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Real-time patient tracking in outpatient care using a Bluetooth Low Energy Identification technology in a low-resource setting: a pilot study in Burundi

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Abstract

Background

Globally, around one third of people in low- and middle-income countries report negative experiences with their healthcare system. One of the most frequently cited reasons is the perceived excessive length of time spent waiting for treatment. Despite increasing digitalization, delays in outpatient care journeys remain largely invisible to healthcare managers because existing hospital information systems can not automatically and continuously track patient movements. This limits identification of bottlenecks and implementation of effective interventions to improve outpatient service delivery. This study aimed to evaluate a patient tracking solution based on "Bluetooth Low Energy Identification" technology designed to automatically monitor outpatient care journeys.

Method

This study was carried out in MURAMVYA district hospital and CPLR Hospital in Burundi, using the Design Science Research Model. The methodology comprised five steps: (1) development and integration of the patient tracking module into the existing hospital information system, (2) implementation of patient tracking, (3) evaluation of the module, (4) implementation of a pilot study, and (5) communication about the pilot experience. Using the technology, 688 outpatient journeys patients were reconstructed and studied. Data analysis was descriptive using R software and departments interaction analysis was carried out using a social network analysis approach with Gephi.

Results

The results showed good technical performance of the module with 95.5 per cent of care journeys fully recorded at MURAMVYA district hospital, and 93.9 per cent at CPLR Hospital. Laboratory, imaging and emergency departments had the highest median times, with 95.6, 90.5 and 72.2 min respectively. The slowest transfers between departments involved laboratory and imaging: 'Imaging to Emergency' (7.3 min), 'Laboratory to Family planning' (6.9 min) and 'Imaging to Laboratory' (5.2 min). "Reception to Billing to Consultation" was the most frequent journey recorded for 22,6% of the patients. Reception, billing and consultation departments were also the main bottlenecks in the outpatient care journey.

Conclusion

Bluetooth Low Energy Identification (BLEID) is a reliable technology for patient tracking and can be successfully implemented to monitor care journeys, identify patient journey's bottlenecks aiming to improve outpatient care delivery.

Clinical trial number

Not applicable.

Key-words: Bluetooth Low Energy Identification, patient tracking, Care journeys, primary health care, responsiveness

Background

Globally, around one third of people in low- and middle-income countries report negative experiences with their healthcare system. One of the most frequently cited reasons is the perceived excessive length of time spent waiting for treatment [1, 2]. Although the majority of patients generally pass through a limited number of departments before receiving the care they need, they often face long waiting times at each step, extending their stay in a hospital. Despite increasing digitalization, delays in outpatients care journeys remain largely invisible to healthcare facility managers because electronic medical records document individual procedures rather than the entire patient journey, omitting time spent in waiting rooms and during transfers between care units. This lack of information is hindering to some extent the implementation of patient experience improvement strategies.

Meanwhile, the World Health Organization (WHO) considers the optimal organization of care delivery to be of great importance and calls on health systems to develop services designed to effectively meet all patients' needs. In this regard, WHO considers that healthcare system performance in provision of care should also be assessed in terms of responsiveness, which evaluates the way in which patients are treated and the conditions under which care is provided. Assessing responsiveness involves eight key dimensions, namely dignity, autonomy, confidentiality, quality of facilities, access to social support, freedom of choice of provider, communication and the speed of care delivery [3].

While other aspects of responsiveness are primarily assessed through individual perceptions, the speed of care delivery requires more objective indicators. Among these, waiting times, treatment times and total time spent in healthcare facilities are widely recognized as indicators of patient satisfaction and the organizational performance of healthcare systems [4, 5]. Therefore, assessment of these indicators should become part of a continuous and regular process [1].

Research [6–8] carried out on the responsiveness of care has mainly been focused on measuring waiting times and consultation duration, which do not allow patient journeys to be fully analyzed and bottlenecks affecting these journeys to be identified [1]. These studies relied on questionnaires administered through occasional assessments requiring significant human, financial and logistical resources, as the existing hospital information systems (HIS) were unable to automatically and continuously produce the required data. This approach limits healthcare facility managers' ability to continuously identify and implement effective interventions to improve health service delivery.

Patient tracking technologies offer a new opportunity to complete existing HIS data. Existing research focused more on the application of this technology in inpatient care, and there is little evidence available on the potential benefits this technology may offer in improving the delivery of outpatient care [9, 10]. Tracking of patients in real time throughout their outpatient care journeys enables to measure the time patients spend in each department, monitor transitions between departments, and identify bottlenecks throughout the patient journey. This study aimed to evaluate a proposed patient tracking solution designed to automatically generate data on

outpatient care journeys and to assess the usefulness of the data for identifying bottlenecks and improving the timeliness of care in low resource healthcare facilities.

Methods

Study context and participants

The evaluation of the proposed patient tracking technology was carried out in two hospitals in Burundi, an East African country. The two hospitals are MURAMVYA district hospital and the Clinique Prince Louis Rwagasore (CPLR). Both hospitals are digitalized and use the open-source OpenClinic GA hospital information system. The MURAMVYA district hospital provides district-level care, whilst CPLR is a national referral hospital. MURAMVYA district hospital has an average of 19,787 outpatient visits per year, while CPLR handles 61,007 outpatient visits.

