Conference Paper Title

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1 INTRODUCTION

A common practice to gauge patients' physiological condition and acute clinical stability is using basic homeostatic measures like vital signs, haematologic findings, and neurological examinations. Various early warning systems have been proposed that use these measurements to assess whether patients face an imminent risk of deterioration or death [Smith13].

The National Early Warning Score (NEWS), developed in conjunction with the Royal College of Physicians, has been widely implemented across the NHS and by healthcare providers outside the UK [RCP17, pp.13]. It is a points-based early warning system to identify clinical deterioration in acutely ill patients based on routinely recorded vital signs: pulse, breathing rate, blood pressure, blood oxygen level, level of consciousness, and temperature. The paper-based NEWS allocates points in a weighted manner based on these measurements. The sum of these points, which makes up the patient's aggregate NEW score, is associated with "triggers" - thresholds that correspond to recommended levels of clinical response and monitoring frequency.

While initially designed to monitor for deterioration in secondary-care, the NEWS has been widely tested and validated across healthcare settings. In its latest revision of the standard, the RCP recommended that the NEWS also be used in emergency departments to "aid the initial assessment of patiens, ongoing monitoring and patient triage decisions" [RCP17, pp.18].

Across studies, the NEWS has been found to perform well in discriminating ward patients at risk of death, critical care admission, or cardiac arrest. The present report introduces the novel SCI dataset, which contains records of adult patients with acute or medical presentation at the Salford Royal NHS Foundation Trust from 2014-2022. We then use this dataset to assess the performance of NEWS in predicting adverse patient outcomes, such as those mentioned above, in the dataset population.

2 METHODOLOGY

2.1 Data Collection and Contents

The SCI dataset is collated from EPR records collected in real time from admissions to acute beds between 1st April 2014 and 31st March 2022. Further, the dataset includes administrative data produced in retrospect for financial (tarrif) purposes.

Our dataset includes records of patients who received ambulatory emergency care (AEC) or same-day emergency care (SDEC) and were discharged before midnight on the day of admission [NHS18]. AEC, alongside the medical admissions unit (EAU) are the two common entry points for adult patients with general medical emergencies. Exceptions present in our records include certain booked admissions and patients directly transferred and admitted to medical or critical care wards.

As a routine part of admission, the responsible staff member (nurse or support worker) records the patient's vital signs withing $\sim$ 30 minutes of arrival. The vital signs that make up the NEWS are measured simultaneously, in a standardised manner, using Dinamap monitors. The readings are manually transcribed into EPR and onto the patient's paper chart. Specifically, this data includes:

- Body temperature ($^\circ$C)
- Pulse (beats/min)
- Diastolic and systolic blood pressure (mmHg)
- Peripheral oxygen saturation (%)

Further, we record the patient's level of consciousness (AVPU), presence of pain, nausea, or vomiting, whether the patient was receiving oxygen at the time of SpO2 measurement and, if applicable, the oxygen flow-rate and mode of delivery. Once these parameters are inputted into EPR, the NEWS score and component sub-scores are automatically computed for the patient. Blood test results (including VBG), where those were peformed, are automatically recorded in the laboratory information management system LIMS) and subsequently imported into EPR.

Other patient information recorded on admission includes: Patient identifier data such as their unique patient number, age, sex, and address. Admission method (e.g., emergency A&E, emergency GP referral, etc), their presenting complaint, arrival time, and the main A&E diagnosis (following initial assessment).

Information gathered in retrospect includes the date and time of discharge, total length of stay (LOS), the wards the patient was admitted to (in chronological order) and the LOS per ward. Diagnoses coded using the ICD-10-CM standard are complied by a clinical coding team based on the existing codes and clinical notes recorded in EPR. Procedures and services are also recorded in detail in EPR, and are similarly coded in retrospect using the OPCS-4 standard.

2.2 Outcomes

The outcomes we track are death during hospitalisation, death within 30 days after discharge, unanticipated admission to critical care, or unanticipated readmission to the same hospital. To assess the NEWS, we check for the occurrence of death or critical care admission within 24 hours, 48 hours, or at any point after the patient's arrival. For readmissions, we consider thresholds of 48 hours, 7 days, or 30 days after discharge.

Where it occurrs, patient death during their hospitalisation is identified from EPR. Mortality after discharge (within 30 days) is primarily determined from the regional primary care databases (Salford Integrated Records & Greater Manchester Care Record). Critical care admission is identified from patients being admitted into the hospital's critical care unit (CCU) or the high-dependency medical unit (HH1M).

