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computer security; data management; disaster planning; pediatric emergency medicine

Abbreviations:
DTA, decision to admit; ED, emergency department; EDIS, emergency department information system; HCR, health care record; IT, information technology

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Learnings From a National Cyberattack Digital Disaster During the SARS-CoV-2 Pandemic in a Pediatric Emergency Medicine Department

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Abstract

Objective: The primary objective was to analyze the impact of the national cyberattack in May 2021 on patient flow and data quality in the Paediatric Emergency Department (ED), amid the SARS-CoV-2 (COVID-19) pandemic.
Methods: A single site retrospective time series analysis was conducted of three 6-week periods: before, during, and after the cyberattack outage. Initial emergent workflows are described. Analysis includes diagnoses, demographic context, key performance indicators, and the gradual return of information technology capability on ED performance. Data quality was compared using 10 data quality dimensions.
Results: Patient visits totaled 13 390. During the system outage, patient experience times decreased significantly, from a median of 188 minutes (pre-cyberattack) down to 166 minutes, most notable for the period from registration to triage, and from clinician review to discharge (excluding admitted patients). Following system restoration, most timings increased. Data quality was significantly impacted, with data imperfections noted in 19.7% of data recorded during the system outage compared to 4.7% before and 5.1% after.
Conclusions: There was a reduction in patient experience time, but data quality suffered greatly. A hospital's major emergency plan should include provisions for digital disasters that address essential data requirements and quality as well as maintaining patient flow.

The adoption of information technology (IT) has transformed health care over the years, and hospitals have come a long way from when all records were captured on paper. This has led to a positive correlation between IT adoption and patient safety outcomes. Many emergency department (ED) workflows depend on IT with demands placed on the availability, usability, and accuracy of the applications involved. Ransomware attacks are more numerous and disruptive throughout the world, and recently the health care sector has become a significant target.[1–3]

On May 14, 2021, during the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic, the largest cyberattack ever recorded on the Irish national health service (Health Service Executive) was discovered and the response shut down national and local systems involved in all core hospital services.[4,5] This resulted in no digital patient administration system, emergency department information system (EDIS) *Symphony*®, laboratory system, national radiology image access,[6] nor Intranet/Internet access. The IT blackout confronted clinicians and administrators, normally in a near fully digitally supported working environment, with the realities of working in an ED during a digital disaster. The hospital did not have a section of its major emergency plan dedicated to such a loss of IT systems.

Most health care workers express an interest in learning to prepare for natural, pandemic, and manmade disasters.[7,8] If a hospital is not prepared for crises and disasters, it undermines the capacity of administration and staff to safeguard the safety of patients.[9] Reflection on disaster incidents can inform future disaster planning, provide an opportunity to identify lessons learned that will drive improvements in emergency management through preparedness and mitigation measures, and provide response innovations.[10]

This descriptive case study illustrates the experience of a pediatric tertiary referral center by describing emergent interventions and the resulting impact by a time series analysis of three 6-week periods before, during, and after the cyberattack IT outage. The data analysis aspect of this study will focus on the patient flow timings (three 6-week period comparisons and the impact of the gradual restoration of each IT system) and the quality of the data captured.

Methods

Study Setting and Approach

A retrospective analysis was performed from a pediatric tertiary multi-university-affiliated teaching hospital in the Republic of Ireland, with yearly pre-pandemic ED attendances of over 39 500. Equal 6-week comparison periods were analyzed before and after, from April 2, 2021, to August 5, 2021 (18 weeks) inclusive, prior to the cyberattack digital disaster from April 2 to May 13, 2021 (Period 1), during the cyberattack from May 14 to June 24, 2021 (Period 2) when all or most IT systems were unavailable, and after from June 25 to August 5, 2021 (Period 3) when all systems were restored. Sub-analysis on patient flow during the staggered restoration of each IT system was analyzed, which included the hospital patient administration system, radiology, pathology, and finally the *Symphony*® (EMIS Health, UK) EDIS. The reporting guidelines for Strengthening the Reporting of Observational Studies in Epidemiology were followed.[11]

Data Sources, Quality, and Measures

A hastily designed and implemented Microsoft® Excel® 2016 MSO (Version 2110) spreadsheet was created by the principal investigator (MB) in the hours following the cyberattack to maintain an accurate ED census and essential data along with additional administrative personnel (a minimum of 1 dedicated Excel sheet administrator and 1 administration runner between registration, triage, and spreadsheet). Paper ED triage and clinical notes were commenced on the day of the cyberattack by adjusting an existing section of the major emergency plan used for mass casualty incidents for the initial generation of unique hospital patient identifying numbers. Further unique hospital patient identifying numbers were generated in consultation with the hospital medical record department for the remainder of the 6-week period.