Digitalization is very advanced in both hospitals, with an electronic medical record system, a module for pharmacy management, billing, laboratory management, computer-assisted maintenance management for equipment and infrastructure, medical imaging management, and so on. The hospitals were selected based on the willingness shown by their managers towards patient tracking implementation.

For this pilot experience, all hospital departments involved with outpatient care have been targeted. These include reception, billing, general or specialist consultations, laboratory, imaging, pharmacy and family planning.

Implementation and evaluation approach

The methodological approach adopted to implement and evaluate this pilot project was based on the Design Science Research Model, which is widely used in information systems research, particularly when assessing the suitability of a new information system [11, 12]. This research model suggests a six-stage methodology, namely (1) problem identification and motivation, (2) objectives of a solution, (3) design and development, (4) demonstration, (5) evaluation and (6) communication.

However, the first and second stages of the process were not implemented in this study because the need to improve the care process had already been identified. This challenge had previously been discussed among stakeholders involved in the digitalization of Burundi's healthcare system, who had reached a consensus on the objective of implementing real-time patient tracking. Consequently, we decided to proceed with the remaining four stages and added a stage to carry out a pilot study. The methodological approach thus comprised the following five steps: (1) development and integration of the patient tracking module into the existing HIS, (2) implementation of the module, (3) evaluation of the module, (4) pilot study, and (5) communication about the pilot experience. This methodological approach is summarized in figure 1.

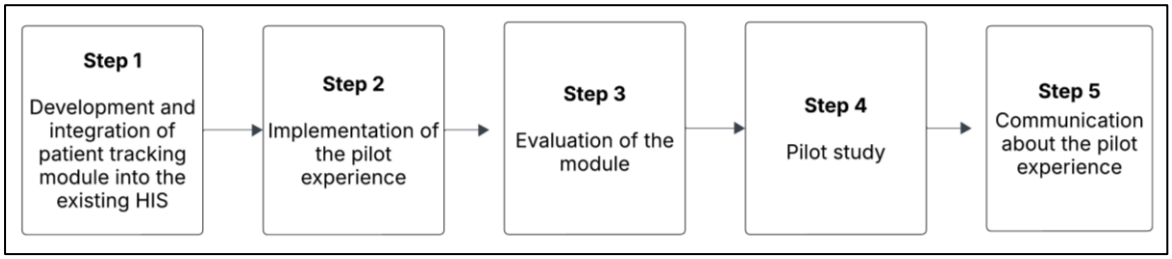


Figure 1: Methodological approach

Step 1: Development and integration of the patient tracking module into the existing hospital information system

For reasons of accessibility, cost-effectiveness, low energy consumption and patient safety, 'Bluetooth Low Energy Identification' (BLEID) technology was adopted. A BLEID based patient tracking module was integrated into the existing hospital information system. At this stage, the module's functionalities and architecture were analyzed.

Step 2: Implementation of the pilot experience

This stage involved analyzing how the module performed in real time within a hospital environment. This stage was particularly important as it was necessary to monitor in real time the recording of patients' movements across different departments and to assess to what extent the module enabled the later reconstruction of patient journeys.

Step 3: Evaluation of the module

This was the most awaited part. The tracking module was assessed on the basis of two criteria: its ability to produce useful data and its technical performance. These two criteria were further broken down into six parameters, namely (i) total number of patient journeys fully recorded and reconstructed, (ii) proportion of journeys fully reconstructed, (iii) total number of BLEID detections, (iv) number of irrelevant BLEID detections (noise), (v) rate of irrelevant BLEID detections, and (vi) average number of BLEID detections per patient.

Step 4: Pilot study

The Design Science Research Model used recommends carrying out a pilot study to assess the effectiveness of suggested solutions to identified problems. Within this model, conducting a pilot study is described as part of the evaluation stage. However, to highlight the results, we have chosen to treat it as a stage in itself.

This study is therefore based on an analysis of the new insights produced on patients' journeys during outpatient care, obtained through patient tracking. It aimed to (i) verify whether the data could be used to reproduce patients' care journeys, (ii) measure the duration of the journey and identify bottlenecks, (iii) analyze patients' journeys, and (iv) analyze the departments interactions.

Study design and duration

A cross-sectional study was carried out over a 30-day period in each hospital as part of the evaluation of this pilot experience.

Participants

A total of 688 outpatients – 310 at CPLR and 378 at MURAMVYA district hospital were included in the study. This sample size was calculated by combining two approaches. First, the aim was to estimate the different proportions of patients attending various departments, as well as the proportions of patients following different types of care journeys. Therefore, sample size estimation formula for estimating a single proportion, with correction for a finite population, was used: n = [N*p(1−p)]/ [(d2/Z21−α/2) *(N−1) + p*(1−p)]. With a 95% confidence interval, z = 1.96, p = 50% (as the value is unknown), a margin of error of 5% and a non-response rate of 10%, the total sample size was 425 patients.

Given that the study was also intended to estimate the time spent by patients in the various departments, the formula for estimating sample size based on the mean and standard deviation – used when the variable of interest is a quantitative variable – was applied: $n = (z * \sigma)^2/d^2$. Using data from a study carried out in Mozambique on waiting times [8] and consultation times, with Z = 1.96, estimated σ = 41.4 minutes for an outpatient visit and a desired precision of 5 minutes, and a non-response rate of 10 per cent, the maximum sample size calculated was 291 patients. Thus, combining the two approaches, a minimum sample size of 425 patients was required. Ultimately, 688 patients were included.