2.3 Data Preparation

We perform all data manipulation in Python using the Numpy and Pandas libraries. As they are the only parameters that are transcribed manually into EPR, we check the patients' vital signs for spurious values against hard ranges (e.g., $0 - 100\%$ for SpO2) as well as soft thresholds that we base on the range of physiologically possible values as determined by professional clinical opinion. For parameters that have a recorded NEWS sub-score but their raw value is missing or marked as spurious, we infer the correct value as the midpoint of the relevant NEWS range. Where a parameter has a valid value but the NEWS sub-score is missing, we compute it in accordance with the specificaton [RCP17, pp.]. We use the same specification to compute the final NEWS score for any patients where this is not recorded in the original data. Full details of how each parameter is pre-processed are available in appendix A.

2.4 Data Analysis

We assess the ability of NEWS to discriminate between patients who did and did not suffer an adverse outcome using AUROC (area under the ROC curve). We compute this using the scikit-Learn library. The minimum possible AUROC value is 0.5 and corresponds to a completely random relationship between the score in question and the tracked outcomes. Generally, a score of $0.7 - 0.8$ indicates reasonable discrimination and values over 0.8 indicate good discrimination.

We investigate the discriminative performance of both the raw NEWS score and the pre-defined "trigger" thresholds for low, medium, and high clinical risk (NEWS of $0 - 4$, $5 - 6$, and ≥ 7 respectively) [RCP17, pp.30].

We measure correlation between ordinal variables (NEWS and LOS) using Spearman's rank correlation. We compare the means of independent samples of normally distributed variables using Welch's unequal variances t-test, and we use the Mann-Whitney U test for non-normally distributed variables. We present characteristics of variables as $mean \pm std$.

TABLE 1
Summary of Findings

Outcome	Time	NEWS ≥ 7	ROAUC (95% CI)
Critical Event	24h	51.13%	**0.914** $(0.896 - 0.932)$
	48h	41.24%	0.890 $(0.877 - 0.903)$
	Any	16.12%	0.769 $(0.763 - 0.775)$
Mortality	24h	62.01%	**0.952** $(0.936 - 0.967)$
	48h	51.15%	0.938 $(0.926 - 0.95)$
	Any	18.67%	0.770 $(0.762 - 0.777)$
Critical Care	24h	26.92%	**0.831** $(0.787 - 0.874)$
	48h	24.64%	0.8 $(0.772 - 0.829)$
	Any	15.1%	0.767 $(0.758 - 0.775)$
Long LOS	$\geq$24h	2.50%	0.602 $(0.598 - 0.605)$
	$\geq$48h	2.72%	**0.607** $(0.604 - 0.61)$
	$\geq$7 days	3.25%	0.598 $(0.594 - 0.602)$
30-Day Mor/ty	24h	3.68%	**0.655** $(0.628 - 0.682)$
	48h	3.78%	0.655 $(0.634 - 0.677)$
	Any	4.28%	0.629 $(0.62 - 0.638)$
Readmission	2 days	1.14%	0.496 $(0.466 - 0.526)$
	7 days	1.04%	0.503 $(0.487 - 0.52)$
	30 days	1.40%	**0.532** $(0.522 - 0.541)$

3 RESULTS

Table 1 summarises our findings on the discriminative ability of NEWS for various outcomes.

3.1 Population Characteristics

Records of 170833 admissions were collated, of which 124162 records, corresponding to 63450 unique patients, had a NEW score recorded on-admission or computed by us during pre-processing. NEW scores ranges from $0 - 18$ with a median score of 1.0 (IQR=2.0). Key characteristics of the dataset population are given in Table 2.

3.2 Critical Event Occurrence

The original study on the NEWS' discriminative ability considered death within 24 hours of a given set of observations. We define a "Critical Events" as the occurrence of either critical care admission or death during the hospital spell. Since the vital signs and NEWS in our dataset are measured on admission, we investigate the subsets of hospital spells with total LOS within certain thresholds, such as 24 or 48 hours.

A total of 8826 with recorded NEWS experienced a critical event, comprising 4371 critical care admissions and 5308 deaths. The AUROCs (95% CI) of NEWS for critical events in records with 24h LOS, 48h LOS, or any LOS were respectively 0.914 $(0.896 - 0.932)$, 0.890 $(0.877 - 0.903)$, and 0.769 $(0.763 - 0.775)$. The ROC curves are given in figure 1. The method for computing the AUROC confidence intervals is given in Appendix B.