Data entry points specific to the ED included existing (if known and confirmed) or new health care record (HCR) number, suspected SARS-CoV-2 status at triage, triage category (5 point scale; category 1= most critical to category 5 least critical),[12] presenting complaint, treating clinician, ED location, specialty referred to, discharge destination, and patient experience times (time points for registration, triage, clinician time seen, specialty referred to, decision to admit [DTA], and discharge time). The bespoke Excel® sheet was on a non-networked standalone desktop computer (connected to a large television in the central administration hub), staffed 24/7 by 1 to 2 newly created ED administrators (in response to the disaster). An administrator updated Excel®, in a contemporaneous fashion from written or verbal information from administrators, nurses, doctors, advanced nurse practitioners, and bed managers. All necessary updates were checked and reinforced at the increasing number (5+) of ED rounds in response to the disaster. Data for the pre (Period 1) and post (Period 3) system IT outage were extracted from the principal EDIS (*Symphony*® [EMIS Health, UK]).

Patient experience times were recorded throughout each period. The Excel® workbook was cross referenced (MB and HO'R) from 2 separate pre-existing paper independent primary sources containing data on admitted patients across all time periods. Additional feature engineering tasks were performed on data sources prior to consolidation into 1 data set (outlined in Supplementary Table 1). A single power outage resulted in a 1 day loss of electronic data, which occurred on May 28, 2021, culminating in a data capture issue; therefore, this date was excluded from the patient flow analysis (Supplementary Figure 1). Also excluded from the patient flow analysis were duration times less than 0 and records with missing date times.

Data quality dimensions[13–17] were used to compare quality between data recorded in Excel® during Period 2 with data recorded in the EDIS during Periods 1 and 3. Data quality characteristics were analyzed using 8 dimensions[16]: accuracy, completeness, consistency, integrity, reasonability, timeliness, uniqueness/de-duplication, and validity. Also included were the dimensions of accessibility and security from the Wang and Strong framework.[17]

Data Analysis

Data were extracted from the EDIS using SQL Server Management Studio, version 18.10, and an analysis was performed in R version 4.1.1.

Categorical data were described using counts and percentages. Continuous data were assessed for normality, using QQ plots and the Shapiro-Wilk test. Median and interquartile range (IQR) were used for non-parametric continuous data and mean and standard deviation for parametric continuous data. Periods 1 and 3 were compared separately, using χ^2 for categorical, t-test for parametric continuous variables, and Mann-Whitney for non-parametric continuous variables.

For the analysis of the gradual restoration of each IT system on ED performance, the difference between the independent groups for non-parametric data was evaluated, using the Kruskal-Wallis test. Post hoc tests[18] were carried out on progress times yielding a significant result, using pairwise comparisons adjusted for multiple comparisons. A 2-tailed P value < 0.05 was considered statistically significant.

Results

The final data set consisted of 13 390 visits: Period 1 comprised 4471 visits, 4596 visits during system outage in Period 2 when all or some IT systems were unavailable, and 4323 in Period 3 when all systems were restored.

Demographics and Characteristics

A significantly younger cohort presented in Period 3 (median 4 years) compared to Periods 1 and 3 (median 6 years). No significant difference was seen for gender, triage, day of the week, and return within 7 days. There was a significant difference ($P < 0.001$) in patients with suspected SARS-CoV-2, 22.1% during system outage (Period 2) compared to 29.5% (Period 1) and 39.7% (Period 3). There was an increase in patients admitted from the ED in Period 2, although not statistically significant. Comparing medians, there were 29 and 67 additional admissions compared with Periods 1 and 3, respectively (Table 1).

Patient Flow

During Period 2, the total length of stay reduced significantly ($P < 0.001$) by between 19 (Period 1) and 22 minutes (Period 3). By comparison of medians, this time reduction was most noticeable from registration to triage (2 to 3 minutes shorter) and from clinician review to discharge (excluding admitted patients) (12 and 16 minutes shorter). An analysis of the return visits revealed no

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Table 1. Characteristics of patient visits, comparing data in period 1, prior to the cyberattack, period 2, during the cyberattack, and period 3, post cyberattack

