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A Real-time Approach for Dynamic Scheduling Pet Activities in a Hospital

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A real-time approach for dynamic scheduling PET activities in a hospital

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ABSTRACT

Background: At present, medical personnel use manual scheduling methods to calculate usage times of PET devices, hospital beds, operating rooms, and other treatment spaces. However, as patient treatment and recovery times are unequal and uncertain, arriving times of the scheduled/temporary patients are unexpected, examination items, beds requirements, and drugs waiting times are different, and scan-again requirements are unexpected. Manual scheduling arrangements are easy to make mistakes and put pressure on employees. With changing scheduling arrangements, it is difficult to announce the estimated time to patients and their families in real time. As a result, family members keep asking medical staff about various situations and waiting time. This makes the process unstable and exhausts the medical staff. Although previous researches proposed algorithms for specific inspections to solve the equipment resource allocation problems and calculate outpatient visit time for outpatient clinics, there is no research on improving the PET process. This paper proposes a real-time automatic scheduling and control system for PET patients with Bluetooth Beacon positioning.

Results: This system can automatically schedule, estimate, and instantly update the start and end time of various tasks of PET patients during examinations, and automatically allocate beds and real-time announce schedule information, allowing the schedule being automated, instant and almost optimized. Moreover, this system promptly reminds medical staffs in each area. This can greatly reduce the work of medical staff, avoid human error, improve the safety of drugs, and provide medical staff, patients and family members to view the inspection progress and estimated waiting time in real time, reducing the number of patients and family members to query medical staff. We implemented this system in an application for the Android system to prove the feasibility of the system. We also collected time data of 200 actual patients for 2 weeks in the Department of Nuclear Medicine of Chang Gung Memorial Hospital, Linkou, and put these data into the implementation program for simulation and comparison. It was found that the average time difference between manual and automatic scheduling was 7.32 minutes, and it could reduce the average examination time of 82% of patients by 6.14 minutes, proving the system's correctness and efficiency. To our knowledge, this paper is the first to propose a real-time automatic scheduling and control system for PET patients.

Keywords PET, automatic scheduling, control system, Beacon

1. Background

Hospital medical equipment resources are often in short supply. Equipment scheduling control is an important issue. This issue is roughly divided into three categories: "reservation scheduling", "real-time scheduling" and "smart device applications".

1.1. Reservation scheduling

There are many different outpatient clinics in the hospital, as well as multiple physical examination equipment. However, the number of patient examination needs is far greater than medical resources. The resources provided by the hospital are in short supply, so good scheduling is required to resolve the problem. Burdett et al. [1] robustly schedule appointments by strategically inserting buffer times, and combine simulated annealing and evolutionary search to improve scheduleability. Jiang et al. [2] found that most studies on appointment systems assume that patients arrive at appointment time, but the actual situation is not the case. Therefore, they proposed a random planning appointment scheduling system considering late patients, using the BD-SAA method to find the best appointment time that reaches the least patient waiting time and doctor idle time. Qiu et al. [3] proposed algorithms using NSGA-II and MOEA / D for a single MRI device to arrange the order of appointment and appointment time for patients of different types of examination. Wu et al. [4] calculated the length of MRI examinations in different body parts and assigned corresponding MRI equipment, and then combined the statistical data to determine the length of each examination to increase the usage of MRI equipment and reduce the patient waiting time. Xiao et al. [5] proposed a method based on genetic algorithms for the nuclear medicine department to solve complex scheduling problems with many conditions. The background of this study [5] is similar to this article, but their method can only be applied in appointment situations, while our proposed method can estimate the patient waiting time for various tasks in real time.

However, appointment scheduling can only maximize the number of patients by arranging the examination dates and order for patients, but it cannot solve the problem that patients do not arrive at the hospital according to the appointment time. In fact, on the examination day, patients often arrive early or late, have not arrived, or join examination temporarily. It will widen the gap between the actual and the appointment time, and the patients' original examination time may change due to these factors. In order for patients to understand the on-site conditions, this paper proposed real-time automatic scheduling and control system. It is an effective method to provide on-site scheduling and estimated inspection time, and it can optimize the entire inspection process and ease the workload of medical staffs.

1.2. Real-time scheduling

Many scholars have proposed solutions to the random variability of on-site patients. Azadeh et al. [6] proposed a mixed integer linear programming model in order to solve the scheduling difficulties caused by multiple examinations in a single patient, and combined genetic algorithms to solve the problem of finding the best solution. Peng et al. [7] proposed a method using discrete event simulation combined with genetic algorithms to maximize the number of patients served. This method can dynamically schedule patients who have been booked, booked on-site or waited on-site. However, they [6,7] can only provide queue status (number of patients, queue position), but cannot provide patients with estimated examination time.

Many scholars [8-10] have proposed methods for outpatients to arrive at the scene close to the consultation time. Montecinos et al. [8] used the method of particle filters to estimate the waiting time of consultation using historical data of patient visit time and new input data. Tantitharanukul et al. [9] developed an estimated waiting time system WTE based on the queuing theory, and used the MQTT protocol to transfer the waiting time and number to the patient's cell phone. Obulor et al. [10] also used the queuing theory to develop an appointment queuing system to provide better resource utilization to solve the problem of long waiting times for patients. These studies [7-10] estimate the time for a single treatment, while the system proposed in this paper is for multi-stage treatment such as PET, and can dynamically estimate the start and end time of each different stage, and instantly announce these time information on the public screen or send it to the patient's mobile phone.

Because appointed patients are sometimes late or absent, which affects the time of patients who are registered and waiting at the scene, the original schedule must be constantly modified and updated in real time. The above studies [9] and [11] are aimed at improving the situation. Qu et al. [11] used the Markov Model to optimize the scheduling of patients waiting on-site, and proposed Heuristic Algorithm for other possible situations. The model divides the time of a day's visits into multiple time slots, and then queues the patients into each time slot one by one.

Ruth Luscombe et al. [12,22] developed Job shop scheduling, combined with heuristic algorithms, to quickly coordinate the activities and resources of emergency departments. Wiesche et al. [13] proposed an optimization model of Optimal Reservation of Capacity for Appointments (ORCA), a system that can arrange patients without appointments and patients who already have appointments, and provide them on days when the demand for patients is low. Make an appointment to get as much capacity as possible to treat a walk-in patient on a high-demand day. The system of Kortbeek et al. [14] used the day process model and access process of scheduled arrivals model to balance "waiting machine time for patients without appointments" and "examination time for patients with appointments" and

divided the time of day into multiple time slot to arrange patients.

However, in the PET examination, it is necessary to consider that each patient has a different medicine cycle time in different examination sites, and there are also cases where the examination fails and the examination is repeated. Therefore, these studies cannot solve the problem of real-time scheduling of PET inspections.

1.3. Smart device applications

Some patients have multiple examinations in the hospital, and some examinations have multiple tasks [19-21]. Without proper time control, patients will spend a lot of time waiting. By recording the start and end time of each task, we can analyze the data and reduce patient waiting time.

Frisby et al. [15] proposed a new method for controlling patients in the emergency room. Each doctor wore a medical Bluetooth device and installed a Bluetooth signal receiver in each bed. Within the acceptable range, the treatment time is automatically recorded, which effectively reduces the doctor's work. Ewing et al. [16] and Elnahrawy et al. [17] have used the instant positioning system to collect data on the patient's movements in the hospital and the time spent at each station to analyze the data and improve the hospital workflow. Kortbeek et al. [14] developed a frame that combines data collection with electronic medical records for data analysis. This method effectively understands the flow of patients in various areas of the hospital, and can be used to control different situations in the future. Naruse et al. [18] set up a Beacon signal receiver made of Raspberry Pi in the room to detect the Beacon signal. When someone enters the room, they will identify the Beacon, transmit the Beacon data to the database, and calculate the duration of the Beacon carrier stay.

This paper proposes a method for arranging mobile phones as receivers in various areas of PET, receiving signals from patients wearing Beacon devices, and automatically recording the time of patients during various inspection tasks, saving medical staff time for manual transcription and improving overall automation.

1.4. Overview of results

This paper proposes a real-time, automatic and dynamic scheduling and control system for PET patients with Bluetooth Beacon positioning. This system can automatically schedule, estimate and update the start and end time of various tasks of PET patients during the examination, and automatically allocate beds and real-time announce schedule information, allowing the schedule being automated, instant and almost optimized. This can greatly reduce the work of medical staff, avoid human error, improve medication safety, and provide medical staff, patients and family members to instantly check the progress of the inspection and estimated waiting time, reducing the number of patients and family members to ask medical staff. We also implemented the proposed method in the Android system to prove the feasibility of the system.

We also developed an app that can automatically collect data. This app collected various "manually scheduled" data from 200 actual patients in the Department of Nuclear Medicine of Linkou Chang Gung Hospital as a control group. We also feed the initial situation of the same 200 original data collected into the above-implemented Android system, and obtain various "auto-scheduled" data as the experimental group. It was found that the average time difference between the "manually-scheduled control group" and the "auto-scheduled experimental group" was 7.32 minutes, indicating the correctness of this method. Besides, the "auto-scheduled experimental group" can reduce the average examination time of 82% of patients by 6.14 minutes, which proves the progress of this method.

2. Methods

This section explains the system requirements and the detailed scheme of the proposed system. In the inspection schedule of PET, due to many conditions and changes to be considered, such as the limitation of the time limit of special drugs, limited medical equipment, and possible re-scanning, manual scheduling and time control are quite difficult. This paper proposes a real-time automatic scheduling and control system for PET examination, which can instantly estimate the examination time, allocate medical resources, and respond possible re-scanning in time.

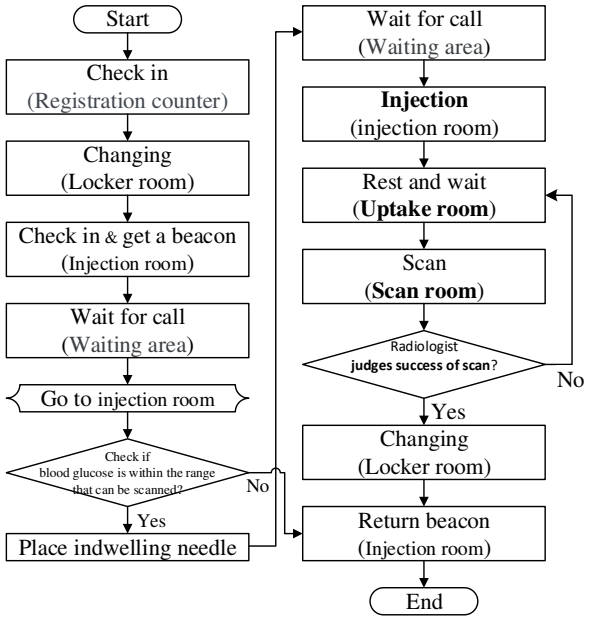


Fig.1. PET Patient examination process.