The outpatient departments included in the study were: reception and triage, billing, consultation, laboratory, pharmacy, imaging, dentistry, family planning and emergency department. Only patients who gave their consent to participate were included. In CPLR, the family planning and emergency department departments were not included for feasibility reasons. In CPLR, family planning is in fact, provided within the department of obstetrics and gynecology. Furthermore, the emergency department is organized as an integrated unit with its own reception area, billing desk and consultation room. Consequently, patients admitted to emergency department have access to all the necessary services within the unit.

Study variables and data collection

The data generated by the patient tracking module has been merged with data from the electronic medical record, including the encounter ID, the ID of the BLE tag worn by the patient, the IDs of the BLE antennas installed in each department, and the arrival and departure times for each department visited by the patient.

Data analysis

Data quality checks were carried out before performing statistical analysis using R software version 4.3.2. The data analysis was initially generally descriptive, focusing on the time spent by patients in each department. Patients' journeys were reconstructed and the duration of their components were calculated.

At each step, analyses were carried out only on the inlier-range by excluding the outliers using the box-plot methodology [13]. Then, the lower and upper limits of the outliers, were calculated respectively as follows: first quartile – 1.5 × interquartile range (IQR) and third quartile + 1.5 × interquartile range.

The analysis of departments interaction was carried out using a social network analysis approach, with Gephi.

Step 5: Communication about the pilot experience

As part of this pilot experience, the communication component involved providing feedback to the participating hospitals and dissemination of the results to a broader audience.

Results

Step 1: Development and integration of the patient tracking module into the existing hospital information system

System components and integration into the HIS

A BLEID patient tracking solution has been used. The system comprises (1) BLE readers (antennas) and (2) BLE beacons (to be worn by the patients), as illustrated in Figure 2. The system is configured directly within the existing OpenClinic GA hospital information system using their MAC addresses, as shown in Figure 3. To suit the low-resource context, the antennas are powered by a standard 5V USB-C power source and the beacons used are equipped with a CR2032 battery lasting for several months and which is easy to find on the local market for replacement.



Figure 2: BLE Antenna (top), Beacon (down)

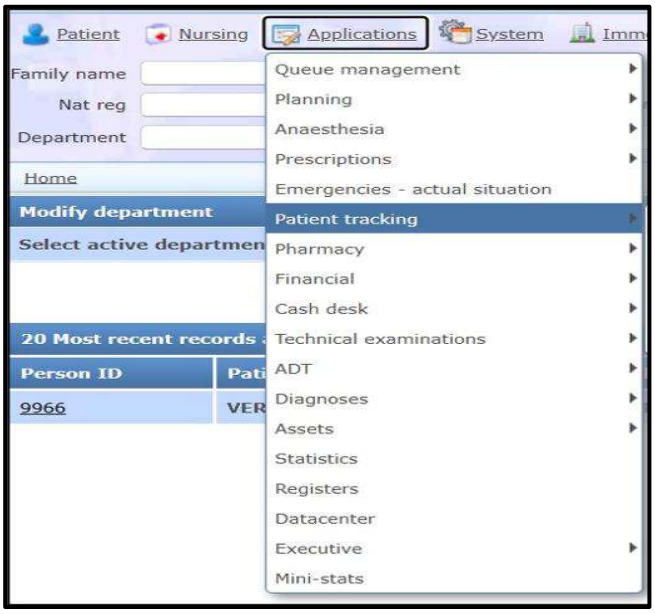


Figure 3: Screenshot showing integration on patient tracking module in the existing health information system

System functions

The module has five key functions which are shown on Figure 4: (i) linking a patient to a beacon, (ii) unlinking a patient, (iii) monitoring beacons, (iv) viewing the active patient's journey, and (v) a dashboard that displays statistics on pass-through times spent by patients in each department and transfer times between departments.

