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Chapter 21

Monitoring Sepsis Patients in the Emergency Department: The Use of a Real-Time Location System

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21.1 Introduction

Sepsis is a worldwide condition with high incidence and morbimortality. It is caused by a dysregulated response of the organism to an infection and affects one million people every year [1]. According to the Third International Consensus Definition Task Force (Sepsis-3), sepsis is defined as a suspected or documented infection with a rapid increase of two points on the Sequential Organ Failure Assessment (SOFA) scale [2, 3]. There are several quick diagnostic scales that were designed for the early detection and management of septic patients, although there has been disagreement on the convenience of their use [4–14]. Likewise, contradictions about their prognostic value have been noticed, not only in Community-Acquired Sepsis (CAS) studies but also in studies based on specific groups of patients, such as the critically ill, [15] surgical, [16] cirrhosis, [17] and oncologic [18].

Although actual sepsis incidence remains unknown, according to the data published in Spain in 2014, 333 cases for every 100,000 inhabitants every year is the estimated rate, some of which evolve into septic shock [19]. Among them, CAS is frequently present: in circa 10% of patients affected by infectious diseases that attend the Emergency Departments (EDs). Moreover, 30–40% of septic patients in intensive care units have their origin in CAS. The economic impact is difficult to quantify due to different definitions and ascertainment methods. Nevertheless, an epidemiological study estimated an average cost of £25,000/case with an annual population-based incidence between 40 and 455 per 100,000 [20]. Measurable increases in healthcare costs, mortality, and secondary endpoints adverse effects are associated with every minute of delay in the administration of treatment.

The sepsis care challenges are currently managed through home-based and in-hospital strategies. Home-based strategies are mainly based on educational programs targeting the early recognition of symptoms. In-hospital strategies involve clinical, nursing, and ancillary staff and are based on: (1) the development of specific early screening and response tools, (2) time reduction for complementary tests, and (3) development of more accurate diagnostic tests and extended eligibility for aggressive treatment procedures. However, these approaches cannot address all elements of the complex cascade of patient work-up in the ED but rather aim to improve one specific aspect (e.g., disease recognition by nursing staff). Dynamic bottlenecks in the ED workflows can only be detected when all elements are analyzed systematically and simultaneously.

Early identification and appropriate management in the initial hours after the disease are associated with lower morbidity and mortality as well as a reduction in healthcare costs. However, the current data management systems are not capable of systematically identifying unnecessary time delays, bottlenecks, and other weaknesses in the workflow. The use of additional resources such as monitoring with a Real-Time Location System (RTLS) could provide improved time-to-intervention in sepsis patients arriving at the ED.

Big Data is required to address this problem due to the volume (e.g., data generated from the intervention of multiple healthcare professionals and the use of multiple facilities), velocity (e.g., real-time data will be generated from the RTLS system), variety and veracity (e.g., Electronic Medical Record (EMR), National (Nationwide) Inpatient Sample (NIS) database, RTLS, Machine log, and Lab data), and value (e.g., resource optimization in ED and time reduction for diagnosis and treatment). Secondary outcomes expected by applying a Big Data approach included better asset, installations, and staff management, increased patient safety, and increased patient throughput through the ED. The coupling of all information could be useful for hospital and department management because it will identify weaknesses in the workflow and help develop improved protocols.

21.2 Methods and Materials for Monitoring Sepsis Patients in the Emergency Department

To identify such potential delays in sepsis patients' care, two methods are applied.

First, data analysis was applied to retrospective patient record data, to establish a general baseline of present outcomes and lengths of stay. Current data management systems were found to be unsuited for identifying unnecessary time delays, bottlenecks, and other weaknesses in the existing workflow for sepsis patient management.