	Prior to cyberattack (Period 1) n = 4471			System outage (Period 2) n = 4596	All systems restored (Period 3) n = 4323		
Characteristic	n (%)	*P*	*P*#	n (%)	n (%)	*P*	*P*#
Age in Years[a]							
Median (Interquartile range)	6 (1-11)		0.47	6 (1-10)	4 (1-9)	<0.001	
Gender (Male)[b]	2478 (55.4)	0.83		2556 (55.6)	2435 (56.3)	0.52	
Triage[c]		0.81				0.55	
1 and 2	719 (16.1)		0.61	754 (16.4)	686 (15.9)		0.46
3	1673 (37.4)		0.84	1722 (37.5)	1668 (38.6)		0.31
4 and 5	2065 (46.2)		0.57	2087 (45.4)	1947 (45.0)		0.66
Suspected SARS-CoV-2 (Streaming)	1317 (29.5)	<0.001		1015 (22.1)	1716 (39.7)	<0.001	
Discharge group		<0.001				<0.001	
Admitted Ward/Another Hospital	524 (11.7)		0.69	551 (12.0)	477 (11.1)		0.16
Death	1		0.58	2	1		0.60
Left Before Completion of Treatment	164 (3.7)		0.08	202 (4.4)	173 (4.0)		0.36
Home	3764 (84.2)		0.01	3777 (82.2)	3645 (84.3)		0.007
Other/Unknown	11 (0.2)		<0.001	55 (1.2)	11 (0.3)		<0.001
Paediatric Intensive Care Unit	7 (0.2)		0.66	9 (0.2)	16 (0.4)		0.12
Presenting Complaint [d] – Top 10		<0.001				<0.001	
Injury – Other	965 (21.6)		<0.001	1182 (25.7)	719 (16.6)		<0.001
Fever	373 (8.3)		<0.001	570 (12.4)	663 (15.3)		<0.001
Abdominal pain	303 (6.8)		0.12	275 (6.0)	183 (4.2)		<0.001
Head injury	292 (6.5)		0.04	252 (5.5)	248 (5.7)		0.60
Breathing difficulties	145 (3.2)		<0.001	234 (5.1)	149 (3.4)		<0.001
Pain/Problem – Extremity	310 (6.9)		<0.001	167 (3.6)	209 (4.8)		0.005
Laceration	147 (3.3)		0.95	150 (3.3)	145 (3.4)		0.81
Vomiting	153 (3.4)		0.21	136 (3.0)	132 (3.1)		0.79
Rash	126 (2.8)		0.39	116 (2.5)	94 (2.2)		0.28
Pain/Problem – Facial	88 (2.0)		0.91	92 (2.0)	98 (2.3)		0.39
Shift[e]		0.10				<0.001	
00:00 – 07:59	267 (6.0)		0.06	318 (6.9)	443 (10.2)		<0.001
08:00 – 15:59	2049 (45.8)		0.15	2026 (44.1)	1817 (42.0)		0.051
16:00 – 23:59	2155 (48.2)		0.63	2226 (48.4)	2063 (47.7)		0.35
Weekday		0.86				0.17	
Monday	690 (15.4)		0.64	693 (15.1)	693 (16.0)		0.21
Tuesday	675 (15.1)		0.24	735 (16.0)	624 (14.4)		0.04
Wednesday	657 (14.7)		0.85	682 (14.8)	621 (14.4)		0.53
Thursday	668 (14.9)		0.78	677 (14.7)	595 (13.8)		0.19
Friday	630 (14.1)		0.83	655 (14.3)	639 (14.8)		0.48
Saturday	589 (13.2)		0.27	570 (12.4)	574 (13.3)		0.22
Sunday	562 (12.6)		0.85	584 (12.7)	577 (13.3)		0.37
Return (Within 7 days)	315 (7.0)		0.33	300 (6.5)	289 (6.7)		0.76

[a]0.2% of overall data missing
[b]3 missing gender
[c]0.5% of overall data missing or patient left before triage
[d]4% of presenting complaints grouped into 'Other'
[e]0.2% of overall data missing
#Individual comparison using binary variable for each characteristic

significant change in the total length of stay between periods. However, registration to triage was again significantly reduced.

For the most critical triage categories of 1 and 2, there was a saving of 5 to 6 minutes from registration to triage and 33 to 35 minutes from clinician review to discharge (excluding admitted patients) during system outage (Table 2).

After an initial increase in time over Days 1 and 2 of the attack, during the remainder of the first week of the cyberattack (Week 1 of Period 2), all patient flow stages decreased. When the EDIS was turned back on in Week 1 of Period 3, the time for all patient flow stages increased, except triage to clinician review (Figure 1).