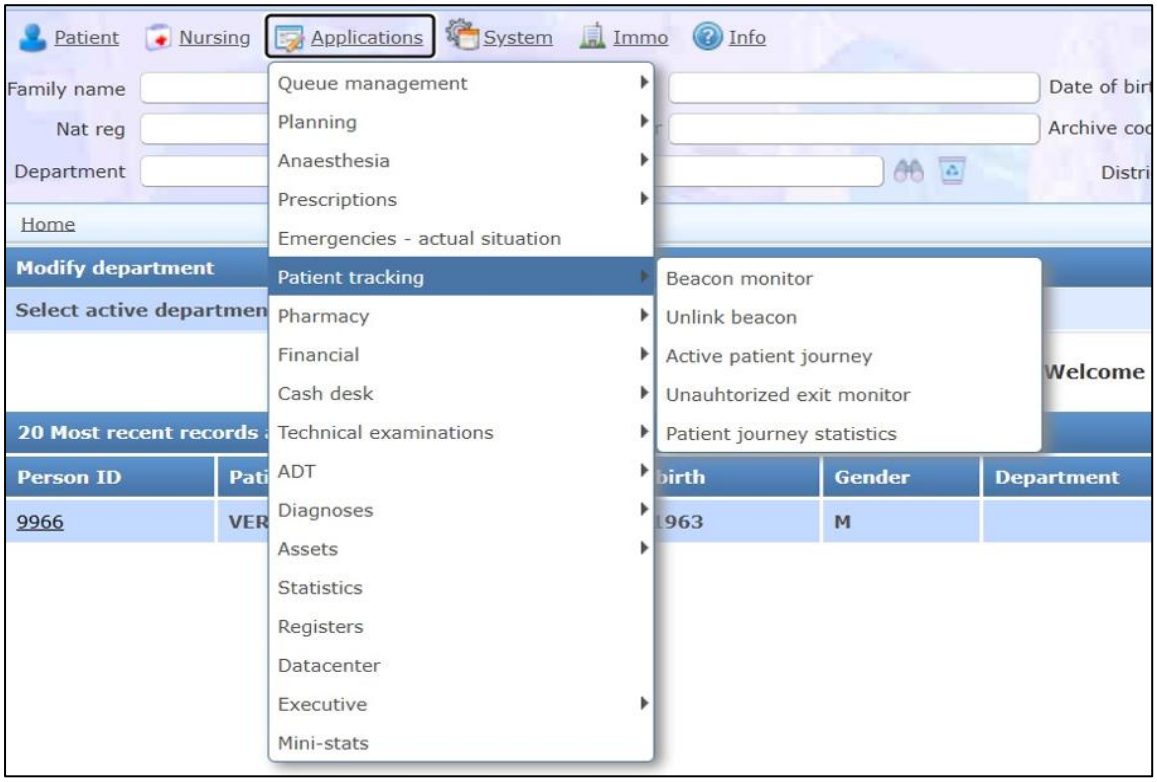


Figure 4: Screenshot showing the five functionalities of patient tracking module

When a patient wearing a beacon enters a department were a BLEID reader has been installed, the beacon transmits its BLE identifier to the reader. The reader then transfers this information to the HIS. A patient can be detected by several readers at the same time, but only the nearest one will be selected by the HIS. Each beacon was configured to synchronize its information every 5 seconds. For each patient, it was possible to reconstruct their care journey from the moment they were linked to a beacon until the moment their ID was unlinked from the beacon.

Step 2: Implementation of the module

Stakeholder engagement

Authorization to implement this pilot experience was obtained from the Ministry of Public Health. Following this authorization, the two hospitals were selected based on their management teams' willingness to support the pilot experience. Once management support had been secured, the management committees – comprising mainly heads of departments and units – were convened to be briefed on the pilot setup. Training was provided to the reception and triage staff, as they were the ones responsible for linking and unlinking the beacons to the patient IDs.

Integration of the tracking system into the workflow

Before the pilot experience started, the antennas and beacons were identified and configured in the hospital information system, after which the antennas were installed in the various departments. An additional antenna was installed at the exit of the hospital to detect patients who might attempt to leave with their beacons, in order to activate an alarm on a computer located at the exit. The antennas were either connected to the staff's computers USB port or plugged directly into 5V USB-C power sockets.

On arrival, a nurse from the reception department explained the patient tracking system and its benefits to the patient, and asked for consent to take part in the study. When the patient agreed, the patient ID was linked to a beacon. Table 1 summarizes some operational parameters relating to the integration of the patient tracking system into the workflow of the two hospitals involved in the pilot trial.

Table 1: Selected operational parameters relating to the implementation of the module

Parameters	MURAMVYA district hospital	CPLR hospital
Duration of the pilot (days)	30	30
Number of departments covered	10	8
Number of BLEID readers installed	13	11
Number of patient tags used	36	22
Number of patients involved	378	310
Number of tags lost	0	5
Number of chargers lost	2	1

Step 3: Evaluation of the module

Technical performance of the module and usefulness of the data

According to the evaluation step of the Design Science Research Model, the module's performance was assessed using indicators relating to its technical operation and its ability to produce reliable, comprehensive and usable data for decision-making. Results are presented in table 2.

Table 2: Technical performance of the module and its ability to produce useful data

Parameters	MURAMVYA hospital	CPLR
Number of patient journeys participating in the study	378	310
Proportion of fully reconstructed care journeys	95.5%	93.9%
Number of BLEID hits in the database	33 687	23 833
Irrelevant BLEID hits in the database	195	813
Rate of irrelevant BLEID hits	0.6%	3.4%
Average number of BLEID hits per care journey	85.2	72.4

The results from table 2 show good technical performance, with 95.5 per cent of care journeys fully reconstructed at MURAMVYA district hospital, and 93.9 per cent at CPLR Hospital.
The average number of BLE beacon detections per patient journey was 85.2 at MURAMVYA district hospital, and 72.4 at CPLR. Irrelevant detections, corresponding to brief detections occurring when a patient passed close to an antenna while moving toward another department, accounted for 0.6% at MURAMVYA district hospital and 3.4% at CPLR.

Step 4: Pilot study results

Visit frequency and time spent by patients in each department

Table 3 presents evidence on the frequency, number of repeat visits and time spent by patients in each department.

