurses showed variability in their responses. However, as a result of the optimisation, they indicated that it is less likely to inappropriately turn alarms off at times due to false alarms and misinterpret the source of alarms generated by different devices. Furthermore, the survey showed that nurses' perception on how architecture of the unit influences the perception and management of alarms has changed. This suggests that appropriate

changes to protocols and settings could be helpful in improving the alarm management irrespective of the NICU architecture. These positive changes perceived by nurses can be linked to the improved clinical workflow in MMC NICU. The number of responses received from nurses for the survey is, however, limited compared to the total number of nurses in the NICU. Some reasons for the low response rate can be found in the free participation to the survey and the fact that surveys were delivered online. Due to the low rate of responses and the possible introduction of selection bias in the analysis, these results can only be used to understand the general perception of the different changes applied to the NICU. No exact conclusions can be drawn from it since statistical analysis was not performed.

This work provides a method for optimisation of alarms while monitoring parameters that are indicative of patient safety. This work also investigates how the workflow optimisation changes are perceived by the nurses. The content of this work can also be extended to others NICUs, irrespectively of the architecture. The most important steps in the clinical alarm management optimisation require appropriate alarm settings (eg, thresholds, delay and averaging methods) and protocols (eg, selection of adequate patient-specific profiles depending on their age, sensor positioning and alarm escalation to buddy nurses). Nurses' training and revision of protocols is an important step to align the behaviour and response of each healthcare provider. Involvement of nurses in programmes as well as capturing their contribution and helping them feel engaged (eg, creation of the '5 golden rules' poster) are important steps in ensuring clinical transformations are performed in the clinic.

Our study has several limitations. Alarms are not classified considering patients' GA and criticality. As target range depends on GA and postmenstrual age, this could affect the current general measurement of time spent in target range, in particular as infants at term-equivalent age are supposed to have a higher saturation compared to very premature infants. However, as both GA and postmenstrual age in all evaluated periods are comparable, this should not affect the observed differences between the three phases. In a previous study, nurses in our NICU indicated that they perceive bradycardia alarm to be the most reliable alarm.[26] Because of this reason no changes have been made concerning the settings of HR alarms. Nonetheless, we think that filtering out short bradycardias, as suggested in the review by Johnson et al,[22] may help to further optimise the system in the future. Also, ventilator alarms were not included in this study since the use of these devices varied over time depending on the conditions of the patients that were present in the NICU and we could stratify for these effects. Therefore, the real alarm burden is higher than reported in this study. In one of our previous studies, the alarm burden increased from 42 to 67 red alarms per patient day when alarms due to ventilation were considered.[21] Future studies could more elaborately investigate nurses' responses by analysing escalation of alarms and the actual time needed for responding to different alarms.

This study was mainly focused on reducing red alarms therefore future works should look more into yellow alarms. Previous studies provided different ideas for reducing yellow alarms including modification of alarm thresholds, increase of alarm delays and introduction of new patient-specific profiles depending on their age.[29,30] Other solutions would require to have a better look into repeated alarm patterns.

5 | CONCLUSION

The introduction of a new alarm management solution and the optimisation of the clinical workflow in MMC NICU led to a reduction in the number of all red monitoring and SpO2 ≤ 80% alarms per patient day and an increase in nurses' response to alarms. Results from surveys indicated that due to the optimisation, false alarms were less likely to cause an inappropriate response. This work has provided a method to decrease alarm fatigue, leading to an improved configuration of alarm workflow and processes that leads to a reduction in alarm pressure while still being safe.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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