DOI: 10.1561/9781638282372.ch20

Chapter 20

Innovative Use of Technology for Acute Care Pathway Monitoring and Improvements: Workflow Management in Acute Stroke Diagnosis and Care

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20.1 Introduction, Context, and Background: Care Management

20.1.1 Planned and Unplanned Care

Healthcare can be planned or unplanned. When planned, it is a strongly organized process, often including predictable, plannable actions with the goal of narrowing down the presenting complaints and symptoms, determining the correct diagnosis, weighting, and sharing the decision on an appropriate course of therapy. Each patient requires unique patient-centric care [1]. This makes the process of healthcare so divergent from those in 'lean' or 'just on time' management strategy, as process steps may need to be performed in alternative order to suit the individual case [2].

Figure 20.1. Relationships between terms used for care processes [8]. Workflow sits on the top of the pyramid as "overall integration".

On the other hand, unplanned care, typically in an Emergency Department (ED), room setting has the same requirements in terms of quality but has an important time-sensitive time aspect as well as a higher, improvisational, multi-disciplinary character.

20.1.2 Care Pathways, Procedure, and Workflow

So-called 'care pathways' have become popular in healthcare and have been shown to have a positive influence on quality, patient acceptance, costs, healthcare provider satisfaction, and even as a methodology for internal process improvability [3, 4]. Introduced in 1985 and attributed to K. Zander and K. Bower, this system for making and documenting steps has been embraced worldwide. Newer iterations of care pathways have integrated patient, medical, and financial aspects in care and may be computer-supported [5, 6]. Similar strategies, such as directed or goal driven care, involve more detailed, feedback-driven strategies for specific aspects of healthcare [7].

Many of the above terms are used interchangeably. Figure 20.1 shows a practical approach to the hierarchy herein. In this hierarchy, the concept of workflow sits at the pinnacle of the pyramid [8]. Great workflow has been described as "working like the Viennese Waltz with the Reverse (Left Cross) Turn": lovely, efficient, and stimulating but requiring compliance of everyone to avoid collisions. In multidisciplinary teams, workflow is the highest attainable level.

20.1.3 Unplanned and Emergent Care

Things change when care becomes unplanned or emergent. Many patients who are admitted to an ED face a lengthy care workflow. Triage is typically applied to determine who needs attention first.

Some subgroups of patients require urgent care with international standards defining time to intervention and time to care (i.e., therapy started within

60 minutes of arrival at the hospital). It has been difficult for hospitals to validate where time is spent during the workflow, particularly in time-sensitive settings with multi-step pathways. These insights could decrease patient morbidity and mortality, increase efficiency, and lower costs including ED overload.

It is noteworthy that even patients with direct life and quality of life-threatening conditions must go through a diagnostic process (i.e., be seen by a nurse and a physician who will, for example, order the requisite ultrasound in order to reach the 'urgent' status needed) [9, 10]. It has been suggested that explicit workflows, and pathways supporting selection, improve care and lower costs [11–13]. Monitoring these pathways and the intended workflow, however, remains challenging [14–16].

Monitoring hyper-acute workflow remains difficult, and physical observation can be a limiting factor. Primarily, the concept of the Hawthorn Bias – that essentially the study of something such as a process has a direct influence on the process and thereby influences the outcome – is applicable [17, 18]. Furthermore, the more complex or acute the workflow is, the more difficult it is to follow its process. Observing (or more accurately analyzing) the effects of content in the process requires a full understanding of the complete pyramid (Figure 20.1) by the observer. In the ED setting, getting a non-obstructive and non-participating expert observer to be on station on time may also be a major logistic difficulty.

20.1.4 Use of Innovative Technology in Workflow Assessment

So-called Big Data, industrialization, and machine learning technologies have been put forward as being able to offer insights into workflow. The most difficult is coupling times to context information. Previous work by our group has shown this to be the case in the healthcare sector [19].

To explore this technology, and more specifically, a Real-Time Locating System (RTLS) in a (hyper-)acute and highly granular, content-rich, setting, we designed a study to track staff and patients presenting at the ED with the working diagnosis of an ischemic, neurologic, stroke.