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Table 2. Volume and Flow by Triage

Characteristic	Prior to cyberattack (Period 1)		Systems outage (Period 2)	All systems restored (Period 3)	
	Median (IQR)	*P*	Median (IQR)	Median (IQR)	*P*
Total Length of Stay (Min)[a]	188 (107-292)	<0.001	166 (99-275)	185 (109-291)	<0.001
Triage 1 and 2	253 (158-381)	<0.001	220 (139-344)	253 (171-373)	<0.001
Triage 3	200 (120-307)	0.003	178 (109-290)	196 (119-316)	<0.001
Triage 4 and 5	158 (86-250)	0.01	143 (84-232)	156 (92-246)	0.003
Registration to Triage (Min)[b]	11 (7-17)	<0.001	9 (5-15)	12 (7-19)	<0.001
Triage 1 and 2	11 (6-18)	<0.001	6 (3-13)	12 (6-20)	<0.001
Triage 3	12 (7-18)	<0.001	10 (5-15)	12 (7-19)	<0.001
Triage 4 and 5	10 (6-16)	<0.001	8 (5-15)	11 (7-18)	<0.001
Triage to Clinician Review (Min)[c]	37 (16-100)	0.10	35 (16-89)	33 (15-87)	0.07
Triage 1 and 2	15 (10-25)	<0.001	15 (5-23)	15 (9-22)	0.04
Triage 3	43 (20-98)	0.19	42 (23-95)	37 (17-84)	<0.001
Triage 4 and 5	55 (19-128)	0.12	50 (19-120)	48 (19-115)	0.68
Clinician Review to Discharge Excluding Admitted Patients (Min)[d]	77 (37-151)	<0.001	65 (31-131)	81 (39-153)	<0.001
Triage 1 and 2	178 (100-258)	<0.001	145 (82-222)	180 (111-259)	<0.001
Triage 3	86 (44-169)	<0.001	75 (35-143)	93 (46-168)	<0.001
Triage 4 and 5	57 (30-104)	<0.001	50 (25-90)	58 (32-111)	<0.001
Clinician Review to decision to admit (Min)[e]	147 (71-235)	0.19	136 (67-230)	145 (71-219)	0.52
Triage 1 and 2	126 (60-220)	0.80	128 (74-214)	107 (55-195)	0.03
Triage 3	157 (83-237)	0.17	142 (60-240)	173 (87-230)	0.05
Triage 4 and 5	206 (147-278)	0.15	160 (68-300)	208 (136-283)	0.17
Decision to Admit to Discharge (Min)[f]	186 (115-289)	0.63	180 (115-270)	233 (143-354)	<0.001
Triage 1 and 2	192 (120-289)	0.55	180 (115-276)	220 (134-341)	0.004
Triage 3	185 (117-283)	0.83	186 (120-237)	249 (151-367)	<0.001
Triage 4 and 5	153 (94-293)	0.74	175 (115-304)	218 (113-338)	0.40
Daily Volume, Mean (Std)	106 (14.6)	0.37	109 (15.7)	103 (13.9)	0.048

[a]1.9% of overall data missing
[b]3.3% of overall data missing or patient left before triage
[c]8.9% of overall data missing or patient left before triage or left before being seen by a clinician
[d]6.9% of overall discharges (excluding admitted patients) missing data
[e]10% of visits with a discharge group of 'Admitted to ward', 'Death', 'PICU' or 'Transfer to another hospital' missing data
[f]6.9% of visits with a discharge group of 'Admitted to ward', 'Death', 'PICU' or 'Transfer to another hospital' missing data
IQR, interquartile range.

The sub-analysis of the gradual restoration of each system showed that compared to the 23 days when there were no IT systems available, patient experience times significantly decreased ($P < 0.05$) during Period 2. Total length of stay reduced from a median of 188 (IQR 107-292) to 166 (IQR 100-285) minutes, registration to triage reduced by 1 minute, triage to clinician review by 3 minutes, clinician review to discharge (excluding admitted patients) by 8 minutes and clinician review to DTA by 12 minutes. None of the system restorations had a greater impact on timings than the EDIS. Upon EDIS restoration, registration to triage doubled from 6 (IQR 4-11) to 12 (IQR 7-19) minutes, clinician review to discharge (excluding admitted patients) from 60 (IQR 29-122) to 81 (IQR 39-153) minutes, and the total length of stay increased significantly from 167 (IQR 98-258) to 185 (IQR 109-291) minutes (Supplementary Tables 2 and 3).

The average patient lengths of stay of Periods 1 and 3 were applied to the number of patients who presented in Period 2 and compared to the actual accumulated average: a reduction of 1149 patient hours (47.8 days) in the ED for the 6-week period during system outage was identified. Applying the same method, 230 hours (9.5 days) were saved from registration to triage and 766 hours (31.9 days) from clinician review to discharge (excluding admitted patients).

Data Quality

Analysis of data quality dimensions revealed many data quality issues with the use of the bespoke Excel®. The EDIS improved the quality in all 10 dimensions (Table 3).