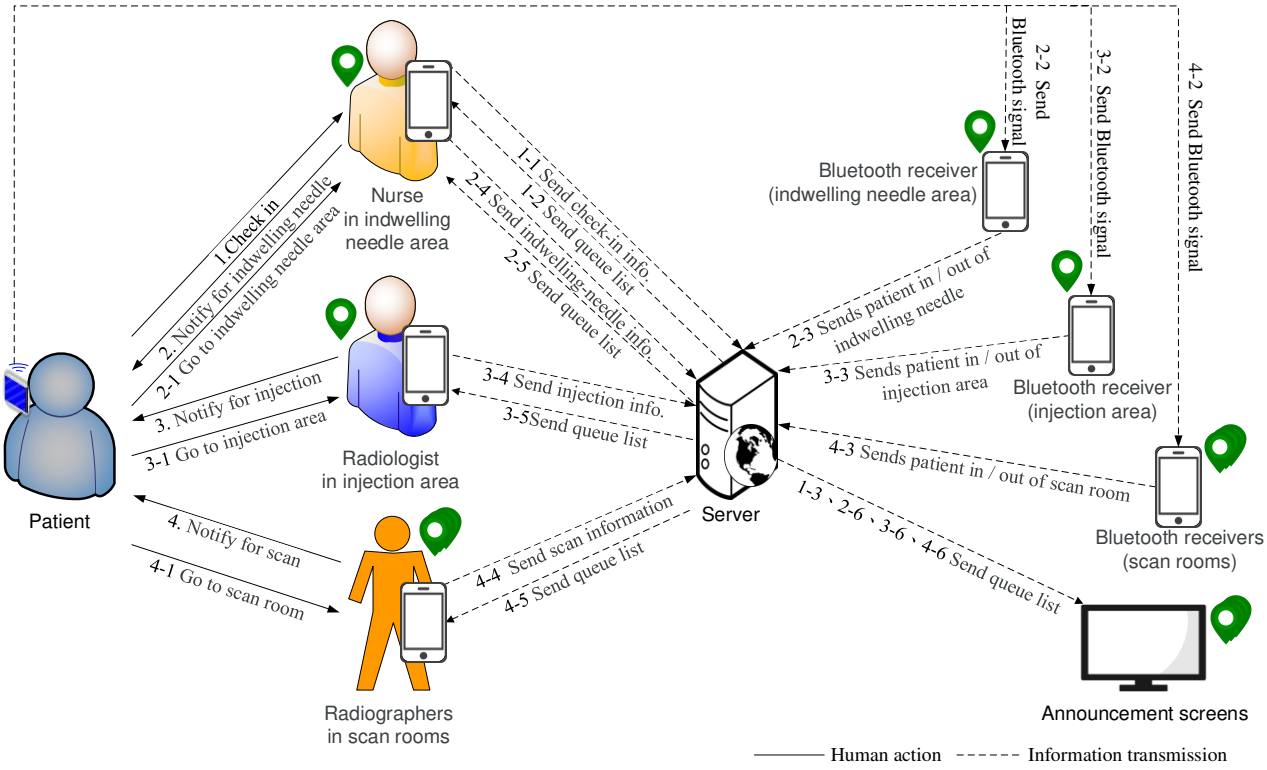


Fig.2. Schematic of automatic scheduling system.

2.1. System requirement

System requirements of the proposed system are described as Definition 1.

Definition 1 (System requirements) The proposed scheme should meet the following conditions. (1) **Real-time automatic scheduling:** The system performs real-time automatic scheduling according to the patient registration time. (2) **Scheduling for different medicines:** The system schedules the best inspection time according to the cycle time of different medicines. (3) **Dynamic update of prediction time:** When a new patient checks in, or after the end of each examination task of the patient, the system immediately updates the expected prediction task time of each patient. (4) **Providing predictive inspection time immediately:** The system provides the predicted inspection time to the medical staffs, patients and their families in real time. (5) **Automatic allocation of general and specific beds:** The system automatically allocates suitable beds to patients waiting for beds according to all patients' inspection tasks completion status. (6) **Automatic detection of all patients' tasks periods:** Automatically detect the start time and end time of each examination task of all patients. (7) **Automatic detection and prediction of examination room conditions:** Automatic detection and prediction of the use and idle periods of each examination room. (8) **Instant re-scheduling:** Automatically arrange patients who need to be re-scanned.

2.2. Details of the proposed system

The traditional PET examination process is shown in Fig. 1. Based on Definition 1 and Fig. 1, we proposed a new scheduling and control system (Fig. 2), which contains five roles and eight phases.

The five roles are patient P_i, medical staff MS, radiologist RD_j, server S and announcement screen, where MS is at indwelling needle area in IV indwelling needle room (or called the outer injection room) R_{IV}, and on the indwelling needle desk we equipped with a mobile device D_{MS} and a beacon signal receiver RC_{MS}. We also equipped with a radiographer RD_j, a mobile device D_{RD_j}, and a beacon signal receiver RC_j in the j-th examination room and on the injection area in the inner injection room. Both RC_{MS} and RC_j have functions to detect the content and strength of Beacon signals. Table 1 defines the symbols and parameters used in the proposed method.

The system is divided into seven phases and two algorithms: initial phase, patient check-in phase, patient indwelling needle phase, bed allocation phase, algorithm for scheduling examination room, estimating injection time and scan time, injection phase, scanning phase, end examination phase, and algorithm to determine Beacon's entry and exit from a certain area.

TABLE 1. Notations

Notation	Definition
P_i	The i-th patient
MS	The medical staff (nurse) in R_{IV}
RD_j	The radiographer in the j-th scan room
S	Server
R_{IV}	IV catheter indwelling room
R_{IJ}	Inner injection room
R_k	the k-th examination room
Bed_j	The j-th bed (j = 1.2.3…..)
$Beacon_j$	The j-th Beacon
$rssi_j$	Signal strength of $Beacon_j$
th_H / th_L	Threshold of rssi strong/ weak signals
D_{MS} / D_{RD_j}	Device of MS / RD_j
RC_{MS} / RC_j	Receivers of MS / RD_j
A_{IV}	List of patient waiting for IV catheter indwelling
A_{inj}	List of patient waiting for injection
A_{BR}	List of patient requesting beds
A_{BV}	List of available beds
A_{R_k}	List of patient waiting for R_k
$A(\alpha)$	The α-th element of the list A
$A(-\alpha)$	The last α-th element of the list A
$b(P_i)$	Body status of P_i (bedridden or non-bedridden)
$t_{abs}(P_i)$	Drug absorption time of P_i (e.g. 30 min.)
t_{IV}^{diff}	Time difference between estimated and actual IV catheter indwelling
t_{inj}^{diff}	Time difference between estimated and actual injection
$\bar{t}_{IV}(\alpha)$	The average IV catheter indwelling time until the α-th time
$\bar{t}_{inj}(\alpha)$	The average injection time until the α-th time
$\bar{t}_{ex}(\alpha)$	The average examination time until the α-th time α
$Bed(P_i)$	The bed of P_i
$Bcn(P_i)$	The Beacon of P_i
$uuid(P_i)$	The uuid of
$Mrn(P_i)$	The medical record number for P_i
$R(P_i)$	The scan/examination room for P_i
$T_{CO}(P_i)$	The examination check-out time for P_i
$T_{IV}^e(P_i)$ / $T_{IV}^a(P_i)$	The estimated/actual IV catheter indwelling time for P_i
$T_{LIV}^e(P_i)$ / $T_{LIV}^a(P_i)$	P_i's estimated/actual time to leave the IV room
$T_{inj}^e(P_i)$ / $T_{inj}^a(P_i)$	The estimated/actual injection time for P_i (e.g. 10:00 AM)
$T_{Linj}^e(P_i)$ / $T_{Linj}^a(P_i)$	P_i's estimated/actual time to leave the injection room
$T_{EE}^e(P_i)$ / $T_{EE}^a(P_i)$	The estimated/actual time to enter the examination room for P_i (e.g. 10:00 AM)
$T_{LE}^e(P_i)$ / $T_{LE}^a(P_i)$	The estimated/actual time to leave the examination room for P_i (e.g. 10:00 AM)
$T_{BV}(Bed_j)$	The bed vacated time of Bed_j
$T_{BA}(P_i)$	The bed available time for P_i
$T_{EI}(P_i)$	The earliest injection time for P_i
$T_{ES}(P_i)$	The earliest scan/examination time for P_i
$T_{ES}(P_i \mid R_k)$	The earliest scan/examination time at R_k for P_i
$T_{IIF}(P_i)$	Time for doctor to finish P_i's DICOM image interpretation

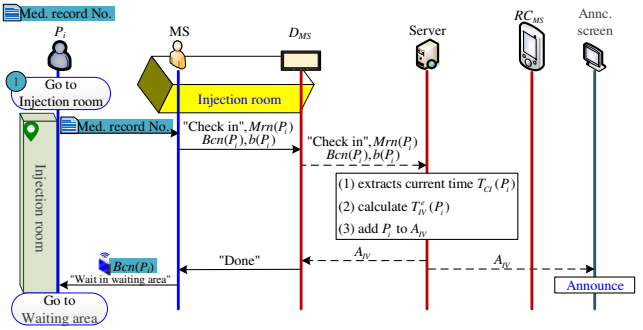


Fig.3. Check-in process.

(1) Initial phase

S let $A_{IV}=\varnothing$, $A_{inj}=\varnothing$, $A_{BR}=\varnothing$, $A_{R_k}=\varnothing$, $T_{ES}(R_k)$ = 17:00, and the average task times $\bar{t}_{IV}(0)$, $\bar{t}_{inj}(0)$ and $\bar{t}_{ex}(0)$ be their average time of the previous week.

(2) Patient check-in phase

When P_i checks in, MS configures a Beacon for P_i, uses D_{MS} to scan P_i's medical-record-number barcode $Mrn(P_i)$, and enters P_i's body status $b(P_i)$ and Beacon serial number Bcn_j, and sends $Mrn(P_i)$, $b(P_i)$ and Bcn_j to S. Then S calculates the estimated IV indwelling time:

$$T_{IV}^e(P_i)=\begin{cases}\text{current time, if } A_{IV}=\varnothing\\ T_{IV}^e(P_{i-1})+\bar{t}_{IV}(n), \text{ else}\end{cases}, \quad (1)$$

and adds $Mrn(P_i)$ to A_{IV}. Finally, patient waits in waiting area. The check-in process is shown in Fig. 3.

(3) Patient indwelling needle phase

When the P_i's previous patient (i.e. P_{i-1} or P_j) indwelling needle ends and leaves R_{IV}, S will receive the message that P_{i-1} (or P_j) has left R_{IV}, and then automatically transfer $A_{IV}(1)$'s $Bcn(P_i)$ to RC_{MS}, letting RC_{MS} knows that the next beacon to be determined whether the signal to enter or leave is $Bcn(P_i)$. (Please refer to 3.3.9 for the detailed determine method.) When the time is one minute before $T_{IV}^e(P_i)$, S sends the indwelling needle notification to D_{MS} (or MS checks D_{MS} and judges that P_i can be indwelling), and MS goes to the waiting area to notify P_i to go to R_{IV} to indwell needle.

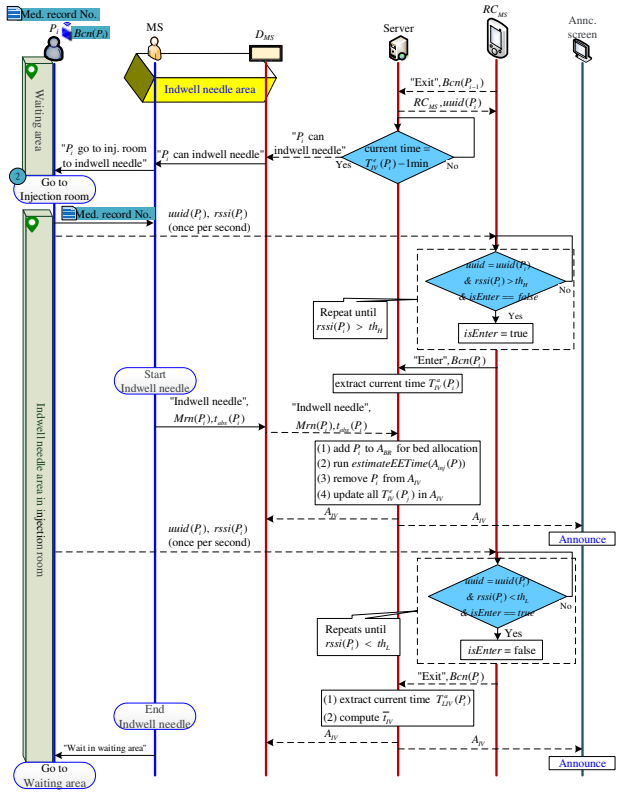


Fig.4. Indwelling needle process.

$assignBed(P_i)$
input : P_i
output : $Bed(P_i)$
allocate each Bed's ratio
$Bed(P_i) = Bed_{\bar{j}}$,
where $Bed_{\bar{j}}.ratio = \max\{Bed_j.ratio \mid Bed_j.isOccupied = false\}$
$T_{BA}(P_i) =$ current time
$A_{inj} = A_{inj}.add(P_i)$
$A_{BR} = A_{BR}.remove(P_i)$
$Bed_j.isOccupied = true$

Fig.5. Bed allocation algorithm.