The death rate and level of disability resulting from strokes could be dramatically reduced by immediate and appropriate medical care: the primary survey, diagnostics, and potential therapy (so-called 'door to needle' time) should all be completed within 1 hour and are described in a step-by-step workflow [20]. Our goals were to validate the usability of RTLS as a monitor of this workflow, RTLS integration of timing integration with the Electronic Medical Record (EMR), develop Big Data feedback allowing insights and potential improvements into the workflow, initiate workflow adaptations, and monitor these effects.

20.2 Methods and Materials in the Study Iteration in ETZ

20.2.1 Setting

The ED at Elisabeth-TweeSteden Hospital (ETZ) is a modern facility including two major intervention rooms (also known as trauma rooms) with a roll-over CT scanner (Siemens^{TM}) servicing both rooms. Workflow patients are admitted directly onto the scan table, and clinical investigation, and therapy (i.e., thrombolysis) can be done immediately.

The ED is manned 24/7, with residents and staff from different disciplines. For the stroke care pathway, a designated consultant neurology staff member is on call 24/7 and on-site within 15 minutes with an on-site neurology resident starting the workflow. Assessment of scans is done in real time, and the hospital has a view-online system that allows neurologic staff to also evaluate a scan on their smartphone and offer advice from anywhere. The Department of Neurology has developed, validated, and implemented a workflow within the setting of the ED – Radiology Department (angio suites) – Stroke Unit to standardize and facilitate the rapid, exact care for these patients (Table 20.1).

20.2.2 RTLS and Its Study Setup in ETZ

RTLSs provide solutions for positioning or localization indoors, where traditional outdoor technologies such as GPS do not work. For the purpose of this study, room-level accuracy was essential (i.e., InfraRed (IR) and Radio-Frequency (RF) solutions by Centrak^{TM}).

Cable-free (wireless, battery-operated) IR beacons were placed on the ceilings. A specific type of IR beacon makes it possible to create virtual walls, that is, to virtually separate large rooms into subzones, down to bed level. The beacons emit invisible IR light containing a unique code representative for that zone, 'filling' that space. The tags detect this IR code when they enter that area, and send this zone code, together with their own unique ID, to a 'Star.' The Stars act as access points and transfer information to the central server. Tags include patient tags, asset tags, and staff badges. Tag location changes were registered continuously, with update rates up to once every second. Data collected include time, tag ID, location ID, motion factor, button press events, and tag type (i.e., function group) [19].

We built the RTLS world within the ED, adjacent halls, Radiology (angio suite), and OR (hybrid operating room). Each professional in a nursing, medical, and logistic discipline involved in the stroke workflow was given an individual badge to wear. A box with reserve badges was made available such that individuals could exchange badges (within their function group) if they so desired to enhance the

Table 20.1. Hyper-acute stroke care pathway for patients who need to be treated by IVT and/or IAT. 1: Ambulance personnel, 2: ED-RN, 3: resident NEU, 4: Tech. RAD, 5: resident RAD, 6: NEU supervisor/staff, 7: RAD supervisor/staff, 8: intervention RAD, 9: anesthesiologist, 10: intensivist, and 11: ANE-RN.

Steps	Time	Events
1	0 min	(2) records exact patient arrival time; (1) hands over to (2, 3); (1,2) transfers patient to CT-table; (2) measures vitals; IV access (2); Blood drawl for lab results (2); PoC Glucose and INR (2); (4) is standby.
2	+5 min	Anamnesis and neurologic examination (3); (3) Orders plain CTC; (3) informs (5); (2) takes away shoes and socks of patient; (4) makes plain CTC.
3	+10 min	(3) evaluates CT-scan, if no intracerebral blood, order CTCa; (3) communicates glucose and INR; (2) makes ECG; (4) makes CTCa; (5) is standby in ED.
4	+15 min	(3) identifies contra-indications for IVT and consults (6); If IVT: (3) gives assignment for thrombolysis preparation to (2); (3) give patient thrombolysis bolus; If CTCa: (5) evaluates CTCa and if necessary consults (7).
5	+20 min	If IVT: (2) starts thrombolysis perfusor; If CTCa: (3) evaluates lab results and contra-indications IAT; (3,5) indicate IAT; If IAT: (3) informs (6) to come; second IV access (2); (3 or 6) informs (8) and asks them to come to angio suite.
6	+25 min	If IAT: (3 or 6) calls (9) and decides necessity for help; (3 or 6) calls (10) if help by (9) is needed but is kept at OR; If help needed by (9 or 10), (11) is sent to angio suite; (3 or 6) asks (4) to arrange two extra colleagues; (3 and/or 6) leave to angio suite.
7	+30 min	If IAT: (3 or 6) organizes admission to SCU for later; (4) opens Angio Suite and informs (2) that patient may come; (11) tests anesthesia station and informs (9 or 10) to come.
8	+35 min	IF IAT: (2) transports patient to angio suite
9	+40 min	IF IAT: (3 or 6) hands over to (4); (2) transfers monitoring to (11); (2) hands over to (11).
10	+45 min	IF IAT: (3 and/or 6) monitor patient and if indicated give medication; (8) arrives at angio suite
11	+50 min	IF IAT: (4) covers patient in sterile drapes for intervention; (9 or 10) gives anesthesia.
12	+55 min	IF IVT only: Thrombolysis ready, (2) transfers patient to SCU. IF IAT: (3 and/or 6, 11) monitor patient; (8) punctures groin and performs IAT; (3) documents IAT procedure in EMR (time arrival ED ("door"), time CT, time start IVT/IAT, NIHSS, delays, etc.)