Consequently, an RTLS layout was developed and the system was deployed in the ED of Hospital Clínico-INCLIVA in Valencia, Spain. The RTLS system provides accurate timestamps of logical (physical) procedure steps that involve patient location changes, such as transport, period in waiting rooms, and so on. Selected medical record data from this patient cohort were used to add other essential timestamps, such as those of sending blood samples for analysis, receiving lab results, completing diagnosis, starting treatment, and so on.

Depending on potential bottlenecks identified, an intervention will be introduced, and the RTLS system and EMR data will subsequently be used in the next stage to measure the post-intervention improvements quantitatively.

21.2.1 Inclusion and Patient Selection

21.2.1.1 Inclusion criteria for subject selection

The subjects are as follows:

- Regarding the retrospective data, data will be extracted from the EMR of those subjects with clinical data of sepsis identified by the quick SOFA (qSOFA) criteria in the triage room during the 2 years prior to the start of BigMedilytics (BML).
- For the prospective RTLS study: RTLS platform implementation and tracking in a real context of adult patients (older than 18 years at the time of admission to ED), both male and female, which have signed the consent document (within 24 hours of ED admission) and with a sepsis diagnostic identified by the qSOFA (2) criteria in the triage room.

21.2.1.2 Exclusion criteria for subject selection

The exclusion criteria are as follows: un-signed consent form and/or no sepsis diagnosis.

21.2.1.3 Criteria and procedures for subject withdrawal or discontinuation

- Subjects can leave the study at any time for any reason if they wish to do so without any consequences for their treatment or management. The investigator can decide to withdraw a subject from the study for urgent medical reasons.
- Withdrawn participants will be replaced until 200 participants have completed the study or when decided that time is too limited to include more participants and finish the measurements according to the project planning.
- The point of enrollment is the time at which, following recruitment, a subject signs and dates the informed consent form. The first subject is expected to be enrolled in September 2018. The clinical investigation is expected to take 18 months. The duration of the participation of each subject can range from hours up to several days (in case of hospitalization).

21.2.2 Study Design

The study was divided into four stages:

The first stage of the study consisted of joint, multidisciplinary, sessions to get a common and full understanding of the sepsis care paths, patient routing, and staff workflow (Figure 21.1).

In the second stage, an initial design for the system layout was made, focusing on the granularity of the RTLS system (Figure 21.2).

Third stage. In a joint session on-site, a so-called Radio-Frequency (RF) survey was performed. In this survey, a test setup is used to check if the actual RF ranges of the stars (receivers for the patient and asset tags and the staff badge signals) correspond to the nominal ranges. RF ranges may deviate, for example, due to elevators or where walls are much thicker than usual.

Based on the outcomes, a final design was made (Figure 21.3).

In the fourth stage, inclusion was started. Patient tags were placed in the triage room. Transition times were collected by the RTLS and monitored from the hospital's Electronic Medical Records (EMRs) of the patients. The time points collected

Figure 21.1. Patient pathway in sepsis care within the ED.

Figure 21.2. Distribution of the areas used in the sepsis care pathway within the ED. The dotted circular lines are the reception area of a "star."