Return visits for 175 patients had an HCR number belonging to another patient. Using the patient's name and date of birth, the HCR number was obtained for 93 visits, and 82 were undetermined. Missing or unreasonable duration times revealed issues with 19.7% of data recorded during Period 2 compared to 4.7% (Period 1) and 5.1% (Period 3). Missing, invalid or the reuse of HCRs was highest during Period 2, with 4.4% of records impacted. Missing timings were highest during Period 2: 3.6% for triage, 4.6% for clinician, 2.5% for discharge, and 11.3% for DTA time; 1.2% of Period 2 visits had no discharge destination recorded. Patient flow durations that were less than 0 minutes for triage to clinician review were lower during Period 2 at 0.8% compared to 2.8% (Period 1) and 2.7% (Period 3); however, all other patient stage timing inaccuracies were higher (see Table 4).

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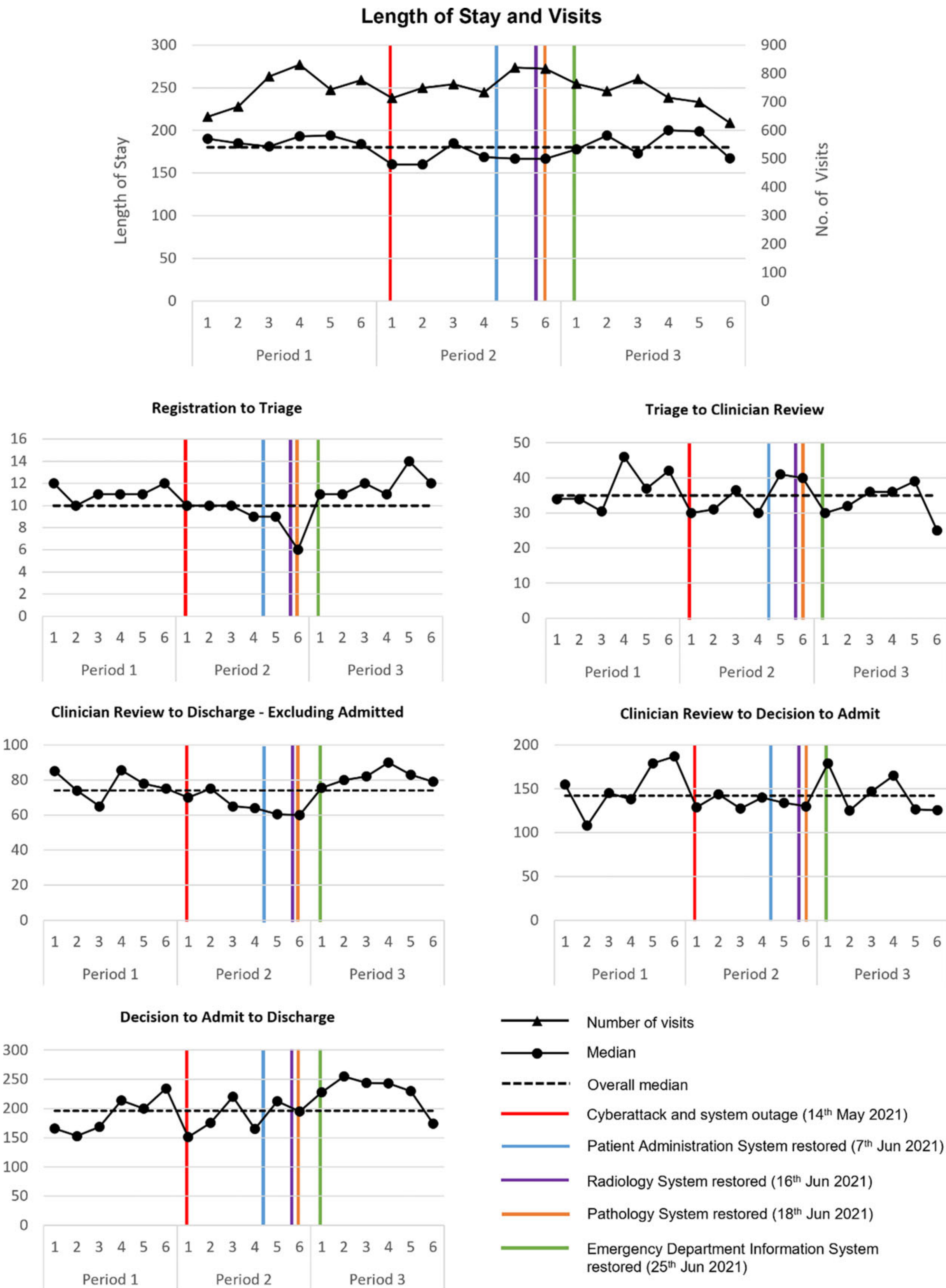

Figure 1. Median patient flow times from periods 1 to 3.