Abbreviations: CT: Cat Scan; CTCa: Ct scan of the carotid arteries with contrast; ECG: electrocardiogram (12 leads); IVT/IAT: intravenous thrombolysis/intra-arterial thrombectomy; PoC: NIHSS: National Institute of Health Stroke Scale; point-of-Care lab determination such as INR, blood glucose level, hemoglobin level, blood gas, and so on.

feeling of privacy. Upon entry into the ED, each patient received a bracelet with a tag which was removed at the end of the initial care pathway. The senior (coordinating) nurse registered the patient's name, hospital ID number, and wristband number in a dedicated file with a date-time stamp.

20.2.3 Inclusion and Privacy (GDPR)

Management of the General Data Protection Regulation (GDPR) played a major role in the study. Enrolment occurred as a matter of course for all patients suspected of having a stroke. Patients were eligible for inclusion if they were diagnosed as having an ischemic stroke and received an intervention in the form of IntraVenous Thrombolysis (IVT), Intra-Arterial Thrombectomy (IAT), or both. Not fulfilling both these criteria or refusal or inability to achieve informed consent led to exclusion. Informed consent was requested in the days following the stroke pathway. EMR data were only accessed and entered into the database after informed consent was received. The local institutional board and the regional Ethical Committee, the hospital data protection officer, the social committee, the legal counsel, and the Board of Directors approved the study [21].

Professionals were informed about the study via their management structure and asked to participate using blinded badges at a functional level (e.g., 20 similarly coded badges for the cohort of residents in neurology). Individual professionals could opt out of wearing a badge.

EMR data were withdrawn by the Data Warehouse service within the hospital, cleaned of GDPR-sensitive data, and entered in an Excel database. Combining EMR data with RTLS has a specific role in ensuring the privacy and ethics of the study as was defined for this specific study. Because some actions might be performed before and after departure from the RTLS monitoring area, the study team defined ± 1 hour for EMR data usage retrieval around admission to the ED.

This database was screened for privacy-sensitive data again before transfer. Raw RTLS data were stored within a dedicated and protected section of the hospital servers. RTLS data were transferred to Philips for further analysis, machine learning, and dashboard composition only after it was reduced to include only data from patients included in the study and who had given informed consent. Subsequently, data are cleaned (e.g., removed if the location is not clear from a process point of view, or manually filled in, from occasional artifacts (i.e., missing detailed location called 'occlusion' in the CenTrak system when a tag is covered by a blanket, the IR signal is blocked but the RF signal works), and formatted for analysis.

20.2.4 Data Analytics Techniques

Once received by Philips, the first step was analytics, which includes a Data Miner, for machine learning-based predictions. Another component was the Data Processor, which aligns the data with different sources, for example, merges two data sources according to timestamp and entity ID. A pattern extractor extracts patterns from the merged data. One level above analytics is the logic and application level, with four components. First is the real-time Machine Learning Scoring Engine. There is an interface between this Scoring Engine with the Data Miner component from the level below. The models produced in the Data Miner were deployed onto the Scoring Engine for real-time scoring. A Rule Engine was responsible for detecting interesting and risky patterns. The Query Engine took queries from the user interface, translated the query into SQL, executed them in the database, and returned data results. The Reporting Engine could run predefined reports given customized parameters.