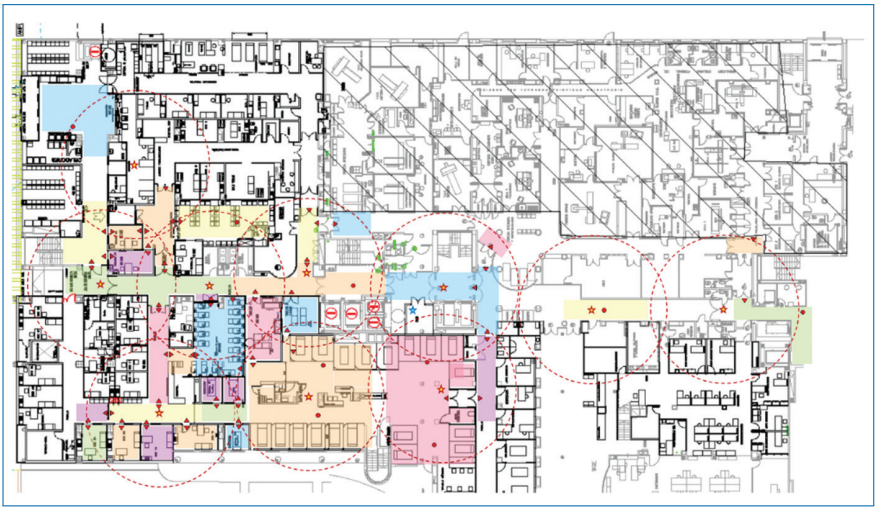

Figure 21.3. Distribution of the sensors.

were as follows: A: admission; IT: start of triage; FT: end of triage; PMC: first medical contact/consultation; AS: obtaining blood for lab test; ATB: administration of antibiotics; HC: obtaining blood for cultures; F: starting intravenous fluids; O: arrival in the observation room; and I: transfer to another hospital ward. The listing is not necessarily also the order in which they were performed.

The main time periods calculated were as follows: IT-FT: start to end of triage; FT-PCM: end of triage to the first medical contact/consultation; PCM-O: first medical contact/consultation to admission at observation area; and O-I time from admission at observation area to transfer to another hospital ward.

In addition: PMC-AS: first medical contact and obtained lab tests; O-AS: arrival in observation room to lab; PMC-F: first medical contact to initiation of administration of fluids; O-F: arrival in observation room and start intravenous fluids; O-ATB: arrival in observation room and administration of antibiotics; and A-I: total time from admission to ED to transfer to another ward. Furthermore, A-ATB: admission in ED to first antibiotics in observation room; A-F: Admission to ED to first IV fluids in observation room were calculated; as well as A-AS: admission to ED to lab workup; and A-HC: Admission to ED to taking blood cultures.

21.2.3 Ethical and Security Issues

The Ethical Committee of the Hospital Clínico of Valencia approved the research, and informed consent was requested from all patients at admission or within a period of 24 hours after admission if the physical condition at arrival was not appropriate. GDPR principles were applied.

The system deployed to perform the prospective study was the RTLS by CenTrak. This system tracked not only the patient flow but also the material resources and their availability. To do so, wristbands, tags/badges, and access points were deployed at the ED. All the information was uploaded to a corresponding platform designed by Phillips. This platform used Big Data tools to process the data and also helped in the data visualization, making it more understandable, the results obtained and the potential improvements to be made. Also, some alerts could be designed for patient safety and installation availability.

The data are accessed and processed in a secure manner; ATOS developed a secure network that monitors and audits all the external connections to INCLIVA's servers where the data are stored. Figure 21.4 illustrates the workflow for the prospective part of the study.

21.3 Results

21.3.1 General Characteristics of the Study Population

A total of 268 patients with a diagnosis of sepsis were monitored, 201 as a retrospective control group and 67 in the prospective study with both EMR and RTLS simultaneously.

The main characteristics of the prospective study patients are given in Table 21.1.

Transition times and clinical indicators prior to RTLS installation (retrospective) are shown in Table 21.2a.

The results for critical steps involving both RTLS and the EMR are shown in Table 21.2b.