Table 3: Frequency and time spent by patients in each department

Departments	% of visits passing through the department	Median time (in minutes)	IQR (Q1_Q3) time (in minutes)	% of patients who return to the department during their care journey
CPLR Hospital				
Reception	90	12.9	25.9 (4.3 - 30.2)	15.8
Billing	82.3	9.4	23 (3.9 - 26.9)	16.1
Consultation	76.5	58.9	67.7 (28.8 - 96.4)	11.6
Dentistry	NA	NA	NA	NA
Imaging	29.4	105.6	155 (51.4 - 206.4)	4.2
Laboratory	34.8	108.9	139.5 (41.1 - 180.6)	1.6
Family planning	DA	NA	NA	NA
Pharmacy	16.5	7.3	9.1 (2.9 - 11.9)	1.6
Emergency	NA	NA	NA	NA
MURAMVYA district hospital				
Reception	92.9	6.2	11.6 (2.6 - 14.2)	30.7
Billing	93.1	5.4	8 (2.4 - 10.4)	41.5
Consultation	90.5	74.6	91.5 (37 - 128.5)	32.8
Dentistry	1.3	70.1	36.2 (64.9 - 101.1)	0
Imaging	11.6	70.4	60.4 (39.1 - 99.5)	0.3
Laboratory	35.2	88.8	108 (36.9 - 144.8)	3.4
Family planning	1.1	61.1	14.4 (47.2 - 61.6)	0.5
Pharmacy	19.8	16.8	31.9 (5.1 - 37)	0.8
Emergency	1.1	72.2	27.3 (56.9 - 84.2)	0
Overall				
Reception	91.6	7.5	17.1 (2.9 - 20.1)	24
Billing	88.2	6.6	12.8 (2.9 - 15.7)	30.1
Consultation	84.2	68.7	82.8 (33.4 - 116.2)	23.3
Dentistry	0.7	71.1	71.9 (64.9 - 136.8)	0
Imaging	19.6	90.5	107.7 (45.7 - 153.3)	2
Laboratory	35	95.6	119.4 (37.2 - 156.6)	2.6
Family planning	0.6	54.2	30.9 (30.6 - 61.5)	0.3
Pharmacy	18.3	11.2	24.8 (3.5 - 28.2)	1.2
Emergency	0.6	72.2	27.3 (56.9 - 84.2)	0

Overall, the results from table 3 show that reception, billing and consultation departments are globally the busiest, with attendance rates of 91.6 per cent, 88.2 per cent and 84.2 per cent of patients respectively, with minor differences between MURAMVYA district hospital and CPLR hospital. For the time patients spend in departments, laboratory, imaging and emergency departments have the highest median times, with 95.6 min, 90.5 min and 72.2 min respectively. The high IQR indicates significant variability in time spent between patients.

Evidence on patient journeys

Hospital departments operate as a network. Analyzing the connections between departments helps to identify slow transitions during patient care journeys, as well as the most common journey components, which may be helpful for the optimization of patient journeys.

Table 4: Slowest transitions with their durations in minutes

Transition	% of patients taking the transition	Median time (in minutes)	IQR (Q1 - Q3) (in minutes)
CPLR Hospital			
Reception – Laboratory	42 (12.9%)	8.9	19.7 (2.1 - 21.8)
Billing – Laboratory	53 (15.2%)	7.9	18.1 (1.8 - 19.9)
Reception – Imaging	21 (6.8%)	5.7	17.6 (2.2 - 19.8)
Imaging – Laboratory	10 (2.6%)	5.2	6.6 (3.4 - 9.9)
Consultation – Imaging	49 (13.5%)	5.1	14.6 (2.5 - 17.2)
MURAMVYA district hospital			
Imaging – Emergency	1 (0.3%)	7.3	0 (7.3 - 7.3)
Laboratory – Family planning	3 (0.5%)	6.9	7.3 (4 - 11.3)
Reception – Pharmacy	25 (6.6%)	5.3	16.7 (1.4 - 18.1)
Laboratory – Pharmacy	8 (2.1%)	5.1	8.1 (1.1 - 9.2)
Consultation – Imaging	32 (6.3%)	5	6.7 (1.6 - 8.3)
Overall			
Imaging - Emergency	1 (0.1%)	7.3	0 (7.3 - 7.3)
Laboratory – Family planning	3 (0.3%)	6.9	7.3 (4 - 11.3)
Imaging - Laboratory	10 (1.2%)	5.2	6.6 (3.4 - 9.9)
Laboratory - Pharmacy	14 (2%)	5.1	9.6 (0.3 - 9.9)
Consultation - Imaging	81 (9.6%)	5	13 (2.3 - 15.3)

According to the results from table 4, the slowest transitions involve the laboratory and imaging departments both in MURAMVYA district hospital and in CPLR hospital. Overall, the slowest transitions are 'Imaging - Emergency' (7.3 min), 'Laboratory – Family planning' (6.9 min) and 'Imaging - Laboratory' (5.2 min). Frequency and duration of all transitions between departments are provided in Supplementary table 1.

The results in table 5 also show that the overall four most frequent journey components are: 'Reception → Billing → Consultation' (25 % of visits), 'Reception → Billing → Consultation → Lab' (18.3 % of visits), 'Reception → Billing → Consultation → Imaging' (7.6 % of contacts) and 'Reception → Billing → Consultation → Pharmacy' (6.8 % of contacts). Top twenty-five most frequent journey and their durations are provided in Supplementary table 2.