The top level is the visualization and alert level. This level interacts directly with users and consists of two parts. The first part is the Alert Dispatcher, which dispatches alerts generated by the Rule Engine to specified users. The Visualization Component was implemented by a Java web server as a back-end and an HTML 5-based front-end. It visualized the current status information and analytic results for the users in the dashboard (Figure 20.2).

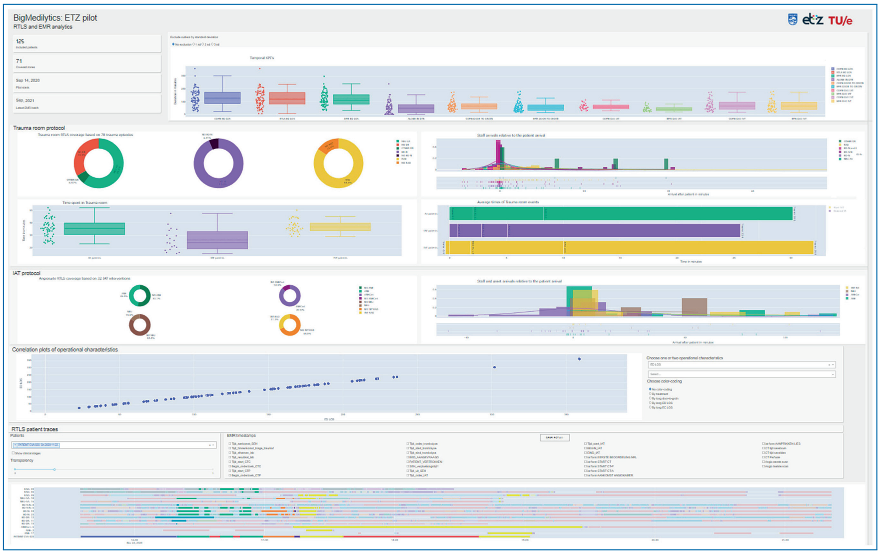

Figure 20.2. An example of Dashboard output, showing the monitoring of specific endpoints and observations. Note, at the lowest level, the report of the (dis)continuous reception of signals from the RTLS.

20.2.5 Combining Context Information with RTLS Output

In many workflows, it is possible to recognize the phase of care using RTLS alone. This is particularly true if the RTLS areas being monitored are carefully defined, the patient is physically moved from room to room, and an association is created between locations, staff members, and the different phases of actions in the workflow. The stroke workflow is highly granular as most of it occurs in one location, with limited staff movement. By integrating staff members with the patient tag, it is possible to define that a step could occur if a particular staff member or group of staff members (i.e., the neurology resident and an ED-RN) were present in the same room as the patient. Nonetheless, in the workflow, there remain contextual steps that are impossible to detect with RTLS. An example is the actual initiation time of thrombolysis. It is defined by the workflow that the start of therapy (an IV bolus of thrombolysis) is done in the intervention room, with the rest of the IV medication given by pump potentially elsewhere in the ED or the angio suite. The preparation of the thrombolysis medication takes time, as does the calculation of the correct dose. While there are timestamps in the EMR and it requires some movement by the ED-RN, it is difficult to pinpoint. EMR timestamps may be pre-, ante-, or post hoc notations.

20.2.6 Primary Endpoints

The primary goals of the study were as follows: (1) Evaluation of the ability of RTLS to offer (useful) insights into the performance of hyper-acute workflow steps, with special regard to the user model of RTLS with EMR data as a high-fidelity monitor, and its ability to demonstrated interventional aspects; (2) patient and caregiver satisfaction and acceptance of RTLS, with special attention to insights into the use of staff badges, patient, and asset tags; logistics involved and scalability; generalization in different use models (anonymity and its consequence); and (3) insights in measures: Number of enrolled and included patients; interventions; general demographics; measurability of time door to CT scan (plain); and times to start treatment (i.e., door-to-thrombolysis (IVT) and door-to-thrombectomy (IAT)).

Note that the neurological diagnosis and treatment of the patient remained outside the parameters of the study.

20.3 Results

Data were collected in the period from September 2020 to August 2021, continuing through the COVID-19 pandemic. A brief pilot (three patients not included in the study) was performed to validate practical and technical aspects.

All consecutively admitted patients via the ED, presenting with signs of stroke (cerebrovascular accident, CVA) were enrolled. In June 2021, interventions into time-sensitive aspects in the workflow were introduced to validate the ability of RTLS to monitor these changes and measure their effects in time.