Critical event occurrence significantly correlated with the NEWS at the same LOS thresholds: chi-square with NEWS ≥ 7: $p < 0.0001$ in all cases. In total, $1423/8826$ (16%) of critical event occurrences had NEWS ≥ 7. Appendix C examines the occurrence of mortality and critical care admission separately.
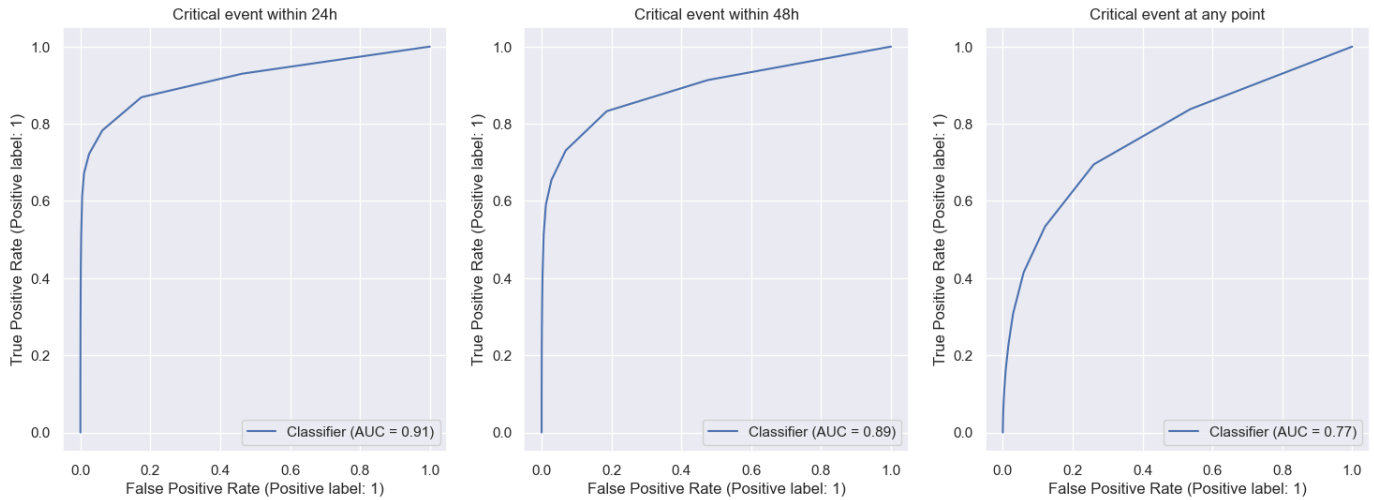
Fig. 1. ROC curves of NEWS for discriminating critical event occurrence in stays with LOS under 24h (left), under 48h (middle), or any LOS (right).

TABLE 2
SCI dataset key characteristics

Parameter	Category	n (%)
Sex	Female	65096 (52.43%)
Admission Method	Emergency A&E	113518 (91.43%)
	Emergency GP Referral	5955 (4.8%)
Admission Ward	EAU	82541 (66.48%)
	AEC	36546 (15.27%)
	Other Medical	2980 (2.4%)
	High-Dependency	2095 (1.69%)
Mortality	No	14768 (92.43%)
	Died During Stay	5308 (4.28%)
	Died within 30 Days	4086 (3.29%)
Critical Care	Yes	4371 (3.52%)
Readmitted (30 days)	Yes	15836 (12.75)
NEWS clinical risk	Low $(0-4)$	118223 (95.1%)
	Medium $(5-6)$	3748 (3.02%)
	High (≥ 7)	2333 (1.88%)

TABLE 3
Distribution comparison dep. on critical event occurrence.

Variable	LOS	Mean (Event)	Mean (¬Event)	Test	p
Age	24h	71.4 ± 18.92	57.62 ± 20.92	Welch	0.0
	48h	70.54 ± 19.56	58.71 ± 21.09		0.0
	Any	71.72 ± 16.85	64.5 ± 20.62		0.0
NEWS	24h	6.82 ± 4.38	0.75 ± 1.07	Mann	0.0
	48h	5.91 ± 4.18	0.78 ± 1.1		0.0
	Any	3.51 ± 3.1	1.04 ± 1.4		0.0

3.3 Post-Discharge Mortality

The proportion of 30-day mortality in the dataset records was 3.29% ($n = 4086$) and corresponds to 6.44% of patients. The AUROCs (95% CI) of NEWS for 30-day mortality in records with 24h LOS, 48h LOS, or any LOS were respectively 0.655 ($0.628 - 0.682$), 0.656 ($0.634 - 0.677$), and 0.629 ($0.62 - 0.638$). Post-discharge mortality significantly correlated with NEWS at the same LOS thresholds: chi-square with NEWS ≥ 7: $p < 0.0001$ in all cases. In total, $175/4090$ (4.28%) of occurrences had NEWS ≥ 7.