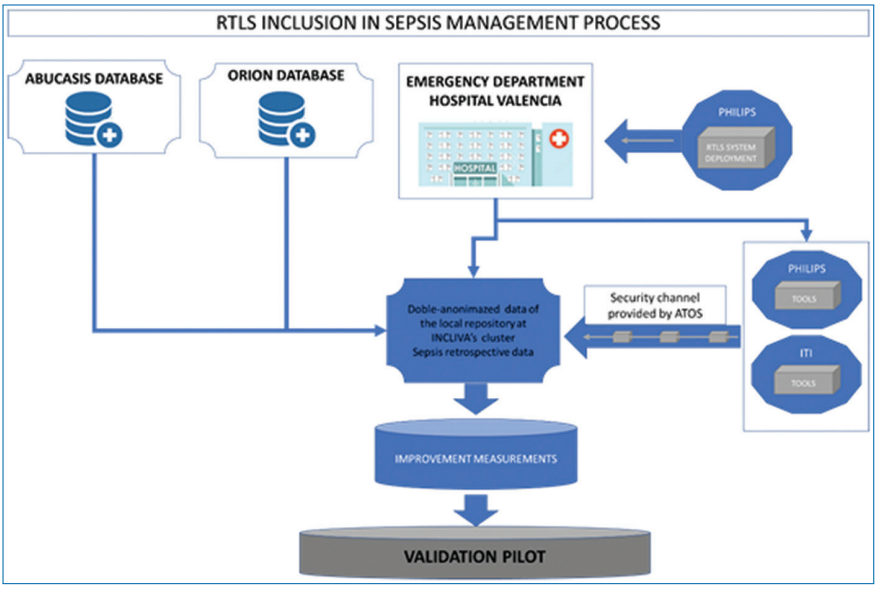

Figure 21.4. Data flow in the RTLS study at Incliva.

Table 21.1. General characteristics of the sepsis patients in the prospective study.

	Total (%)	Discharged alive (%)	In-Hospital mortality	Mortality in 3 months	*p* value
Total (201)	267 (100,0)	163 (56,5)	79 (31,5)	30 (12,0)	
Gender (male)	108 (53,7)	55 (27,3)	34 (16,9)	19 (9,5)	NS
Age (SD)	77 (11,9)	72,7 (10,9)	81,3 (12,3)	81,2 (11,3)	0,029
Diabetes	74 (37,0)	41 (20,5)	26 (13,0)	7 (3,5)	NS
Vital Signs:					
Temperature	37,5 ± 15,0	37,5 ± 1,4	37.0 ± 1,6	36.8 ± 1,2	0,021
SaO2 mmHg	91,9 ± 6,1	93,0 ± 5,0	92,0 ± 6,0	90,0 ± 9,0	0,011
FiO2 mmHg	0,26 ± 0,1	0,24 ± 0,11	0,29 ± 0,17	0,28 ± 0,14	0,016
Systolic BP (mmHg)	107 ± 29	109 ± 29	100 ± 30	108,0 ± 28,0	NS
Diastolic BP (mmHg)	61 ± 18	64 ± 18	62 ± 19	61 ± 17	NS
Heart rate (beats/min)	103 ± 25	100 ± 22	109 ± 29	99 ± 25	0,034
Respiratory rate ≥ 22 (resp/min)	72 (52,9)	33 (24,3)	29 (21,32)	20 (5,6)	0,013
Glasgow scale ≤ 13	64 (35,6)	20 (11,1)	42 (18,9)	11 (5,6)	<0,001

Table 21.2a. Main transition times obtained from the EMR before implementing RTLS system. Abbreviations: **IT-FT:** start to end of triage; **FT-PCM:** end of triage to the first medical contact/consultation; **PCM-O:** first medical contact/consultation to arrival in observation area; **O-I:** time from arrival in observation area to transfer to another hospital ward.

Time (min)	IT-FT	FT-PMC	PMC-O	O-I
Average	12,05	2,47	19,41	620,97
Median	8,00	2,00	7,00	541,00
SD	11,23	3,05	32,87	388,27

Table 21.2b. Main transition times obtained from the EMR before implementing RTLS system. Abbreviations: **A-ATB:** admission in ED to first antibiotics in observation room; **A-F:** Admission to ED to first IV fluids in observation room **A-F:** admission to ED to first IV fluids in observation room were calculated; as well as **A-AS:** admission to lab workup and **A-HC:** admission to taking blood cultures were calculated.