Table 5: Top ten most frequent journey with their durations in minutes

Journey	Frequence (%)	Median time (in minutes)	IQR (Q1 - Q3) (in minutes)
CPLR hospital			
Reception → Billing → Consultation	22,6	165,4	168,6 (98 - 266,7)
Reception → Billing → Consultation → Laboratory	14,2	368,8	201,7 (298 - 499,7)
Reception → Billing → Consultation → Imaging	9,7	424,3	202,6 (304,9 - 507,5)
Reception → Billing → Consultation → Imaging → Pharmacy	7,1	442,5	192,4 (329,1 - 521,5)
Reception → Billing	4,8	60,9	72 (36 - 108)
Reception → Consultation	4,5	148,1	71,5 (92,5 - 164)
Reception → Consultation → Laboratory	3,5	332,4	175,7 (216,3 - 392)
Reception → Billing → Consultation → Pharmacy	3,2	191,3	173,2 (149,3 - 322,5)
Reception → Billing → Consultation → Laboratory → Imaging	3,2	464,1	202,6 (360,7 - 563,4)
Reception → Billing → Laboratory	3,2	251,2	136,2 (205,4 - 341,5)
MURAMVYA hospital			
Reception → Billing → Consultation → Laboratory	21,7	362,6	151,6 (283,1 - 434,8)
Reception → Billing → Consultation	27	222,7	160,5 (145,5 - 306)
Reception → Billing → Consultation → Pharmacy	9,8	269,6	201,5 (183,6 - 385,1)
Reception → Billing	7,1	99,8	106,3 (39,6 - 145,9)
Reception → Billing → Consultation → Imaging	5,8	370,5	115,3 (299,3 - 414,5)
Reception → Billing → Consultation → Laboratory → Pharmacy	5,8	415,5	124,4 (375,9 - 500,2)
Reception → Consultation	4,8	191,3	140,8 (111,1 - 251,9)
Billing → Consultation	4,2	121,3	95,4 (92,3 - 187,7)
Reception → Billing → Consultation → Laboratory → Imaging	1,9	364,2	113,4 (312,9 - 426,3)
Billing → Consultation → Laboratory	1,3	370,4	55,4 (348 - 403,4)
Overall			
Reception → Billing → Consultation	25	203,7	172 (118,9 - 290,8)
Reception → Billing → Consultation → Laboratory	18,3	363,7	166,1 (288,1 - 454,2)
Reception → Billing → Consultation → Imaging	7,6	386,3	187,6 (294,7 - 482,3)
Reception → Billing → Consultation → Pharmacy	6,8	268,9	205,5 (171,8 - 377,3)
Reception → Billing	6,1	80,9	100 (39,6 - 139,6)
Reception → Consultation	4,7	150,2	123,8 (106 - 229,8)
Reception → Billing → Consultation → Imaging → Pharmacy	3,8	437,2	187,3 (324,9 - 512,3)
Reception → Billing → Consultation → Laboratory → Pharmacy	3,6	407,4	124,9 (374,8 - 499,7)
Billing → Consultation	3,5	124,3	91,4 (96,3 - 187,7)
Reception → Billing → Consultation → Laboratory → Imaging	2,5	398,6	140,5 (340,4 - 480,9)

Insights into the departments network and bottlenecks

Six key network parameters illustrate the dynamics of interactions between departments. Firstly, there is the weighted degree, which summarizes the level of connectivity of each department within the network, taking into account incoming and outgoing patient flows. It summarizes the department's level of activity. Secondly, there is the weighted incoming degree, which measures the volume of patients arriving at the department and provides an indication of which departments act as major entry points. Thirdly, there is the weighted outgoing degree, which measures the volume of patients leaving the department for other departments and therefore plays an important role in coordinating the care journey. Fourthly, the closeness centrality identifies the departments that occupy central positions within the network. Fifth, the eigenvector centrality was calculated, which represents the extent to which a department is

connected to important departments and enables identification of the group of key departments. Finally, there is betweenness centrality, which identifies the departments that act as bridges or gateways between the others.
These five parameters of the healthcare network, combined with long waiting times and a high number of re-admissions in each department, identify bottlenecks in the patient care journey. Table 6 summarize the results of the analysis of the departments network and the bottlenecks.

Table 6: Analysis of departments network and bottlenecks

Departments	**Weighted degree**	**Weighted incoming degree**	**Weighted outgoing degree**	**Closeness centrality**	**Eigenvector centrality**	**Betweenness centrality**	**Median time**	**% of readmissions**
Reception	1461	450	647	0,89	0,88	7	7,5	32,10
Billing	1268	732	729	1	1	11	70,2	26,30
Consultation	1097	649	619	0,89	1	2,33	9,1	23,70
Dentistry	423	5	5	0,8	0,49	1	13,4	5,60
Imaging	250	140	110	0,8	0,78	0	91,8	8,90
Laboratory	197	246	177	0,72	0,88	0	54,2	50
Family planning	12	6	6	0,67	0,72	0,66	71,1	0
Pharmacy	10	131	66	0,61	0,78	0	97,5	6,20
Emergency	6	3	3	0,57	0,30	0	84,2	0

Table 6 shows that reception, billing and consultation departments are the ones which combine high weighted degree, high weighted incoming degree, high weighted outgoing degree, high closeness centrality, high eigenvector centrality, high betweenness centrality, high median time and high re-admissions rates. Departments network during outpatient care at MURAMVYA and CPLR are provide in supplementary Figure 1 and 2.

Figure 5 below shows the department network constructed as a directed graph with nodes representing departments and edges reflecting the flow of patients from one department to another.