TABLE 2. Weight allocation in the intake room

Bed Type / $b(P_i)$	A	B	C
Bedridden	6	0	0
General and $t_{abs}(P_i) = 30$	1	3	2
General	1	2	3

When P_i enters R_{IV}, RC_{MS} judges that P_i has entered R_{IV} indwelling needle and then informs S. S then captures the time of entering R_{IV} as the start time of the indwelling needle $T^a_{IV}(P_i)$, add P_i to A_{BR} and delete it from A_{IV}, and calculate the actual and estimated time difference:

$$t^{diff}_{IV} = T^a_{IV}(P_i) - T^e_{IV}(P_i). \quad (2)$$

S then uses t^{diff}_{IV} to update the estimated indwelling time for patients in A_{IV}:

$$T^e_{IV}(a_{IV}) = T^e_{IV}(a_{IV}) + t^{diff}_{IV}, \forall a_{IV} \in A_{IV}. \quad (3)$$

During P_i indwelling, MS transmits $t_{abs}(P_i)$ to S via D_{MS}. Next, S allocates an uptake room for patients in A_{BR}, calculates the estimated injection time $T^e_{inj}(P_i)$ and the estimated scan time $T^e_{EE}(P_i)$ (for detailed methods, refer to 3.3.4 and 3.3.5), and uses $T^e_{EE}(P_i)$ to calculate the $T^e_{inj}(P_i)$ back.

After the indwelling needle is completed, P_i leaves R_{IV} to the waiting area to wait for the injection. At this time, RC_{MS} automatically determines that P_i is leaving R_{IV} and sends a "P_i has left R_{IV}" message to S. Nest, S extracts current time $T^a_{LIV}(P_i)$, and calculates the length of the P_i indwelling needle:

$$t_{IV}(n) = T^a_{LIV}(P_i) - T^a_{IV}(P_i). \quad (4)$$

Finally, S calculates the average indwelling time from P_1 to P_i:

$$\bar{t}_{IV}(n) = \frac{(n-1)\bar{t}_{IV}(n-1) + t_{IV}(n)}{n}. \quad (5)$$

The indwelling needle process is shown in Fig. 4.

(4) Bed allocation phase

After processing a "successful scan" patient P_i, RD_j uses D_{RD_j} to send $T_{IIF}(P_i)$ to S. S then runs $Bed(P_i).isOccupied = false$ to vacate P_i's bed, and runs $Bed(P_j = A_{BR}(1)) = assignBed(P_j)$ to assign this bed to the next waiting patient P_j (Fig. 5). Besides that, when the patient P_i indwelling needle ends, S also performs the bed allocation algorithm $Bed(P_i) = assignBed(P_i)$ to try to assign an vacated bed to P_i.

There are three types of beds in the uptake room, and all three types can be allocated to general patients. However, bedridden patients can only use type-A beds, while patients with short drug absorption times (i.e. $t_{abs} = 30$) are often allocated to type-B beds, while type-C Beds can be dispensed to short-absorption-time or general patients. We use "weight allocation" to calculate the priority of bed allocation in the uptake room. The allocation method is shown in Table 2, where 0 means not applicable.

S chooses the unoccupied bed with the highest weight as $Bed(P_i)$. If P_i is allocated to a bed, S extracts the current time as $T_{BA}(P_i)$, and adds P_i to A_{inj} and removes it from A_{BR}. S then runs the algorithm for estimating scan time:

$estimateEETime(P_i)$ (Fig. 6). Otherwise if P_i is not allocated to any bed, P_i continues to wait at A_{BR} until there is a vacated bed in the uptake room.

(5) Algorithm for scheduling examination room, and estimating injection and examination time

After executing $assignBed(P_i)$, S then executes the algorithm $estimateEETime(P_i)$ one by one for patients whose injection has not been estimated in A_{inj}, where $estimateEETime(P_i)$ is used for arranging examination room $R(P_i)$, estimating injection time $T^e_{inj}(P_i)$ and start/end examination time $T^e_{EE}(P_i)/T^e_{LE}(P_i)$ (Fig. 6). If P_i is a patient who has not completed the indwelling needle, S lets P_i's the fastest injectable time $T_{EI}(P_i)$ be $T_{BA}(P_i)$. Otherwise, S lets $T_{EI}(P_i)$ be $T_{BA}(P_i)$.

Next, S separately determines which of $T_{ES}(P_i)$ and $T^e_{LE}(A_{R_k}(-1))$ is earlier to find out the fastest available scan time $T_{ES}(P_i \mid R_k)$ in each examination room R_k, where $T^e_{LE}(A_{R_k}(-1))$ is the estimated time to leave the examination room R_k for the last patient waiting for R_k. For $R_{k'}$, if $T_{ES}(P_i) \geq T^e_{LE}(A_{R_{k'}}(-1))$, it means the fastest scan time $T_{ES}(P_i \mid R_{k'})$ of P_i in $R_{k'}$ is $T_{ES}(P_i)$. Otherwise, it means P_i has the opportunity to scan before $T^e_{LE}(A_{R_{k'}}(-1))$. Therefore, S searches for free time space between $T_{ES}(P_i)$ and $T^e_{LE}(A_{R_k}(-1))$.

If there is enough time (higher than the average examination time $\bar{t}_{ex}$) in the time space between $T^e_{LE}($ $A_{R_k}(\alpha-1))$ and $T^e_{EE}(A_{R_k}(\alpha))$ or between $T^e_{EE}(A_{R_k}(\alpha))$ and $T_{ES}(P_i)$, it means P_i can perform examinations in the free time gap between "patient $A_{R_k}(\alpha-1)$ end scan" and "patient $T^e_{EE}(A_{R_k}(\alpha))$ start scan". Because $T_{ES}(P_i)$ may fall before $T^e_{LE}(A_{R_k}(\alpha-1))$, that is, $T_{ES}(P_i)$ is just when $A_{R_k}(\alpha-1)$ is inspecting, this situation is not feasible. Therefore, the fastest time for scan should be $T^e_{LE}(A_{R_k}(\alpha-1))$ to be a reasonable time. $T_{ES}(P_i)$ may also fall behind $A_{R_k}(\alpha-1)$, hence the fastest available time can be $T_{ES}(P_i)$ directly. Therefore, S chooses $T_{ES}(P_i \mid R_{k'})$ = max{ $T_{ES}(P_i)$, $T^e_{LE}(A_{R_k}(\alpha-1))$ }. If there is not enough time between $T_{ES}(P_i)$ and $T^e_{LE}(A_{R_{k'}}(-1))$, then let $T_{ES}(P_i \mid R_{k'})$ be $T^e_{LE}(A_{R_{k'}}(-1))$.

Finally, S selects the minimum value from $\{T_{ES}(P_i \mid R_j) \mid \forall j = 1,2,...\}$ as $T^e_{EE}(P_i)$, uses it to compute estimated injection time $T^e_{inj}(P_i)$ and estimated end-examination time $T^e_{LE}(P_i)$, and adds P_i to A_{R_k}.

(6) Injection phase

When the $P_{i'}$ injection ends and leaves R_{IJ}, S will receive the message of "$P_{i'}$ is leaving R_{IJ}", and then automatically pass $Bcn(P_i)$ from $A_{inj}(1)$ to RC_0 to let RC_0 know the next beacon determining entry or exit is $Bcn(P_i)$. (Please refer to Fig. 10 for detailed Beacon algorithm.) When the time is one minute before $T^e_{inj}(P_i)$, S sends an injection notification to D_{RD_0}. After receiving the notice, RD_0 goes to the waiting area and tells P_i to go to R_{IJ} to inject.

When P_i enters R_{IJ}, RC_0 judges that $Bcn(P_i)$ enters R_{IJ} for injection and informs S. S then extracts the current time as the injection start time $T^a_{inj}(P_i)$, and removes P_i from A_{inj}. When P_i leaves R_{IJ} to $Bed(P_i)$ at the end of the injection, RC_0 judges that $Bcn(P_i)$ has left R_{IJ} and notifies S. S extracts the current time as the departure time $T^a_{Linj}(P_i)$, and calculates P_i's injection length:

$$t^n_{inj} = T^a_{Linj}(P_i) - T^a_{inj}(P_i). \quad (6)$$

Finally, S calculates the average injection time from P_1 to P_i:

$$\bar{t}_{inj}(n) = \frac{(n-1)\bar{t}_{inj}(n-1) + t^n_{inj}}{n}. \quad (7)$$

The patient injection process is shown in Fig. 7.

estimateEETime(P_i)
input : P_i
output : $R(P_i), T^e_{EE}(P_i), T^e_{LE}(P_i), T^e_{inj}(P_i)$
(1) foreach R_k,get $T_{ES}(P_i \mid R_k)$ as follows.
Let $T_{ES}(P_i) = T_{EI}(P_i) + \bar{t}_{inj} + t_{abs}(P_i)$
  if ($T_{ES}(P_i) \geq T^e_{LE}(A_{R_k}(-1))$)
    return $T_{ES}(P_i \mid R_k) = T_{ES}(P_i)$
  else (i.e. $T_{ES}(P_i) < T^e_{LE}(A_{R_k}(-1))$)
    foreach α such that ($T^e_{EE}(A_{R_k}(\alpha)) \geq T_{ES}(P_i)$)
      if ($T^e_{EE}(A_{R_k}(\alpha)) - T^e_{LE}(A_{R_k}(\alpha-1)) \geq \bar{t}_{ex}$) && ($T^e_{EE}(A_{R_k}(\alpha)) - T_{ES}(P_i) \geq \bar{t}_{ex}$)
        return $T_{ES}(P_i \mid R_k) = \max(T^e_{LE}(A_{R_k}(\alpha-1)), T_{ES}(P_i))$
    endfor
    return $T_{ES}(P_i \mid R_k) = T^e_{LE}(A_{R_k}(-1))$
(2) $T^e_{EE}(P_i) = \min_{k \in N}\{T_{ES}(P_i \mid R_k)\}$
(3) $R(P_i) = R_{\bar{k}}$ such that $T_{ES}(P_i \mid R_{\bar{k}}) = T^e_{EE}(P_i)$
(4) $T^e_{inj}(P_i) = T^e_{EE}(P_i) - t_{abs}(P_i) - \bar{t}_{inj}$
(5) $T^e_{LE}(P_i) = T^e_{EE}(P_i) + \bar{t}_{ex}$
(6) $A_{R_{\bar{k}}}.add(P_i)$ where $R_{\bar{k}} = R(P_i)$

Fig.6. Algorithm for estimating examination-process time.

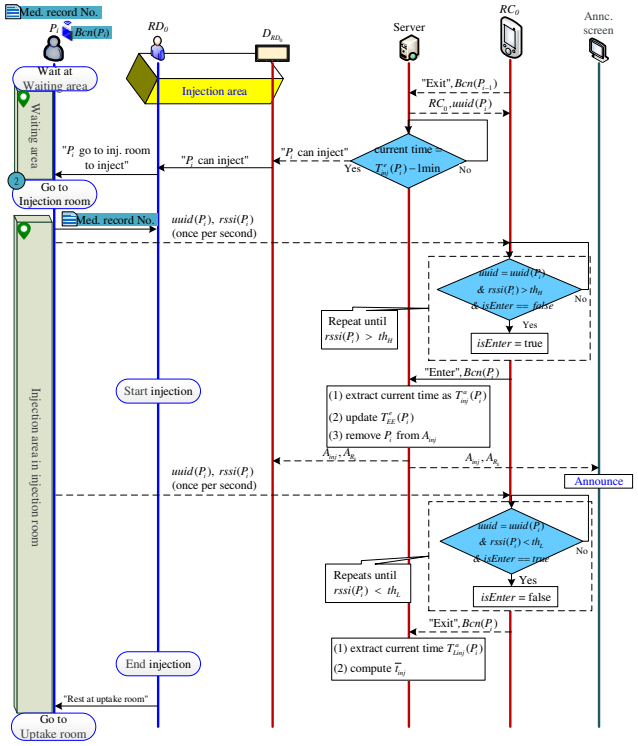


Fig.7. Injection process.