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Table 3. Data Quality Dimensions

Data Quality Dimension	System Outage – data recorded in Excel®	Prior and Post System Outage – data recorded in the Emergency Department Information System (EDIS)
Accessibility	A worksheet was created for each of the 42 days during system outage. These sheets needed to be merged, aligning columns and formats before including in the dataset to enable analysis to be performed. Time fields were converted to date/time to calculate durations.	A basic SQL query was generated to extract data into the dataset, without the need to change data type formats, enabling the easy insertion of data into the dataset.
Accuracy	A true measure of accuracy would be to validate the data recorded in Excel® against a reliable data source or to manually confirm that the data reflects real life entries. Although the data could be compared against the paper-based records produced during this time, this would be beyond the methodology of this study.	Data recorded on the EDIS would be considered the single reliable source of data and it would be difficult to validate other than to reproduce data collection or to manually confirm that the data reflects real life entries.
Completeness	The issue of missing data was the highest during system outage, there were no mandatory fields, therefore no controls in place to mitigate. The absence of prompts and structured pick lists leading to incomplete data being captured. Minimal data fields were captured, 21 in total.	The EDIS has several fields that auto populate with data such as date/time stamps and would have mandatory fields, structured drop-down menus for value selection, business/validation rules and prompts. These controls minimise the effects of missing or incomplete data. For each patient visit, 489+ fields would be populated with data in general for each visit.
Consistency	Expected logical characteristics were not always present, patients with an outcome of admitted did not always have a decision to admit date/time, patients with a triage category were missing the triage date/time, discharge destinations were missing even though the discharge date/time was entered and vice versa.	The EDIS did not mitigate issues around missing timings for logical characteristics, except for registration and discharge date/times. System controls ensured registration times, discharge destinations and discharge times were always completed.
Integrity	No referential integrity was maintained, there was no unique identifiers used for each visit leading to duplication. Unique patient identifiers were also absent resulting in missing or the re-use of healthcare record numbers.	Referential integrity is built into the EDIS providing mandatory unique identifiers for visits and patients. No duplication of visits was found and all patients had a unique patient ID leading to no healthcare record numbers being re-used, although some healthcare record numbers were missing.
Reasonability	Data patterns did not meet expectations for the recording of SARS-CoV-2 streaming, the significant drop in patients presenting with SARS-CoV-2 symptoms indicating data capture issues. Data capture issues were also responsible for the exclusion of data recorded on the 28th May 2021, which exhibited unreasonably high lengths of stay in the ED. Patient duration times with minutes less than 0 were also evident.	SARS-CoV-2 streaming rates were within the expected range when compared to previous and subsequent time periods in the EDIS. Although there were many outliers when calculating length of stay, none were as extreme as those recorded on the 28th May 2021. The occurrence of duration times less 0 were not prevented in the EDIS.
Security	The Excel® workbook was password protected, but no traceability back to the individual who entered the data could be implemented. Data in an Excel® file has the potential to be copied/removed from a PC.	The EDIS provides a secure login for each staff member with full traceability for all data entered on the system. Data is stored on a secure server.
Timeliness	The currency of data was assessed to see how up to date the information was at the time. The patient location in the ED was not kept up to date and as there was one row in Excel® containing all information for the visit, the locations could only be overwritten if updated.	The recording of patient location in ED was also a problem in the EDIS, as it was not always updated. Although when the ED location was updated, all previous locations for the patient remained and were reportable from the EDIS.
Uniqueness/ De-duplication	Two visits were identified as duplicates and were removed from the dataset.	No duplicate visits were present.
Validity	Data types were not clearly defined, columns were formatted as time instead of date/time, free text or inconsistent pre-defined lists were used. For a small number of records, values were entered into the wrong columns. Conditional formatting/data validation rules were not used which may have highlighted/prevented data entry issues. This all culminated in extensive data processing prior to performing any data analysis.	The EDIS is a relational database with set data format types for each field and pre-defined lookup tables controlling values that can be entered and limiting the use of free text. Data validation rules are built in and some fields are mandatory or auto populated. Although the system does not prevent all data quality issues, more preventative controls are in place.