Time (min)	A-ATB antibiotics	A-F fluids	A-AS blood test	A-HC blood culture
Average	113,49	103,84	58,93	140,31
Median	53,00	53,00	41,00	56,00
SD	132,97	144,58	60,15	202,82

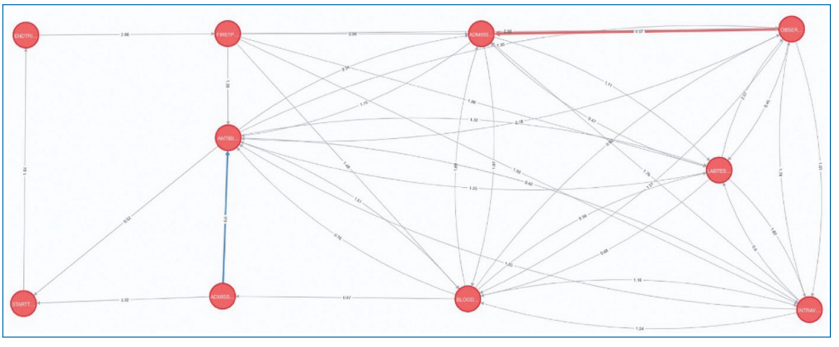

Figure 21.5. Real transition of patients.

Table 21.3. Times calculated with EMR timestamps were the following (retrospective part). Abbreviations: **A:** admission; IT: start of triage; **FT:** end of triage; **PMC:** first medical contact/consultation; **AS:** obtaining blood for lab test; **ATB:** administration of antibiotics; **HC:** obtaining blood for cultures; **F:** starting intravenous fluids; **O:** arrival in observation room; **I:** transfer to another hospital ward.

Time (min)	A-IT	IT-FT	FT-PMC	PMC-O	O-I	PMC-AS	O-AS	PMC-F	O-F	O-ATB	A-I
Average	8.0	2.0	5.0	34.0	340.0	15.0	18.0	17.0	21.0	21.5	378.0
Median	6.6	2.0	12.0	74.8	245.4	7.9	72.0	54.6	80.1	84.5	251.4
SD	9.4	2.7	8.6	52.3	371.7	15.7	38.1	36.6	39.8	43.3	431.6

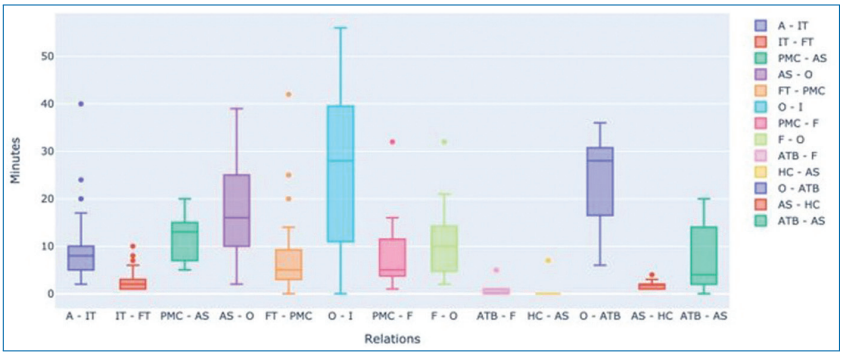

Figure 21.6. Graphical image (dashboard) of the distribution of times. Abbreviations: **A:** admission; **IT:** start of triage; **FT:** end of triage; **PMC:** first medical contact/consultation; **AS:** obtaining blood for lab test; **ATB:** administration of antibiotics; **HC:** obtaining blood for cultures; **F:** starting intravenous fluids; **O:** arrival in observation room; **I:** transfer to another hospital ward.

21.3.2 First Approach: Assessment Using EMR (Retrospective Study)

The transitions identified are shown in Figure 21.5, and the times obtained from the EMR are in Table 21.3 and Figure 21.6.

Having the transitions detected above, the Boxplot of Figure 21.6 allows the user to visualize the time distribution between stages in the workflow and detect anomalies in time measures. For example:

- O-I transition is the transition with a higher variability and a greater mean time.
- FT-PMC has three anomalies (outliers = dots) for the time required.
- ATB-AS has an asymmetric distribution for time which means that usually it requires a lower quantity of time, but sometimes, the required time could increase considerably.