(7) Scanning phase

When the P_i' examination ends and leaves R_k, S will receive the message of "P_i' is leaving R_k", and then automatically pass $Bcn(P_i)$ from A_{R_k} (1) to RC_j to let RC_j know the next beacon determining entry or exit is $Bcn(P_i)$. (Refer to Fig. 10 for detailed algorithm.) When the time is five minute before $T^e_{EE}(P_i)$, S sends an examination notification to D_{RD_j}. After receiving the notice (or RD_j determines that P_i can be scanned via checking D_{RD_j}), RD_j goes to the uptake room and tells P_i to go to R_k to wait for examination.

When P_i enters R_k, RC_j judges that $Bcn(P_i)$ enters R_k and informs S. S then extracts the current time as the examination start time $T^a_{EE}(P_i)$, and removes P_i from A_{R_k}.

If RD_j, which monitors the patient's photographic image in the background, judges that P_i's scan image is successful, he uses D_{RD_j} to transmit $T_{IIF}(P_i)$ to S. S empties $Bed(P_i)$, and then automatically allocates the bed to a patient in A_{BR}. In addition, P_i needs go to R_{IV} to pull the needle and return Beacon to complete the inspection.

If RD_j judges that the scan image of P_i fails, then P_i needs to be scanned again. RD_j uses D_{RD_j} to select a patient

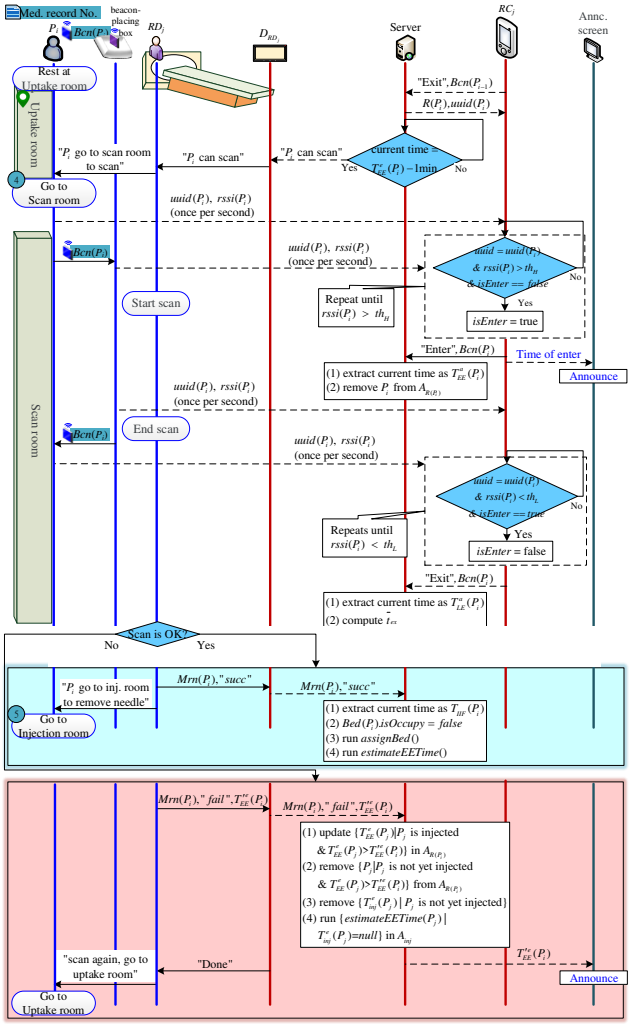


Fig.8. Examination process.

so that P_i should be re-scanned after the patient's end examination. S then updates all the estimated examination time of the patients who are injected in A_{R_k}, clears the estimated injection and examination time of all patients in A_{inj}, and re-executes $estimateEETime(P_i)$ to calculate the new estimated injection and examination times of all patients.

When P_i leaves $R(P_i)$ at the end of examination, RC_j judges that $Bcn(P_i)$ has left $R(P_i)$ and notifies S. S extracts the current time as the departure time $T^a_{LE}(P_i)$, and calculates P_i's examination length:

$$t^n_{ex} = T^a_{LE}(P_i) - T^a_{EE}(P_i). \tag{8}$$

Finally, S calculates the average scan time from P_1 to P_i:

$$\bar{t}_{ex}(n) = \frac{(n-1)\bar{t}_{ex}(n-1) + t^n_{ex}}{n}. \tag{9}$$

The patient examination process is shown in Fig. 8.

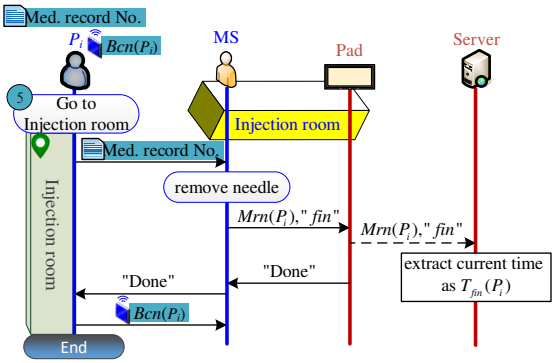


Fig.9. End examination process.

```
judgeEnterExit(R_k, P_i, uuid(P_i))
input : R_k, P_i, uuid(P_i)
output : "P_i Enter" or "P_i Exit"
initialize : isEnter = false, uuid = null, num = 0;
Get (R(P_i), uuid(P_i)) from server;
if (receiver(R_k) ∉ R(P_i))
  break;
time t = current time;
do {
  t+ = 1 second;
  scanning each beacon Bcn_j;
  if (uuid(Bcn_j) == uuid(P_i)){
    if ((isEnter == false) & (rssi(Bcn_j) > th_H)) {
      num + +;
      if (num ≥ 5) {
        isEnter = true;
        num = 0;
        return "P_i Enter";
      }
    }
    else if ((isEnter == true) & (rssi(Bcn_j) < th_L)){
      num + +;
      if (num ≥ 5) {
        isEnter = false;
        num = 0;
        return "P_i Exit";
      }
    }
    else
      num=0;
  }
} while ( t <= current time);
```

Fig.10. Algorithm to determine Beacon's entering / leaving from a certain area.

(8) End examination phase

Patient P_i, who had been successfully examined, would return to the injection room, remove the needle, and return his Beacon. MS then clicks the end button via D_{MS} to inform S, and completes the PET inspection. (Fig. 9.)

(9) Algorithm to determine Beacon's entering or leaving from a certain area

RC_{MS} or RC_j can judge whether $Bcn(P_i)$ enters / leaves an area based on whether $rssi(Bcn(P_i))$ is "greater than th_H" or "less than th_L" (Fig. 10). However, when P_i approaches the entrance to the area, the value of $rssi(Bcn(P_i))$ will oscillate back and forth between th_H and th_L, making it impossible to determine whether P_i enters or leaves the area. Therefore, we design that $rssi(Bcn(P_i))$ must be detected greater than th_H / less than th_L for more than 5 consecutive times before it can be judged as entering / leaving.

3. Materials

We first collected the status and time data of various tasks and examinations of 200 actual patients at the Linkou Chang Gung Hospital as a PET medical database and control group. We also implemented the proposed system in the Android system, and fed the patient's physical condition, check-in time and rescan status of the PET medical database data collected above into our implementation system, using the obtained time data as the experimental group. Finally, we do data analysis, compare and analyze the results of the experimental group and the control group.

3.1. Data collection of control group

We set up receivers in five places in Linkou Chang Gung Hospital (Fig. 11). We let actual patients wear Beacon and perform PET inspection procedures under the current manual scheduling method, and record time data and examination information of 200 patients for two consecutive weeks (12 days).

We used a desktop computer (using Windows 10 operating system, Intel (R) Xeon (R) CPU E3-1230 @ 3.3GHz&3.7GHz processor, 8G RAM memory) as the server to collect data, calculate and process communication matters. We also used four Android 5.0 operating system phones, including three HTC Desire816 (Qualcomm S400 1.6GHz quad-core processors) as Beacon signal receivers in three scan rooms to determine patients' in or out of the room, and another HTC One E8 (Qualcomm S801 2.5GHz quad-core processor) is responsible for inputting and transmitting patient examination information to the server. We chose THLight's B3029T as the Beacon for each patient.

The system program structure of data collection is divided into six parts according to different tasks: nurse device during check-in phase, nurse device during indwelling needle, radiologist device during injection, radiologist APP on the scan room side, Server, and receivers in scan rooms. The communication method between the Server and the mobile devices of the medical staff is Wi-Fi. The screens of the mobile phone APP operated by the medical staff at each inspection stage are described below.

(1) Patient check in

When the patient checks in, the nurse at the needle-indwelling area of the injection room will enter the patients' report information screen. Because there are many numbers in the patients' medical record number, it is easy to make mistakes when manually inputting it. Therefore, the scan button "SCAN" is designed to scan the one-dimensional barcode of the medical record number to reduce the error (Fig. 12).

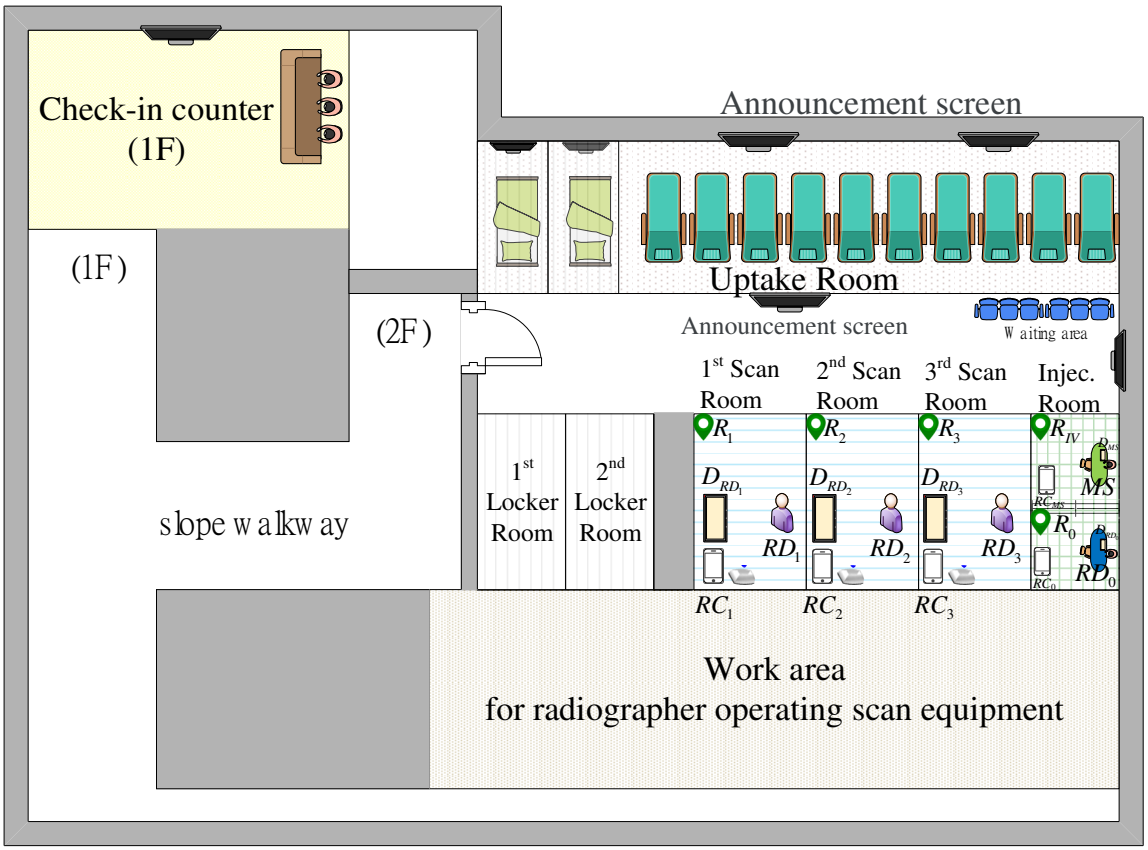


Fig.11. PET outpatient area layout of Linkou Chang Gung Hospital.