Limitations

This study provides a unique insight into ED performance when moved from high dependence on IT systems to none or partial access for 6 weeks as a result of the cyberattack[5] and back again. Limitations include the fact this is a retrospective single site study and prone to all the biases therein; however, prospective work on this subject is unlikely. Presenting complaint categorization was based on decision rules around free text; a patient may have many symptoms recorded, and only 1 was used. Data entry variations may be a contributing factor to significant differences in presenting complaint, SARS-CoV-2 streaming and increased use of "Other/Unknown" for discharge destination in Period 2. Hospital number was used to determine returns; missing and the reuse of hospital numbers impacted this calculation. Although data quality imperfections were most apparent in the timings in Period 2, this was based on 2 measures alone: missing timings and durations

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Table 4. Data Quality Analysis for Missing Data and Duration Times < 0 Minutes

Characteristic/Timing	Prior to Cyber-attack (Period 1) n (%)	System outage # (Period 2) n (%)	All systems restored (Period 3) n (%)
Missing data			
Date of Birth/Age		24 (0.5)	
Gender		3 (< 0.1)	
Missing or Invalid Healthcare Record Number		201 (4.4)	8 (0.2)
Triage[a]	1 (< 0.1)	23 (0.5)	1 (0.2)
Discharge Group		54 (1.2)	
Presenting Complaint	14 (0.3)	6 (0.1)	39 (0.9)
Shift and Registration Time		26 (0.6)	
Triage Time[a]	2 (< 0.1)	164 (3.6)	8 (0.2)
Clinician Review Time[b]	31 (0.7)	200 (4.6)	33 (0.8)
Decision to Admit Time[c]	7 (1.3)	63 (11.3)	10 (2.0)
Discharge Time		113 (2.5)	
Total minutes < 0			
Registration to Triage[a]	19 (0.4)	95 (2.1)	1 (<0.1)
Triage to Clinician Review[b]	120 (2.8)	35 (0.8)	117 (2.7)
Clinician Review to Discharge[b]	10 (0.2)	30 (0.7)	11 (0.3)
Clinician Review to Decision to Admit[c]	14 (2.6)	16 (2.9)	12 (2.4)
Decision to Admit to Discharge[c]	2 (0.4)	4 (0.7)	

[a]as a percentage of visits excluding did not wait before triage
[b]as a percentage of visits excluding did not wait
[c]as a percentage of visits with a discharge group of 'Admitted to ward', 'Death', 'PICU' or 'Transfer to another hospital'
[#]Included data for 28th May 2021, which was excluded from time series analysis due to significant data quality issues.

less than 0 minutes. An audit of each individual timestamp would not be feasible to perform. The EDIS does not have controls in place to mitigate against the recording of inaccurate timings, having similar controls to those of Excel® except for mandatory discharge times. These data discrepancies are limitations and reflect data quality results. Partial restoration of IT systems such as radiology allowed only small sample size (229 attendances) comparisons.

Discussion

This study describes the situation, response, and outcomes of the pediatric ED during a 6-week digital disaster. There are learnings present in the data and experiences during that disaster that will enhance the department's efficiency day to day with EDIS and the preparation and response to the next digital disaster. To the best of our knowledge, no such report exists in the literature. There was no significant change to most demographics and characteristics of patient visits presented in Table 2. Significant variance was found in the recording of SARS-CoV-2 status, presenting complaint and discharge group; however, data capture issues and input value differences indicate probable cause (see Table 4). The overall ED length of stay reduced significantly in Period 2, by between 19 and 22 minutes (based on the median). Within the first week of Period 2 (cyberattack), all patient experience times had reduced. The restoration of each IT system did not have as big an impact on timings until the EDIS was restored, resulting in a significant increased patient experience times within the first week of Period 3 (except for clinician review to DTA). The 10 data quality dimensions revealed significant compromise in data quality with the use of Excel® during Period 2 compared to data recorded in the EDIS (19.7% data imperfections in Period 2, 4.7% in Period 1, and 5.1% in Period 3).

The perception amongst providers is that administration and triage processes were much faster in Period 2 and uncertainty about being better for the patient. The reduction in length of stay during system outage was most significant from registration to triage and clinician review to discharge (excluding admitted patients). These are times associated with the largest volume of patient-related data entry. The ED management team postulate that this reflects a combination of inadequate pre-existing local IT infrastructure and current EDIS workflows that were bypassed by both the simple pen and paper and human resourced administration processes. A reduced number of data points was captured electronically during Period 2, 21 data points compared to over 489 data points that are generally entered on the EDIS for each patient attendance (see Table 4). During Period 2 registration, triage and clinical assessments were paper-based and therefore portable, easily accessible, and apparently more efficient from a patient experience perspective. Dedicated 24/7 administrative staff entered information, and timings in Excel® upon verbal instruction allowed delegation of data entry from the clinician to an administrator. Electronic data take longer to record than paper,[19] and the use of electronic documentation in some EDs was associated with significant increases in patient length of stay.[20] On the use of scribes, there are conflicting reports with some finding no difference to length of stay[21,22] and others reporting a reduction.[23–25] In this instance, the process of administrative staff data entry was associated with significantly improved patient experience times. Owing to the computer infrastructure limitations and EDIS interface, the real time accuracy of the EDIS timing pre- and post-system outage comes into question. Ward et al. observed that more data errors were present after EHR implementation emphasizing differences between observed and inputted electronic timestamps.[26] Dedicated administration improved the apparent currency of these timings with Excel®.