In an analysis done on the EMR data of the patients included in the study, it was possible to understand the correlation between all the transition stages of the pathway. Looking at the EMR data also provides insights into clinical steps that cannot be monitored using RTLS (such as administration times of intravenous fluids or antibiotics). Figure 21.7 provides an overview of the correlation between the different stage transitions of the sepsis pathway. Where negative values mean that spending more time in one of the contrasted transitions implies requiring less time for the other.

The following graphs of Figures 21.8 and 21.9, from the prospective part of the study, allow for the visual identification of the parts of the process that require more time and the ones where there's a greater possibility for improvements.

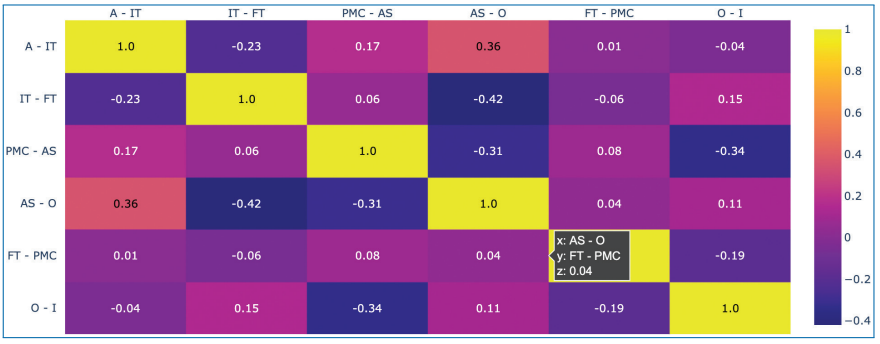

Figure 21.7. Correlation between stages of the sepsis pathway. Abbreviations: **A:** admission; **IT:** start of triage; **FT:** end of triage; **PMC:** first medical contact/consultation; **AS:** obtaining blood for lab test; **ATB:** administration of antibiotics; **HC:** obtaining blood for cultures; **F:** starting intravenous fluids; **O:** arrival in observation room; **I:** transfer to another hospital ward.

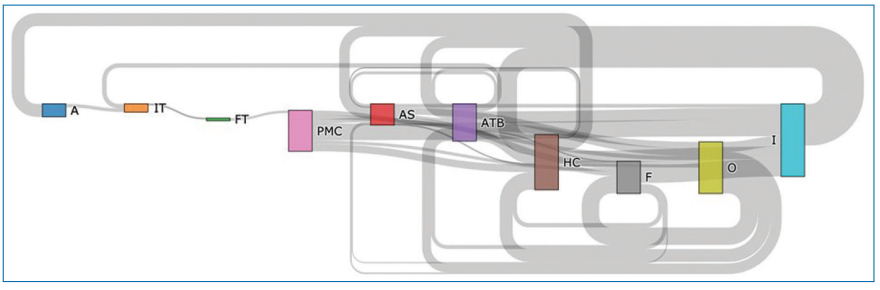

Figure 21.8. Mean time required per directed transition. Abbreviations: **A:** admission; **IT:** start of triage; **FT:** end of triage; **PMC:** first physician contact; **AS:** lab tests; **ATB:** antibiotics; **HC:** blood cultures; **F:** intravenous fluids; **O:** observation room; **I:** admission hospitalization.