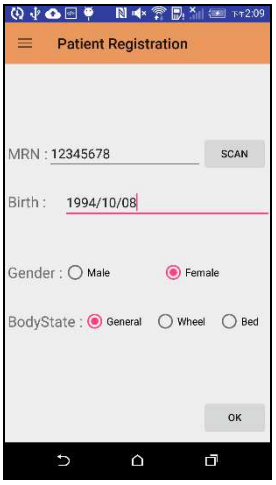


Fig.12. Operation screen of patient check-in phase.

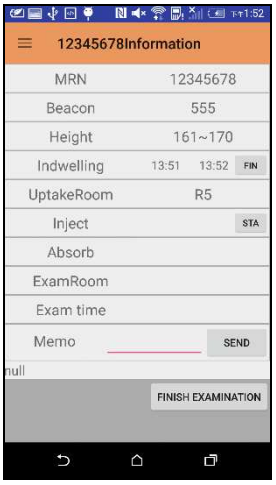


Fig.13. Interface for indwelling needle and injection phase.

(2) Indwelling needle and injection phase

The interfaces of the medical staff during the indwelling phase and during the injection phase are the same (Fig. 13). The medical staff enters the patient information required for the examination. When the needle or injection is started, click the start button "STA" to capture the start time. When the indwelling needle or injection ends, click the button again to grab the end time.

(3) Patients' queue list and scan-room waiting list for each scan room

The information of patients who have completed the indwelling needle but have not yet arranged a scan room is shown on the left in Fig. 14 for the radiologist RD_0 at the injection phase to view and arrange the scan room. The radiologist can click on the MRN number (i.e. "9876543") to go to the interface of Fig. 13 to enter scan information. For

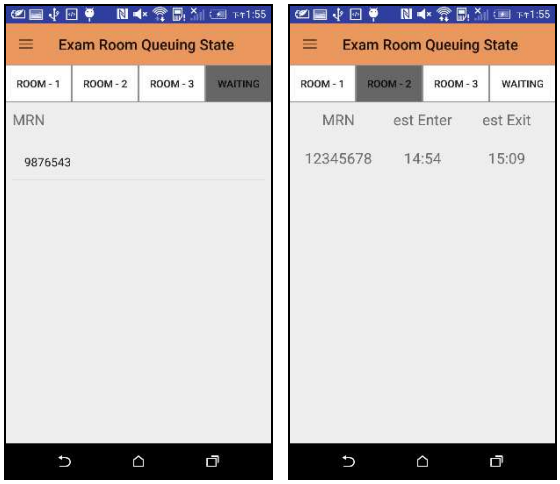


Fig.14. Waiting list for scan rooms and patient queues for each scan room.



Fig.15. Total queue list interface.

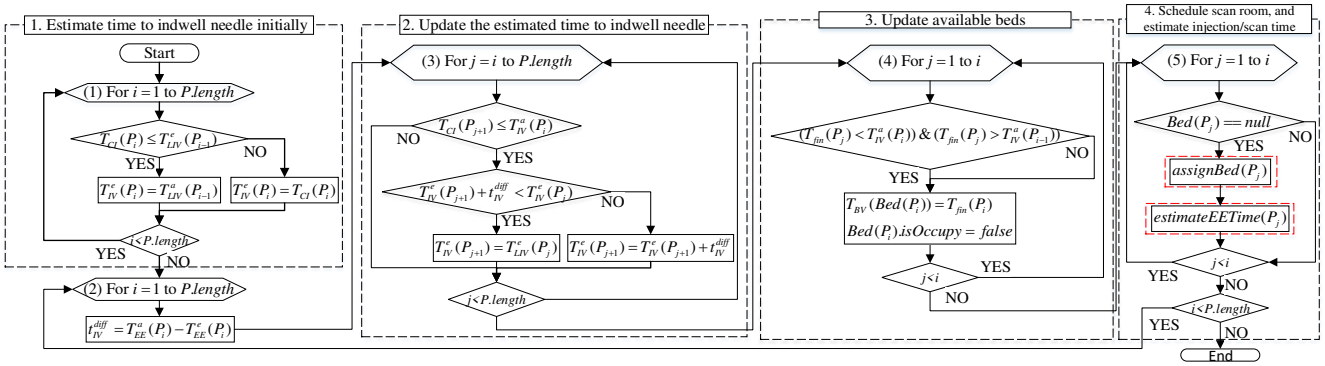


Fig.16. Experimental group data output flow chart.

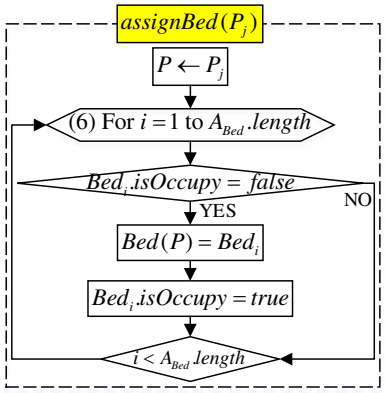


Fig.17. Flow chart for arranging beds.

patients who have been assigned a scan room, their information is displays in each page according to each different scan room (shown on the right of Fig. 14).

(4) Total queue list

Patients who have already checked in and have not completed the examination will be displayed in the screen of Fig. 15 for medical staff at each stage of the examination. Clicking on the MRN number will jump to interface of Fig. 13 for medical staff to enter or view detailed information. When there are a large number of patients, it is not easy to find the medical record number to view detailed information. We can use "SCAN" button to scan the MRN barcode of a patient, and the system will directly display the detailed information of the patient.

3.2. Data collection of experimental group

We then fed these 200 PET medical database data on the patient's physical condition, report time and rescan status into our proposed system for the output of experimental group data. (Fig. 16)

(1) Estimate time to indwell time initially

Initially, the program downloads one day's data from the database, and then calculates the initial estimated indwelling time for all patients.

(2) Update the estimated time to indwell needle

After the initial estimated indwelling needles for all patients have been calculated, the patients are sequentially entered into the next phase of the loop: Update the estimated time to indwell needle. The value of i in the first loop indicates the serial number of the patient who started the indwelling needle, and the patient is represented by P_i. The program subsequently uses the time of P_i's indwelling needle as the

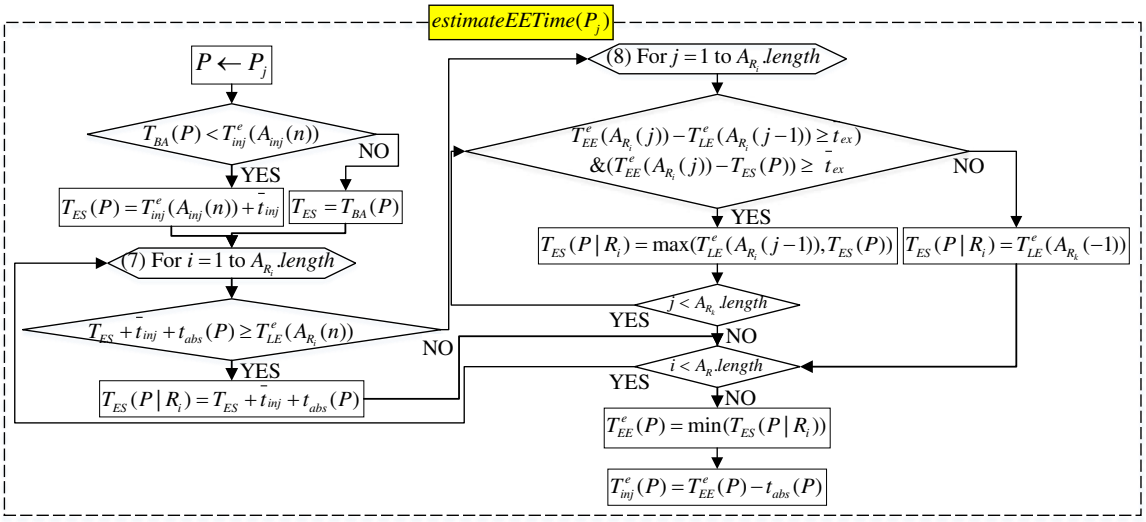


Fig.18. Flow chart of estimating injection time and scan time.

current time, and then uses this time to determine the sequence of other times. The program first calculates the difference t_{IV}^{diff} between the actual and estimated indwelling time of P_i. After calculating the content via executing the second loop, the program will update the estimated indwelling time for all patients after P_i. Because not every patient checks in before the P_i's indwelling needle, it is necessary to judge the timing of $T_{CI}(P_{j+1})$ and $T^a_{IV}(P_i)$ first. If the patient P_j has already checked in before $T^a_{IV}(P_i)$, the program will update $T^e_{IV}(P_j)$ for the patient. The detailed algorithm is shown as Eq. (1) in section 2.

(3) Update available beds

After updating the estimated indwelling time, the program then updates the available beds. The first loop searches for all patients who have been scanned before the P_i's indwelling needle and determines whether there is a $T_{IIF}(P_j)$ between $T^a_{IV}(P_i)$ and $T^a_{IV}(P_{i-1})$. If there is, it means a patient's bed can be vacated during this time gap, and bed vacancy at $T_{IIF}(P_j)$.

(4) Schedule scan room and estimate injection/scan time

After updating the available beds, the program executes the fourth procedure to allocate beds for patients P_j who have not been allocated a bed before $T^a_{IV}(P_i)$. If P_j is assigned to a bed, the program then proceeds with his estimated time of scan and injection.

A. Arrange beds

The bed allocation algorithm *assignBed*(P_j) is shown in Fig. 5 of Section 2, and the program flow is shown in Fig. 17.

B. Estimate injection time and scan time

For patient P_j assigned to a bed, the program then performs *estimateEETime*(P_i) to estimate injection and scan time. The algorithm is shown in Fig. 6 of Section 2, and the program flow is shown in Fig. 18.

4. Discussion

In this section, we compare and analyze the experimental group and the control group, and discuss the results in four parts.

We first calculate the average time difference between the two groups at three start times (i.e. indwelling needle, injection, and scan) in 12 days to see if there is an error between the time calculated by the experimental group and the actual time of the control group (Table 3.) "Absolute value" and "Relative value" respectively represents "with" and "without" positive and negative values, and respectively stands for the average value of the "absolute value" and "relative value" of each experimental group time minus the control group time on a certain day. We also explored whether the estimated time by using the proposed automatic scheduling method can be faster than the original manual scheduling time, and what the proportion of time earlier is. (That is, how many patients benefit from this.) "Ahead rate" represents the proportion that the estimated times of the experimental group is earlier than the actual times of the control group.

We then analyze and discuss the proposed method in four parts.

(1) Analysis of indwelling needle time

The last update time for each patient is the time the previous patient entered the scan room. Comparing the final data with the actual data collected, the average time difference is about 2.94 minutes. (Table 3) Maximum value (time early up) and minimum value (time late up) are 17 and -12 minutes, respectively. (Table 4)

TABLE 3. Time difference between the two groups and ahead rate (unit: min.)

Time difference	Indwelling needle			Injection			Scan		
	Absolute value	**Relative value**	**Ahead rate**	**Absolute value**	**Relative value**	**Ahead rate**	**Absolute value**	**Relative value**	**Ahead rate**
Day 1	4.17	-1.00	33%	4.91	-4.00	91%	7.00	0.25	18.2%
Day 2	3.62	-1.32	58%	6.50	-6.50	100%	5.33	-4.17	75%
Day 3	1.67	-0.92	33%	12.36	-12.36	100%	5.91	-0.43	64%
Day 4	4.73	-0.58	2%	4.20	-4.00	80%	9.20	1.20	30%
Day 5	1.67	-1.00	54%	14.91	-14.91	100%	8.73	-0.53	64%
Day 6	2.93	-1.32	53%	8.21	-8.21	100%	5.71	1.00	35.7%
Day 7	2.38	-0.92	50%	11.27	2.87	93%	12.33	1.01	13%
Day 8	1.88	-0.58	31%	5.20	-4.93	53%	3.93	2.33	33%
Day 9	2.71	-1.00	71%	5.77	-0.85	54%	7.85	0.78	0%
Day 10	2.79	-1.32	63%	7.31	-6.69	94%	7.50	-3.25	56%
Day 11	3.25	-0.92	62%	4.65	-4.48	78%	5.74	0.96	43%
Day 12	3.53	-0.58	57%	10.06	-9.61	89%	8.56	-6.11	72%
Average	2.94	-0.96	47%	7.95	**-6.14**	86%	7.32	-0.58	42%
Std. error	0.93	0.26	0.18	3.32	4.61	0.16	2.14	2.45	0.23

TABLE 4. Maximum and minimum time difference between the two groups (unit: min.)