20.3.1 Primary Outcomes

In total, 829 patients were enrolled. A total of 127 were approached for informed consent of which two patients refused, leaving 125 inclusions (98% inclusion rate), with 32 inclusions in the post-intervention phase of the study. Of the 125 patients, 80 received IVT treatment, 29 patients underwent IAT treatment, and 16 received both IVT and IAT. The mean age of included patients was 70.5 ± 13.2 years. Totally, 62 patients were female (49.6%). There were no patients < 21 years old, or mentally impaired prior to their admission.

One RTLS tag or badge generated approximately 3,600 data points per hour. Per patient, overall, 10 tags and 1 badge were involved and of interest. This leads to 36,000 data points per included patient, or approximately, 4.5 million RTLS data points overall.

An accurate T0 is essential for three of the most important indicators for our pathway. Door time = T0 is the patient arrival time at the ED and the beginning of the DTN time. T0 was documented in 100% of cases in the EMR. However, other senior ED-RNs with other work strategies were shown to impact its actuality [22]. For example, T0 was inaccurate when the senior ED-RN mistook which ambulance had just arrived. An RTLS solution for this issue is described below. Accuracy in data points was diverse. Cross-checking T0 with other data in EMR, as well as with RTLS, confirmed inaccuracies.

20.3.2 Patient and Caregiver Satisfaction and Compliance

Professionals were sensitive to (their) privacy and autonomy. To our knowledge, only two opted out. Compliance (i.e., all RTLS badge data for a professional during one workflow was available) was 67%. Compliance was affected by badges not being seen by the registration points, particularly due to clothing or positioning for CT scanning. This remained an issue despite retraining on the importance of the position. Alternative locations (i.e., on the shoulder) were found to have their own limitations. Some expressed concerns that the data could be used for other purposes such as ‘benchmarking’ individual workload, speed, or accuracy. Overall practical acceptance of badges was good.

20.3.3 Dashboard Representation

The core analytics were represented in the Dashboard with RTLS, EMR, and combined data point representations. The dashboard could show individual cases or aggregated data over any cohort or time frame selected. Thus, we can use data from a unique source, such as RTLS, the EMR (i.e., the CT scan), or a combination of both. The dashboard was ideal to analyze whether a reduction of some 20% in the workflow (time) aspects could be reached and where or how.

20.3.4 Study Interventions and Their Effect

Interventions with the care pathway, based on big data insights, were initiated in June 2021 and continued until the closure of enrollment. The week prior to the start of inclusion and interventions was used for training purposes.

The interventions in June were as follows: (A) Focusing on accuracy in patient arrival time by using RTLS badges as a push button system at the ED ambulance bay entrance (to be used by the EMS nurse – which worked well), senior nurse workplace, and intervention room entrances; (B) tagging the IVT intervention box and bundling all the medication and materials in it and move it into the intervention room, which removes the need for nurses to leave the intervention room area; and (C) permanently placing an anesthesia cart in the angio suite for IAT.

Additionally, on point B, the medication was previously kept in the central medication room within the ED. This is a locked location, with the medication spread according to the alphabet in drawers and syringes, tubing, etc., kept in their own drawers.

The overall time effect of the interventions was a clinically relevant reduction of more than 20% (as a clinically relevant measure).

20.4 Discussion

To our knowledge, this study is the first to use RTLS and Big Data technology to monitor a fully operational medical hyper-acute workflow with the incorporation of time-sensitive content data from the EMR as a methodology to find improvement points, create interventions, and monitor the effects of the interventions.

We were able to enroll (signed informed consent) 98% of the patients who were eligible and created a database with 125 patients with an ischemic stroke who received treatment. More than 200 different individual professionals wore badges. Millions of data points were collected. We identified, added remediation, and monitored the effects of >3 points in the workflow to good effect.