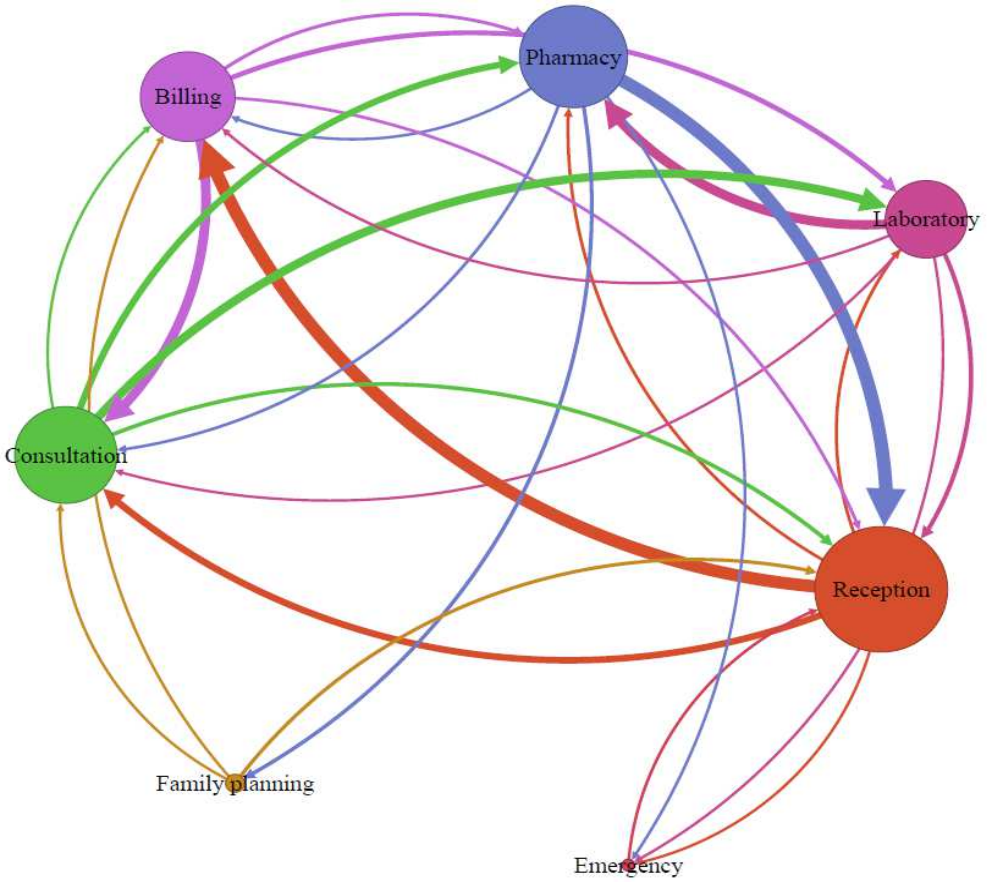


Figure 5: Overall departments network during outpatient care

Evidence on organizational performance

The analysis of organizational performance was carried out by comparing the time spent by patients in the healthcare facility, clinical time and the time spent travelling between departments. The results are presented in Table 7.

Table 7: Analysis of organizational performance

Indicator	**Median time (in minutes)**	**IQR (Q1 - Q3) (in minutes)**
CPLR hospital		
Total time spent in the health facility (min)	263.2	288.9 (132.9 - 421.9)
Time spent travelling between departments (min)	34.7	70 (7.5 - 77.4)
Clinical time (min)	159.8	223.1 (71 - 294.1)
MURAMVYA district hospital		
Total time spent in the health facility (min)	283.5	219.2 (178.5 - 397.7)
Time spent travelling between departments (min)	29.5	45.9 (11.6 - 57.5)
Clinical time (min)	194.9	199.4 (111.3 - 310.7)
Overall		
Total time spent in the health facility (min)	276.7	251.9 (151.5 - 403.4)
Time spent travelling between departments (min)	32.9	57.2 (9.5 - 66.7)
Clinical time (min)	181.4	213 (92 - 304.9)

Overall, results from table 7 show that the median duration of an outpatient visit is 251.9 minutes, of which 32.9 % is spent travelling between departments. Clinical time includes time spent in contact with healthcare professionals and time spent in the waiting room before seeing the clinician and is 159.8 minutes at CPLR hospital and 194.9 minutes at MURAMVYA district hospital.

Step 5: Communication on the pilot experience

Communication began at the start of the implementation, in line with our plan to secure the commitment of all stakeholders. During the study, we found that some service providers were disconnecting the reader antenna because they thought it was being used to track their movements. However, following additional communication to clarify the purpose of the study, the pilot proceeded smoothly until its completion.

Discussion

The results of this pilot study suggest that the used real-time patient tracking module works technically fine and produces data that is useful for reconstructing patients' care journeys. Analysis of the data provided insights that can contribute to improving the care process.

Patient tracking data made it possible to identify department attendance rates, average patient length of stay in departments, most frequently used patient journey components, slow transitions and bottlenecks in patient care. This data was not previously available because electronic medical records only capture what is done for the patient at the point of care, but rarely capture the full care journey within healthcare facilities. With the additional patient tracking data, hospital managers now gain a clearer view on patients' care journeys, with the possibility to zoom in on clinical journeys where time is a critical factor, such as severe malaria cases or respiratory and cardiovascular emergencies. As a result, they can answer questions that were previously difficult to address, such as: how much time do patients spend in each department? Which journeys are most common? Where are the bottlenecks in patients' care journeys?