	Indwelling needle	**Injection**	**Scan**
Maximum	17	23	33
Minimum	-12	-29	-25

(2) Analysis of injection and scan times

At the stage of estimating the injection, the time difference may be caused by that the pharmacy cycle time has a buffer time of plus or minus ten minutes and the radiologist manually calculating the estimated time. According to our observations at the scene, the radiologist had only grasped the approximate time during the manual calculation, resulting in extra time between the end of the injection by the previous patient and the time when the next patient started the injection. In addition, when each time the indwelling needle ends, the nurse must call the pharmacy to ask the pharmacist to give the medicine, and the radiologist must wait for the pharmacist to give the medicine before injecting the patient. These actions will take up the time of the patient inspection process. However, the method proposed in this article can remove the above problems. If the medical staff performs the inspection process based on the estimated time calculated by the APP, the injection process can be advanced 6.14 minutes in average. (Table 3)

During the estimated scanning stage, the radiologist will try to let the patient scan five to ten minutes in advance. However, the proposed algorithm is designed according to the standard pharmaceutical cycle time, allowing the radiologist to adjust the scan according to the standard time. As a result, the high time difference (Table 4) and low ahead rate is caused (Table 3.)

Besides, the reason the standard deviation is larger during the injection phase and the photographic phase that the indwelling needle phase is that some machines were idle for less than the average imaging time of the patient, but some radiologists still arranged the patient to the gap to reduce the idle time of the imaging equipment. In addition to causing the time difference, it also makes it very compact for the patients who need to be scanned again in the future.

In addition to the above-mentioned causes of time differences in injection and scan phases, unexpected situations sometimes occur on the scene, and the delay of the process is also one of the reasons for the time differences.

(3) Analysis of allocating beds

Because bed-ridden patients require larger space, some require special equipment, and the types of uptake rooms vary, if the general patients occupy the uptake room of the bedridden patient, it will lead to prolonged waiting time of the bedridden patient. The proposed weight allocation method (Table2) (i.e. using $b()$ function) can shorten the average waiting time from indwelling needle to injection by

3.29 minutes (Table 5), save 40.35% of patient waiting time, and effectively solve this problem.

(4) Overall improvement

After analysis, the proportion of patients with a time difference of less than ten minutes reaches 68%, indicating that about 70% of the number is close to the actual situation, achieving high accuracy. In addition, 82% of the patients had an average reduction of 6.14 minutes (based on the estimated injection time), which verified the high efficiency of the proposed system.

TABLE 5. Average waiting time from indwelling needle to injection

	(1) Without *b*()	(2) With *b*()
Day 1	6 min.	2 min.
Day 2	18 min.	16 min.
Day 3	3 min.	1 min.
Day 4	10 min.	6 min.
Day 5	14 min.	7 min.
Day 6	1 min.	1 min.
Day 7	5 min.	1 min.
Average	8.14 min.	4.86 min.

TABLE 6. Comparison with proposed and previous works

	[5]	[9]	[12]	proposed
(1) Real-time automatic scheduling			v	v
(2) Scheduling for different medicines	v			v
(3) Dynamic update of prediction time		v	v	v
(4) Providing predictive inspection time immediately		v		v
(5) Automatic allocation of general and specific beds			v	v
(6) Automatic detection of all patients' tasks periods				v
(7) Automatic detection and prediction of examination room conditions				v
(8) Instant re-scheduling				v

5. Comparison

This section analyses and compares the properties including the eight requirements in definition 1 and other features. Table 6 summarizes the comparison of the properties for the proposed system and those schemes proposed by Xiao et al. [5], Tantitharanukul and Throngjai [9], and Luscombe and Kozan [12], and Table 7 displays those for the proposed automatic scheduling system and the current manual scheduling system.

5.1. Comparison with proposed and previous works

Based on the system requirements proposed in Definition 1, we compare our method with previous works (Table 6).

5.2. Comparison with proposed and current scheduling system

We functionally compare the current manual system with the proposed automatic system (Table 7). Our system has four automatic functions to solve the problem of smooth processes. We also compared the two systems in "the time required" for medical staff or patients to process each task. The details are as follows.

A. **Scheduling of patient examination order:** Scheduling: The system automatically orders the order of patient examinations, eliminating the need for radiologists to manually order.

B. **Scheduling of each inspection time:** The system calculates the best patient examination time for different drug cycle times, and the radiologist does not need to calculate it manually.

C. **Patient interrupts MS workflow by asking questions about examination time:** The system calculates the estimated time of each inspection task and announces it to medical staff and patients, reducing the number of times when medical staff is interrupted by patients' inquiry.

TABLE 7. Comparison with proposed and current scheduling system (unit: second)

	Tasks	Current system	Proposed system
Medical staff	A. Order scheduling	Manual scheduling (10s)	APP automatic scheduling (0s)
	B. Inspection time scheduling	Manual calculation (60s)	APP automatic calculation (1s)
	C. Being interrupted	MS was interrupted due to patients inquiry times (30s)	MS was not interrupted because patients watched the screen by themselves (0s)
	D. Dispensing reminder	MS calls pharmacist (30s)	Pharmacist checks the APP device (0s)
	E. Patient estimated time reminder	MS pay attention to patient examination time (anytime)	MS waits for APP notification (0s)
Patient (family)	F. Time inquiry	Manually inquiry MS (30s)	View announcements (5s)

D. **Dispensing reminder:** The pharmacist checks the APP's patient injection status to dispense medicine, eliminating the need for MS to call and let the pharmacist dispense medicine.

E. **Patient estimated time reminder:** The system sends a reminder message when the estimated time for each patient task is approaching.

F. **Patient and family inquiries:** Patients and family members can check the examination time by themselves, reducing the number of inquiries.

6. CONCLUSION

Due to the limited equipment resources and cycle time of PET, it is not an easy task for medical staff to calculate time and allocate resources on their own. This paper proposes a method for real-time estimation and scheduling of multi-resource allocation and pharmacy limitation, combined with Beacon to automatically detect patient entry and exit, and effectively control the inspection process. The results showed that the time difference between the experimental group and the control group was about 2.94 minutes, 7.95 minutes, and 7.32 minutes in the indwelling needle phase, the injection phase, and the scanning phase, respectively. Moreover, the proportion of patients with a time difference of less than ten minutes reaches 68%, indicating that most number is close to the actual situation, achieving high accuracy. In addition, 82% of the patients had an average reduction of 6.14 minutes, verifying the high efficiency of the proposed system. Therefore, the proposed system not only reduces the work of medical staff, but also provides patients and their families with credible estimates of time.

Future research will focus on more detailed data analysis to improve the accuracy of estimated time. In addition, some patients will not only have a PET examination on this day, there will be other radiological procedures to be performed. The radiologist must consider these conditions together to schedule. Future studies can consider combining the scheduling of other radiology departments to make the entire radiological diagnosis process easier and smoother.

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Not applicable.

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Authors' Contributions

Lin designed the study. Chiou performed the scheduling and statistical analysis, wrote the manuscript, and built the figures and tables. Dong collected the clinical data, and helped to design the study and write the manuscript. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Approval to collect data for our study was validated by Chang Gung Medical Foundation Institutional Review Board , with registration no. 201801251B1, and patients' consent to use anonymised data for research purposes was sought on an opt-out basis.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author upon request.

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Figures

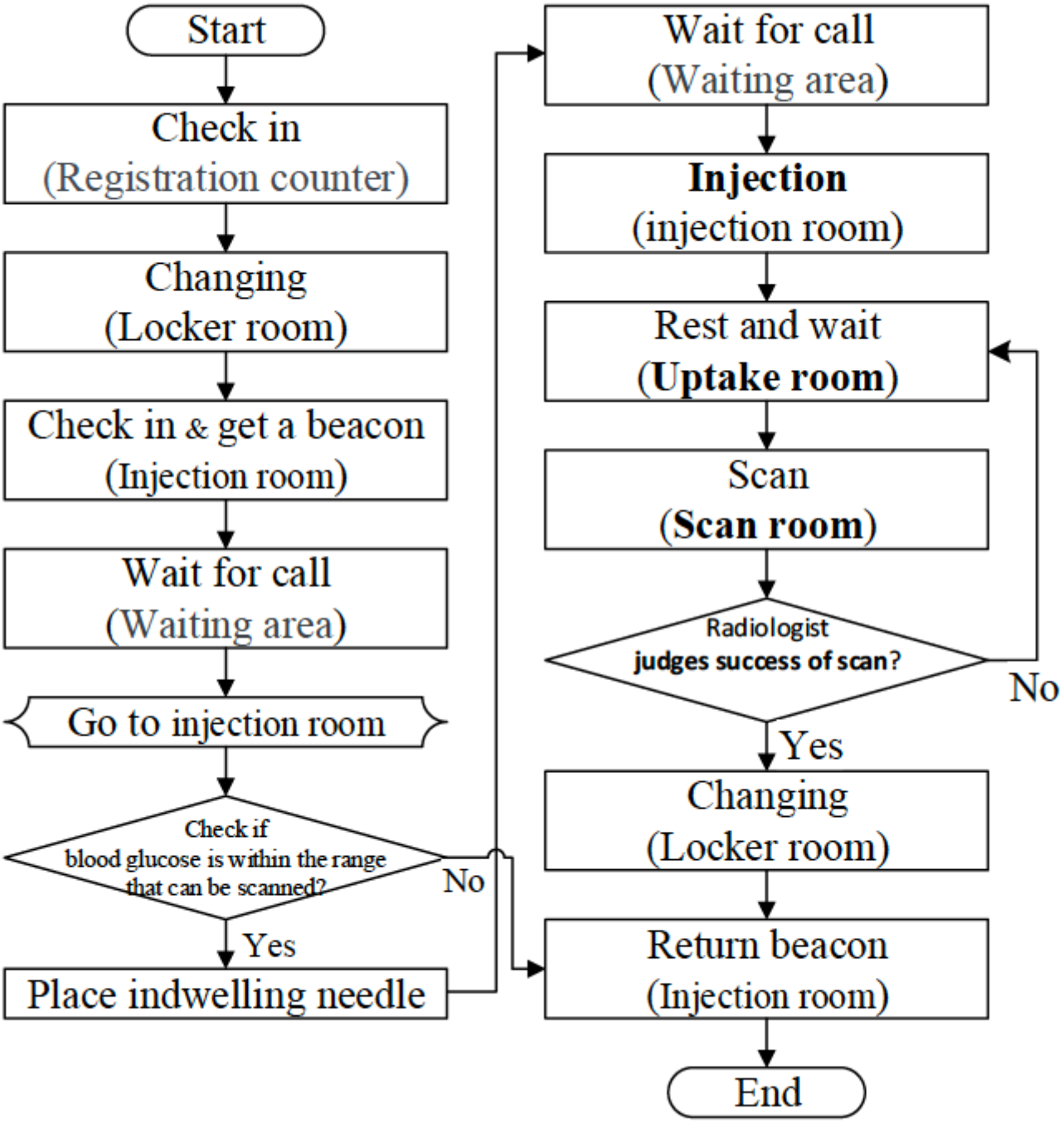


Figure 1

PET Patient examination process.