Patients who died within 30 days were older (77.05 ± 13.10 years; Welch's unequal variances t-test: $p < 0.0001$) and had higher NEWS (2.0 ± 2.11; Mann-Whitney U test: $p < 0.0001$) compared to patients who survived (mean age 64.6 ± 20.54 years; NEWS 1.19 ± 1.68). The mean total LOS was 13.49 ± 18.99 for patients who died after discharge and 6.57 ± 14.65 for survivors (Mann-Whitney U test: $p < 0.0001$). Table 3 gives the same information across the tested LOS thresholds.

Patients who experienced critical events were older (71.72 ± 16.85 years; Welch's unequal variances t-test: $p < 0.0001$) and had higher NEWS (3.51 ± 3.1; Mann-Whitney U test: $p < 0.0001$) compared to patients who did not (mean age 64.5 ± 20.62 years; NEWS 1.04 ± 1.4). The mean total LOS was 16.32 ± 24.25 for patients who experienced critical events and 6.07 ± 13.62 for those who did not (Mann-Whitney U test: $p < 0.0001$). Table 3 gives the same information across the tested LOS thresholds.

APPENDIX A
DATA PRE-PROCESSING

APPENDIX B
AUROC

We assess the discriminative ability of the NEWS using an area under the receiver-operating characteristics (AUROC) curve. This measurement is commonly used to assess the accuracy of a criterion variable whose value will be used to make a binary decision. We construct the ROC curve by plotting the false-positive rate (1 minus the specificity) on the x-axis against the true-positive rate (sensitivity) on the y-axis for each decision threshold for prediction between $0 - 100\%$. In our methodology, we use scikit-Learn for automatic plotting and AUC computation.

For large samples, the distribution of the AUC is approximately normal. Hence, we use the standard normal distribution to claculate the confidence interval for the AUC as:

$$AUC \pm z_{\alpha/2} SE(AUC) \tag{1}$$

The formula for $SE(AUC)$ is [Henley82]:

$$SE(AUC) = \sqrt{\frac{AUC(1 - AUC) + (N_1 - 1)(Q_1 - AUC^2) + (N_2 - 1)(Q_2 - AUC^2)}{N_1 N_2}} \tag{2}$$

where,

$$Q_1 = \frac{AUC}{2 - AUC}, \ Q_2 = \frac{2AUC^2}{1 + AUC} \tag{3}$$

APPENDIX C
RESULTS FOR MORTALITY AND CRITICAL CARE ADMISSION

C.1 Mortality

The proportion of in-hospital mortality in the dataset records was 4.28% ($n = 5328$) and corresponds to 8.386% of patients. The AUROCs (95% CI) of NEWS for mortality in records with 24h LOS, 48h LOS, or any LOS were respectively 0.952 $(0.936 - 0.967)$, 0.938 $(0.926 - 0.95)$, and 0.770 $(0.762 - 0.777)$. Mortality significantly correlated with NEWS at the same LOS thresholds: chi-square with NEWS ≥ 7: $p < 0.0001$ in all cases. In total, $955/5328$ (17.9%) of occurrences had NEWS ≥ 7.
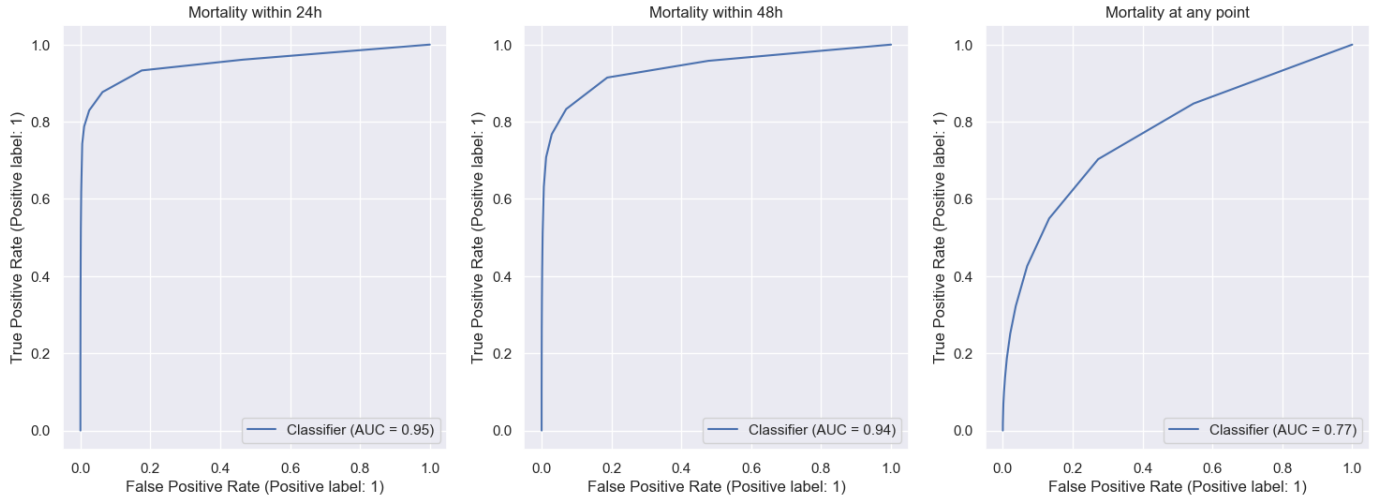