20.4.1 Brief Learnings

Patient and caregiver satisfaction and acceptance of RTLS: The study was able to show that it is possible to get a large number of professionals to accept and wear the RTLS badges. We note that the study team was fully blinded to which professional (as an individual) was actually wearing a specific badge. However, an overall compliance of 67% is not high. Badges were anonymously handed out to the different functional groups and changing badges within that functional group was encouraged. This did mean that maintenance of badges (i.e., battery state), recognition of non-compliance (i.e., badge inside obstructive pockets), and follow-up of missing data (i.e., furthering understanding of why certain data points were not being registered) were not possible. In many patient cases, one or more staff members were not seen (in the RTLS data) during the workflow. Since the patient was progressing through the workflow, and EMR entries confirmed their presence, they had to have been there. This interfered with machine learning rules, and in some cases required manual assessments [23]. Our study confirms findings from other settings that privacy concerns may remain an active threat to the use of this technology [24]. Good information, an understanding of the technology, and the data it produces are essential for success [2]. Acceptability seems to be strongly associated with personal and professional responsibility and autonomy, as shown by RTLS success in many logistics-oriented sectors. Our study is unique, as it is the largest in the medical setting, involved both professionals and patients and involved a time-sensitive workflow that is used by healthcare authorities as a quality measure. RTLS was shown to be more accurate (shorter times) than EMR data in reporting workflow (run-through) time, supporting the enthusiasm of the responsible professionals in their participation. Future improvements can be made by institutions in adding privacy and monitoring aspects to employment contracts.

All patients enrolled were happy with the wrist tag: it was not annoying, and keeping it uncovered (i.e., outside blankets) was possible. The two patients who refused informed consent did so from privacy concerns.

Evaluation of the ability of RTLS to offer (useful) insights into the performance of hyper-acute workflow steps: Fidelity in the (timing of) tagging the patient with special attention to arrival time was complex and a central aspect in its use [25, 26]. Despite all the patients being presented by EMS and pre-announced, clarity in 'door time' (T0) proved itself a relevant confounder. The EMR allows patients to arrive (digitally) before physically, i.e., to 'block' the room and allow orders to be placed. The study documented one patient in whom the EMR time for CT scan was 20 minutes before their physical arrival. RTLS data were suggested to be highly accurate, as far as ground truth data or verification was possible. These discrepancies make machine learning difficult.

The study investigated the high granularity of data, as gross movement (i.e., from room to room) was limited. The combination of EMR data with RTLS, after choosing ground truth items, such as the time registered in the CT-scan slices themselves, was very valuable and reproducible. Important delay markers in the workflow were able to be found, interventions conceived and implemented, and their effects monitored for validity without much difficulty. Three main interventions were the addition of RTLS badges to verify T0, moving and bundling the thrombolysis medication such that the nurse need not leave the intervention room (and thus would not be distracted by others while walking through the ED on the way to-and-from the medication storage, leading to time loss), and supporting ready-to-start anesthesiology setup in the angio suite. Clinically relevant time (20%) saving was demonstrated and maintained, showing no Hawthorn effect.

We plan an even higher granularity study with EMR and RTLS using the teams involved in trauma admission.

Insights in measures: The results show that RTLS can offer insights into a hyper-acute pathway when combined with EMR data. RTLS can support the process aspects and has allowed for interventions to be introduced. The age (ca. 70 years old), with a relevant spread in pre-existing comorbidity underlines that early and accurate diagnostics and treatment will have a major impact on the rest-of-life healthcare costs, such as healthcare consumption, costs of supportive care, and so on, even though return to the workplace is not a focus.

The industrialization of care pathways via RTLS, thus, requires monitoring and intense care in its analysis. Using time stamps from EMR remains fraught with dangers as time stamps from orders, start investigation and stop investigation as well as its formal report, often had a chronological progression which was physically impossible (i.e., the patient must be present to perform a CT scan).

The RTLS system is readily placed or removed for other purposes and could be used by the institution to achieve similar goals elsewhere. A potentially good choice for the role of "owner/facilitator" would be the medical technology department.

20.5 Conclusion

The integration of EMR data with RTLS data in the proprietary Philips dashboard generated unique insights and interventions that resulted in clinically relevant improvements. Big Data showed strengths and bottlenecks otherwise invisible. Machine learning requires high compliance from users. Our integrated EMR and RTLS data showed that the use of only EMR data may skew analysis not only in statistical but also in (large) clinically relevant ways.

Granularity using workflow to allow sufficiently detailed understanding to be developed, combining selected data from the EMR with the RTLS, in a team approach should also be manageable not only in the ED but also in a wide range of potential locations within healthcare. We showed a >20% reduction in put-through time as a clinically relevant time-saving after monitoring. Compliance needs to be further investigated in the clinical setting.

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