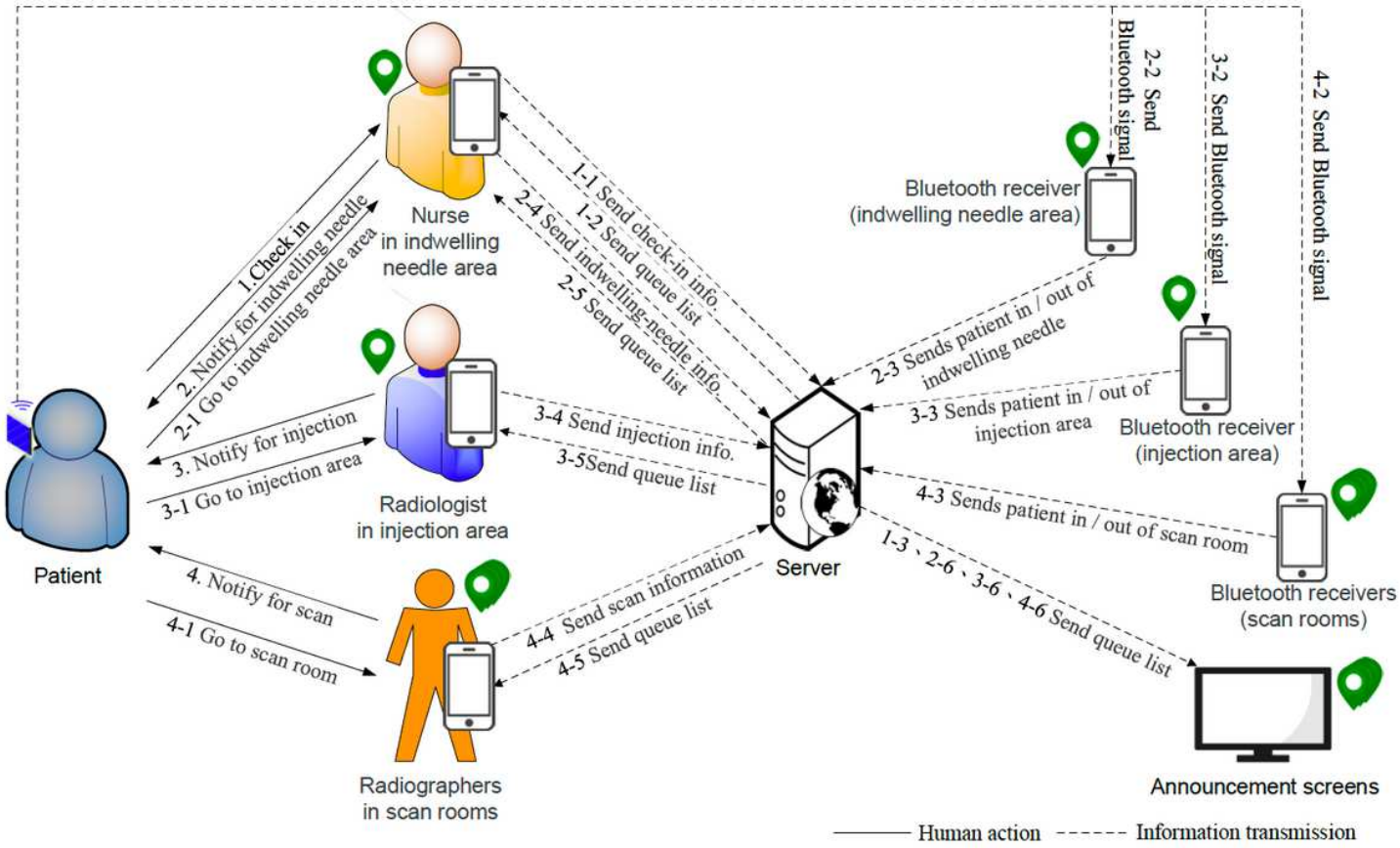


Figure 2

Schematic of automatic scheduling system.

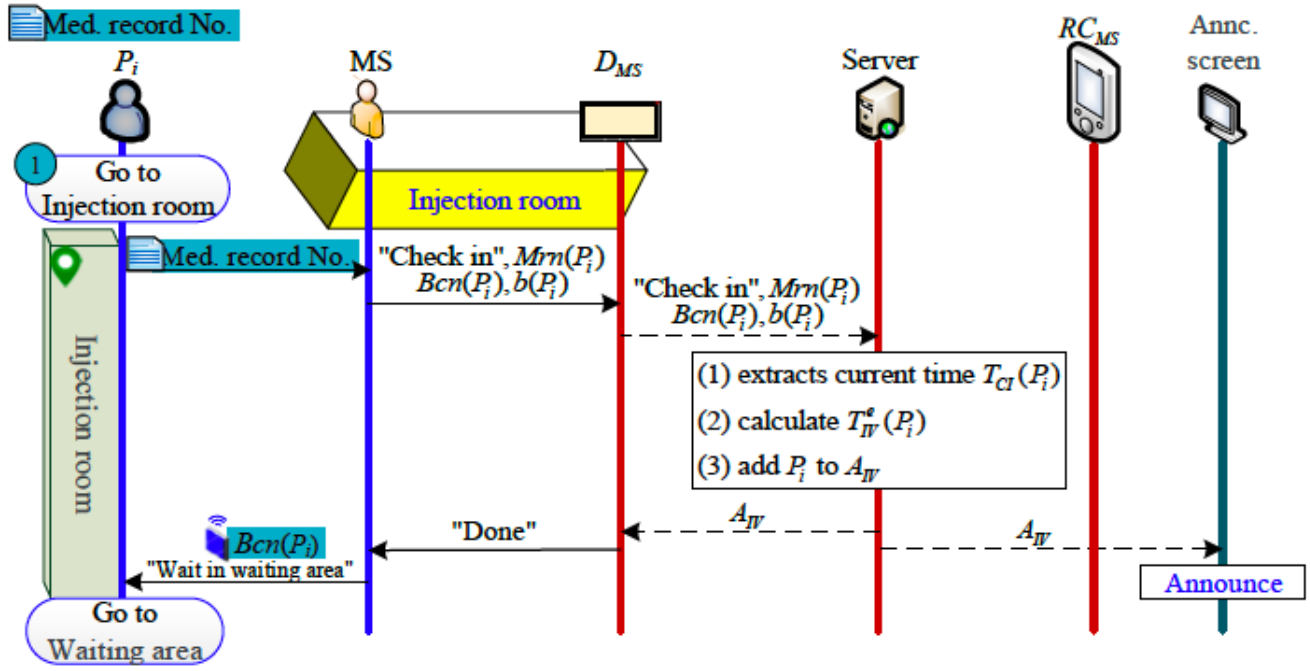


Figure 3

Check-in process.

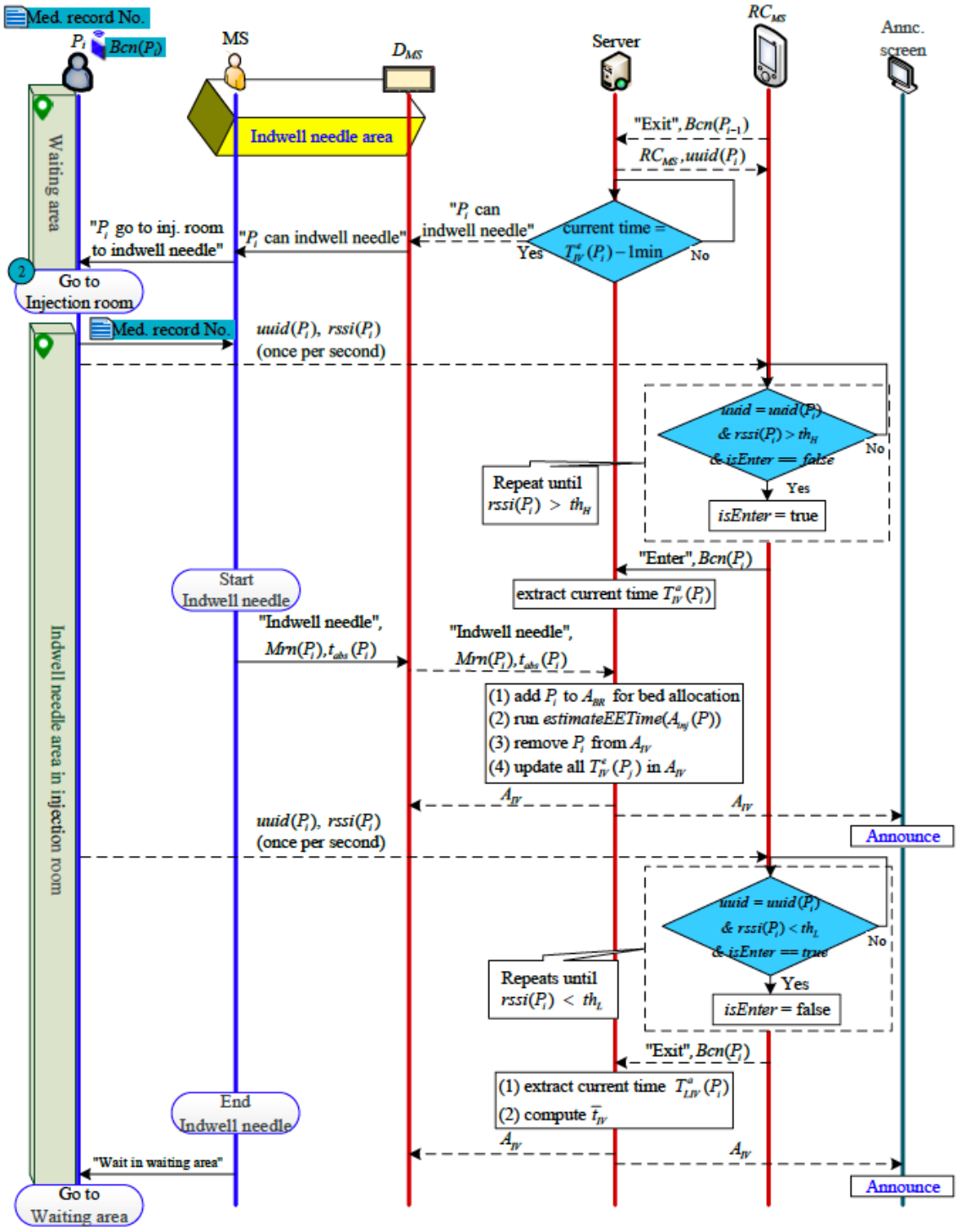


Figure 4

Indwelling needle process.

$assignBed(P_i)$
input : P_i
output : $Bed(P_i)$
allocate each Bed's ratio
$Bed(P_i) = Bed_{\bar{j}}$,
where $Bed_{\bar{j}}.ratio = \max\{Bed_j.ratio \mid Bed_j.isOccupied = false\}$
$T_{BA}(P_i) =$ current time
$A_{inj} = A_{inj}.add(P_i)$
$A_{BR} = A_{BR}.remove(P_i)$
$Bed_j.isOccupied = true$

Figure 5

Bed allocation algorithm.

$estimateEETime(P_i)$

input : P_i

output : $R(P_i), T^e_{EE}(P_i), T^e_{LE}(P_i), T^e_{inj}(P_i)$

(1) foreach R_k ,get $T_{ES}(P_i \mid R_k)$ as follows.

Let $T_{ES}(P_i) = T_{EI}(P_i) + \bar{t}_{inj} + t_{abs}(P_i)$

if $(T_{ES}(P_i) \geq T^e_{LE}(A_{R_k}(-1)))$

return $T_{ES}(P_i \mid R_k) = T_{ES}(P_i)$

else (i.e. $T_{ES}(P_i) < T^e_{LE}(A_{R_k}(-1))$)

foreach α such that $(T^e_{EE}(A_{R_k}(\alpha)) \geq T_{ES}(P_i))$

if $(T^e_{EE}(A_{R_k}(\alpha)) - T^e_{LE}(A_{R_k}(\alpha-1)) \geq \bar{t}_{ex}) \,\&\, \&(T^e_{EE}(A_{R_k}(\alpha)) - T_{ES}(P_i)) \geq \bar{t}_{ex})$

return $T_{ES}(P_i \mid R_k) = \max(T^e_{LE}(A_{R_k}(\alpha-1)), T_{ES}(P_i))$

endfor

return $T_{ES}(P_i \mid R_k) = T^e_{LE}(A_{R_k}(-1))$

(2) $T^e_{EE}(P_i) = \min_{k \in N}\{T_{ES}(P_i \mid R_k)\}$

(3) $R(P_i) = R_{\bar{k}}$ such that $T_{ES}(P_i \mid R_{\bar{k}}) = T^e_{EE}(P_i)$

(4) $T^e_{inj}(P_i) = T^e_{EE}(P_i) - t_{abs}(P_i) - \bar{t}_{inj}$

(5) $T^e_{LE}(P_i) = T^e_{EE}(P_i) + \bar{t}_{ex}$

(6) $A_{R_{\bar{k}}}.add(P_i)$ where $R_{\bar{k}} = R(P_i)$

Figure 6

Algorithm for estimating examination-process time.