Fig. 2. ROC curves of NEWS for discriminating in-hospital mortality with LOS under 24h (left), under 48h (middle), or any LOS (right).

C.2 Critical Care Admission

The proportion of critical care admission in the dataset records was 3.53% ($n = 4384$) and corresponds to 6.90% of patients. The AUROCs (95% CI) of NEWS for critical care admission in records with 24h LOS, 48h LOS, or any LOS were respectively 0.831 $(0.787 - 0.874)$, 0.8 $(0.772 - 0.829)$, and 0.767 $(0.758 - 0.775)$. Admission significantly correlated with NEWS at the same LOS thresholds: chi-square with NEWS ≥ 7: $p < 0.0001$ in all cases. In total, $662/4384$ (15.1%) of occurrences had NEWS ≥ 7.
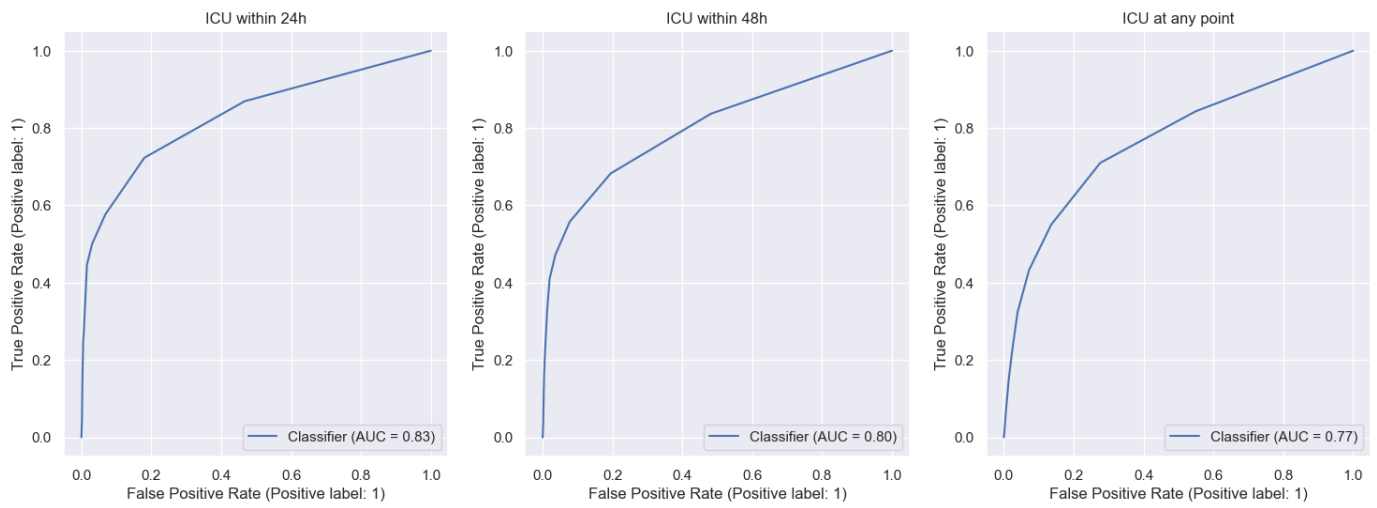
Fig. 3. ROC curves of NEWS for discriminating critical care admission in stays with LOS under 24h (left), under 48h (middle), or any LOS (right).