Getting stakeholders on board was crucial from the start. Some service providers feared that the system was installed to monitor their movements and deliberately unplugged the BLEID reader antennas. Additional communication, accompanied by demonstrations, played a vital role in dispelling doubts. This highlighted the fact that keeping stakeholders fully engaged remains essential for the successful implementation of new technologies. This finding has also been observed in other studies evaluating the introduction of new digital solutions in the healthcare sector [14, 15].

Reception, billing and consultation departments were the primary bottlenecks in the patient journey during outpatient care. Reception constitutes a bottleneck because it represents the first point of contact for patients and must process multiple administrative tasks before proceeding to subsequent departments. For billing, patients need to prepay at each step before accessing different care services which delays the patient journey when a large number of patients need

to complete payment. Lastly, outpatient consultation represents another bottleneck as it depends on doctors' availability and generally requires more time than other departments.

Although the proportion of fully reconstructed care journeys was high, particular attention must be paid to incomplete journeys. During implementation, incompleteness was caused by power cuts in the hospitals involved in the trial, a technical issue commonly reported in other studies in low-resource countries [16, 17]. Also, the deliberate unplugging of antennas by healthcare providers who were not yet familiar with the system at the start of the experience interfered with journey completeness.

The loss of beacons was observed only at CPLR and seems to be linked exclusively to the physical beacon design. Initially, the beacons used at CPLR were designed like watches, which attracted children's interest as they considered them to be toys, while some uninformed patients mistook them for real watches and did not return them after their consultation. Furthermore, the exit alarm system designed to detect patients leaving with the beacons had not yet been developed at the time of the pilot study at CPLR. To prevent such losses, beacons designed as medallions with a necklace were used at MURAMVYA District Hospital, and an exit alarm system was installed to detect patients attempting to leave before returning the beacon. These operational changes were necessary and caused the pilot to be suspended for a few months, but afterward they allowed us to avoid beacon losses. Thus, the physical design of the beacons is a key factor to be taken into account when deploying such a solution, particularly in a low-resource setting. Other studies have also reported the loss of beacons [18, 19].

As reported in other studies, BLEID technology may also have several other applications than patient tracking in hospitals. The module could also be adapted to biomedical equipment tracking [20, 21], access control to restricted areas such as laboratories, infection control [9, 21, 22], patient identification [23], remote monitoring of vital signs [24] or preventing patients from leaving the hospital without being discharged.
Additional studies in other hospitals with different organizational structures may be necessary before the system can be rolled out more widely, given that the two hospitals in the study were both public, albeit of different levels, with one district hospital and one national referral hospital.

Study strengths and limitations

The study has several strengths. The first strength of this study is that it shares an experience of tracking patients integrated into an existing HIS in a resource-limited setting, at a time when most experiences shared have been carried out in developed countries. The second strength of this study is that it was conducted under real-world patient tracking conditions, which ensures the relevance of the results in practice. The third strength is that it produced data that is usually unavailable in standard electronic medical records and that can be used to optimize the patient care journeys. The last strength is the methodological rigor applied through the use of the design science research approach.

Nevertheless, this study has its limitations. Firstly, the pilot was carried out in only two hospitals, which still limits the generalizability of the results. Secondly, patient movements

occurring outside the coverage area of BLEID readers were not captured, potentially limiting the completeness of data on patient movement throughout the hospital. Thirdly, this evaluation was limited to the technical performance of the devices and did not address the economic aspects of the intervention, which would have provided more insight into the economic feasibility and return on investment. Finally, health professionals may have altered their performance to reduce the time spent providing care (Hawthorne effect). Several measures were taken to mitigate that potential bias. Before date collection, we first discussed the study with the staff and demonstrated that the tracking system were not recording the health workers. We also extended the study's duration because people cannot maintain altered behavior for a long time. In addition, we also reduced research team members presence in and around the department by positioning ourselves at the hospital exits.

Conclusion

The study described a new solution aimed at real-time patient tracking during outpatient care in a low-resource setting. It also added evidence on patient's journey during outpatient care at the limited knowledge on the responsiveness of health systems. Results suggested that the Bluetooth Low Energy Identification (BLEID) technology is suitable for patient tracking. Health managers may be guided by these findings to implement this technology to improve outpatient care delivery.

List of abbreviations

BLEID: Bluetooth Low Energy Identification
WHO: World Health Organization
CPLR: Low- and Middle-Income Countries
HIS: Health Information System
IQR: Interquartile Range

Declarations

Ethics approval and consent to participate

The study was approved by the National Ethics Committee of Burundi (Decision No. CNE/29/2025) in accordance with the Declaration of Helsinki. Informed consent to participate was obtained from all of the participants in the study.

Consent for publication

Not applicable.

Availability of data and materials

The dataset analyzed in this study is available from the corresponding author, upon reasonable request.

Competing interests

We declare that we have no competing interests.

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No funding was received for this research.

Authors' contributions

AN participated in study design, conducted field data collection, performed data analysis, prepared the initial draft of the manuscript, reviewed the manuscript.

FV, RB, JN and MN participated in study design, supervised data collection, provided guidance on data analysis, substantially contributed in results verification and interpretation, closely reviewed the manuscript.

All authors have read and approved the final manuscript

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- Supplementarytable1Frequencyanddurationoftransitionsbetweendepartments.docx
- Supplementaryfigure2DepartmentsnetworkduringoutpatientcareatCPLRhospital.docx