Although data were entered in a timelier manner, they were at a significant cost. The quality of data suffered with 19.7% of the records exhibiting issues in Period 2. User training and systematic safeguards can prevent dirty data in databases,[27] keeping in mind data quality dimensions during the initial setup.[16,17] Temporary processes and infrastructure had to be put in place quickly (hours) with little time for development or training. SARS-CoV-2 infection control processes from registration were undermined. Variables such as presenting complaint and discharge destination were completed by multiple users of varying experience in a busy work environment most likely contributing to data quality issues. The reuse of HCR numbers presented a risk which could have been mitigated by applying referential integrity[16] at the patient level.

Incidents of hospital-targeted cybercrime are becoming more widespread and a proactive approach should be taken to prevent an attack taking hold in the first instance.[28] Key cyber security principles should be put in place centered around leadership, governance, cyber security expertise, IT infrastructure, and staff awareness and training.[5,29,30] This should be incorporated by the hospital emergency planning committee into the hospital's major emergency/disaster plan.[31] If a breach occurs, it may take time to recover systems from offline backups; a business continuity plan should be implemented, including preparations for workarounds for the total loss of IT systems[5] that may be inaccessible for weeks. Continuity plans should include how and where data will be recorded to support clinical workflows. An Excel® workbook was used in the ED; the design could have been improved by following data quality dimensions and implementing backups. A considerable gap has been identified in this study, which could be filled by the pre-emptive creation of a simplified bespoke electronic patient information system that operates on standalone computers. The investment of new additional staff to the ED is critical to support the implementing and maintaining of temporary information systems and assisting new workflows.

Externally, it should be noted that cyberattack-related national public announcements did not result in the desired outcome of reducing pediatric ED attendances. This is hugely different from initial SARS-CoV-2 pandemic experience[32] and during the WannaCry attack across the NHS in England; visits to the ED decreased by an average of 6% per infected hospital per day.[33] In this study, despite a 25% decline in attendance on the second day following the cyberattack compared to the average for all 3 periods, daily visits during system outage were on average 3% higher compared to Period 1 and 6% higher compared to Period 3, despite public announcements. Compared to matched periods in 2019, visits were higher for all 3 periods of time in 2021. The observed increase in attendances during the cyberattack period reflects the role placed upon the pediatric ED in the Irish health system for the provision of unscheduled primary and secondary care during a National Cyberattack.[34]

Interestingly, this cyberattack made it possible to learn about the current IT system/infrastructure. Existing clinical/digital workflows are not efficiently supported by processes, and IT structures with insufficient computer hardware in key locations were identified. This affects accurate recording of patient journey times in 2 ways; a proportion of the clinician's time is spent accessing the EDIS and, separately, the time competing clinical priorities also result in a delay in data entry due to prioritizing patient assessments and clinical care.

Conclusions

The loss of IT systems from a digital disaster for 6 weeks was uniquely associated with a reduction in ED patient experience time. This may be due in part to increased clinician administration efficiencies and administrative staff assisting with data entry; however, data quality suffered greatly. A hospital's major emergency plan should proactively include a low-tech cyber-disaster plan, and this study uniquely provides the experience of digital disaster management and resultant outcomes in a pediatric ED.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/dmp.2023.86

Data availability statement. The underlying anonymized data will be made available upon reasonable request to the corresponding author pending the approval of the data protection office.

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Author contribution. FL and MB conceptualized the study. MB created the Excel® file and implemented workflows with PD, CB, LM, BC, ER, KB, and DH. For the data recorded in Excel® during system outage, PD, BC, CB, KB, DH, ER, LM, and MB coordinated the data with administrators, while MB, H'OR, and FL prepared the Excel® data for analysis. FL extracted the data from the Information Technology systems, created the final data set and carried out the primary analysis. FL, MB, H'OR, PD, CB, and BC provided a substantial contribution to the design, methodology, and analysis of data in the initial stages. All authors have reviewed, provided critical feedback, contributed to the writing of the manuscript, and approved the final version.

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Ethical standard. This study was registered with the Children's Health Ireland research ethics office (Communication June 28, 2021). All data processing and storage complied with GDPR and data protection policies. This service evaluation study was exempt from requiring ethical approval by the hospital research ethics office (Communication June 29, 2021).

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