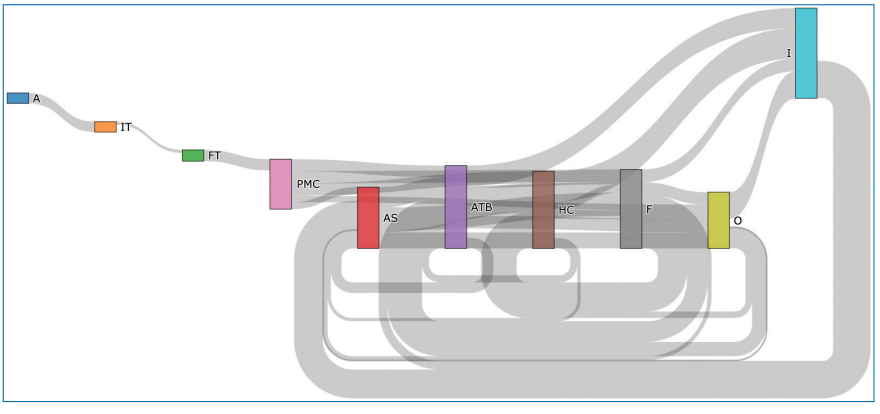

Figure 21.9. Standard deviation between transitions. Abbreviations: **A:** admission; **IT:** start of triage; **FT:** end of triage; **PMC:** first physician contact; **AS:** lab tests; **ATB:** antibiotics; **HC:** blood cultures; **F:** intravenous fluids; **O:** observation room; **I:** admission hospitalization.

Table 21.4. Times of Transitions between different RTLS areas calculated with RTLS timestamps. Abbreviations: **IT-FT:** start to end of triage; **FT-PCM:** end of triage to the first medical contact/consultation; **PCM-O:** first medical contact/consultation to arrival in observation area; **O-I** time from arrival in observation area to transfer to another hospital ward.

Time (min)	IT-FT	FT-PMC	PMC-O	O-I
Average	1.0	2.5	49.0	352.8
Median	4.6	23.2	22.5	331.2
SD	2.6	6.8	51.2	442.9

Table 21.5. Times calculated with EMR and RTLS timestamps combination. Abbreviations: **A:** admission; **IT:** start of triage; **FT:** end of triage; **PMC:** first medical contact/consultation; **AS:** obtaining blood for lab test; **ATB:** administration of antibiotics; **HC:** obtaining blood for cultures; **F:** starting intravenous fluids; **O:** arrival in observation room; **I:** transfer to another hospital ward.

Time (min)	PMC-AS	AS-O	PMC-F	F-O	O-ATB	A-I
Average	13.9	31.1	13.6	25.9	25.4	427.9
Median	10.0	26.4	60.5	29.4	30.0	324.3
SD	16.1	37.8	37.7	33.5	30.0	497.0

The Sankey graph (Figure 21.8) shows the mean time required per directed transition. The wider the edge, the greater the mean time required for the transition. It allows a visual identification of the part of the process that requires more time.

The Sankey graph (Figure 21.9) shows the standard deviation of time between transitions. The wider the edge, the greater the variability of the time found for the transition. A great dispersion indicates possibilities for improvement in the transition that should be studied.

21.3.3 Second Approach: Assessment Using Both EMR and RTLS (Prospective Study)

We observed an average difference of circa 60 minutes between the time of transfer recorded in the EMR and the actual time the patient is moved from the Observation Area of the ED to be admitted to another ward or discharged. Further investigations have shown that this disparity reflects the way in which the EMR is used at the ED. In some cases, the timestamp shown in the EMR refers to the time in which a request for transfer to another Ward was made and not the actual time of transfer.

This supports the idea that the EMR alone can lead to less accurate results for KPI and target measurements at the hospitals (Table 21.4).

Combining data sources has also been shown to have an impact on the calculation of Pathway indicators that include clinical steps of the pathway that cannot be calculated using RTLS data alone (Table 21.5).

21.4 Conclusion

We observed an average difference of circa 60 minutes between the time of transfer recorded in the EMR and the actual time the patient is moved from the observation area of the ED to be admitted to another ward or discharged. Further investigations have shown that this disparity reflects the way in which the EMR is used at the ED. In some cases, the timestamp shown in the EMR refers to the time in which a request for transfer to another ward was made and not the actual time of transfer.

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