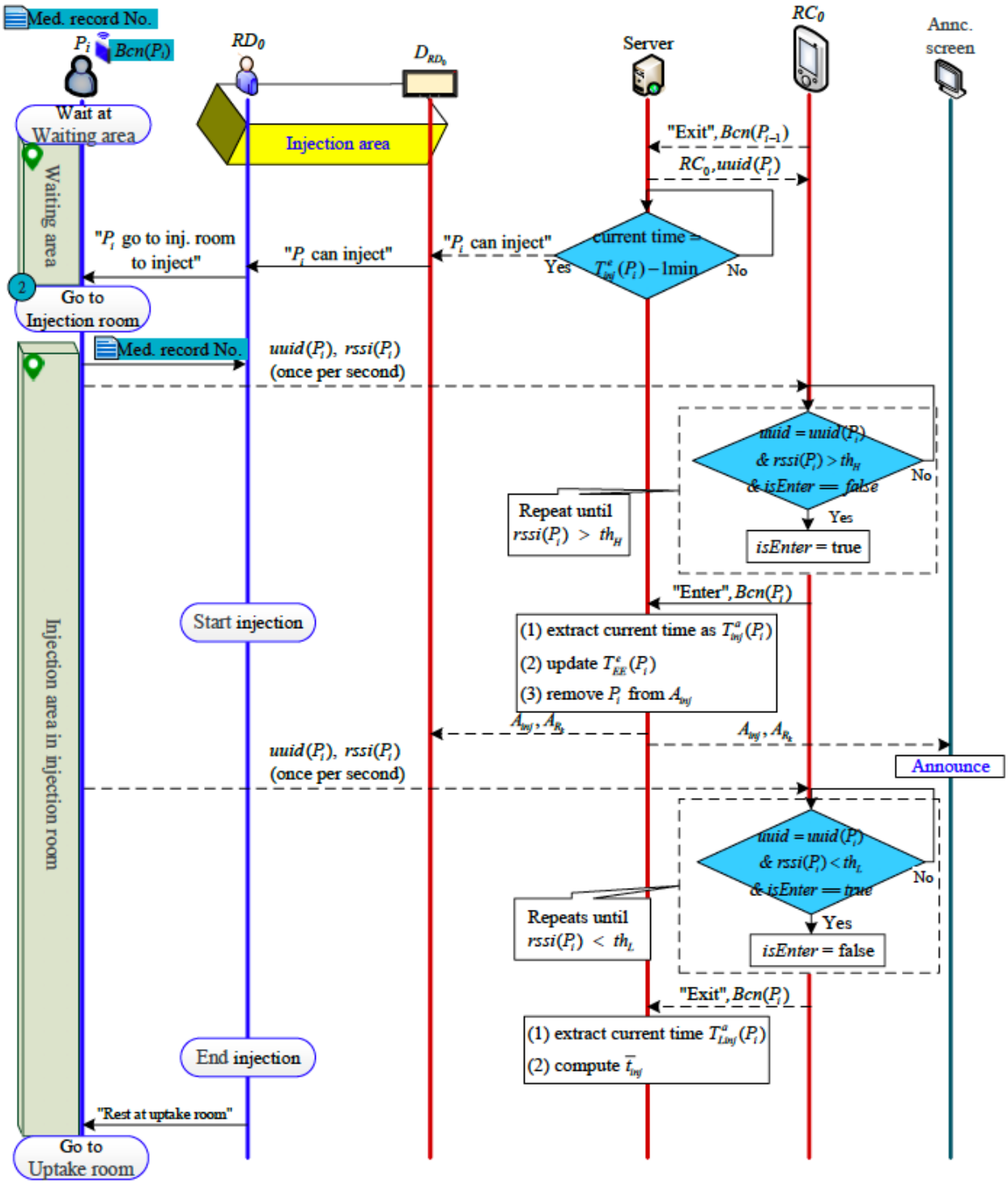


Figure 7

Injection process.

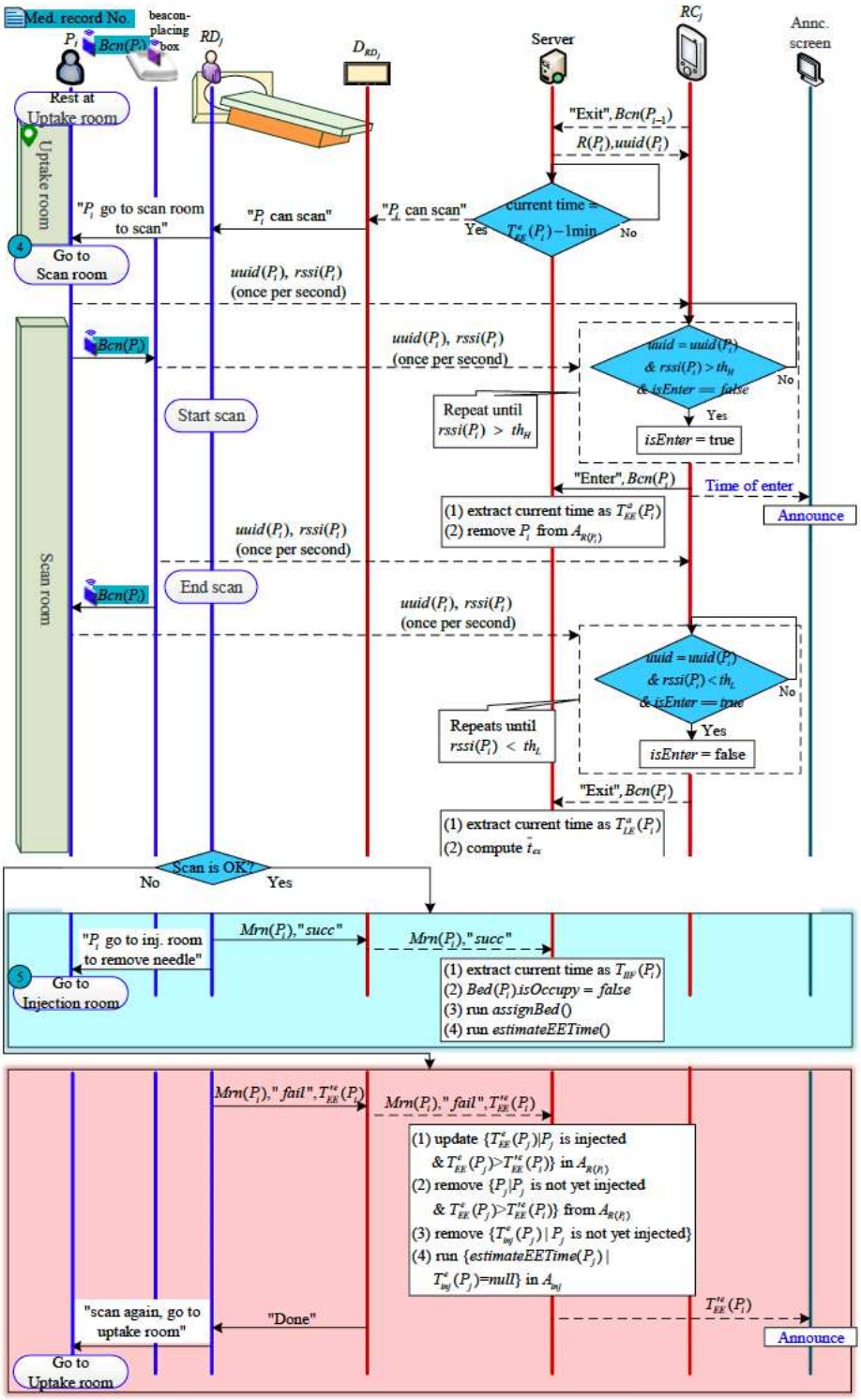


Figure 8

Examination process.

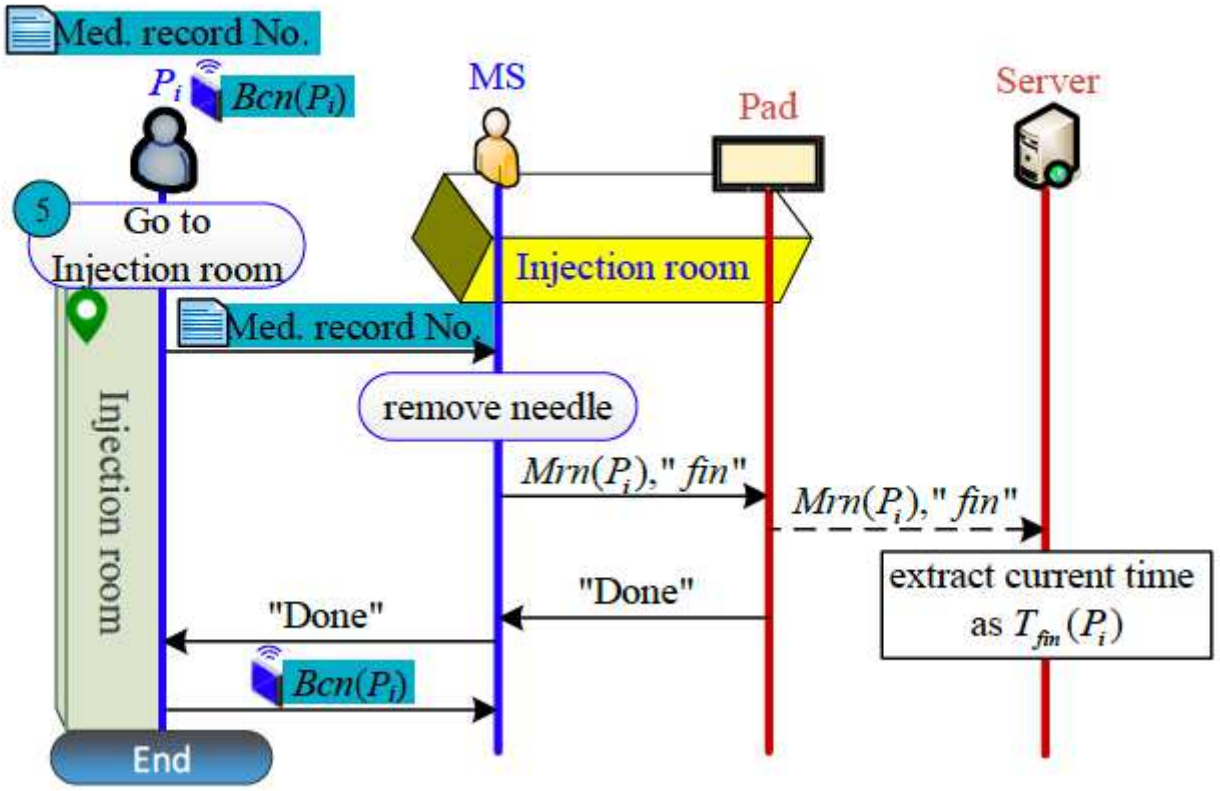


Figure 9

End examination process.

```
judgeEnterExit(R_k, P_i, uuid(P_i))
input : R_k, P_i, uuid(P_i)
output : "P_i Enter" or "P_i Exit"
initialize : isEnter = false, uuid = null, num = 0;
Get (R(P_i), uuid(P_i)) from server;
if (receiver(R_k) ∉ R(P_i))
  break;
time t = current time;
do {
  t+ = 1 second;
  scanning each beacon Bcn_j;
  if (uuid(Bcn_j) == uuid(P_i)){
    if ((isEnter == false) & (rssi(Bcn_j) > th_H)) {
      num++;
      if (num ≥ 5) {
        isEnter = true;
        num = 0;
        return "P_i Enter";
      }
    }
    else if ((isEnter == true) & (rssi(Bcn_j) < th_L)){
      num++;
      if (num ≥ 5) {
        isEnter = false;
        num = 0;
        return "P_i Exit";
      }
    }
    else
        num=0;
  }
} while ( t <= current time);
```

Figure 10

Algorithm to determine Beacon's entering / leaving from a certain area.

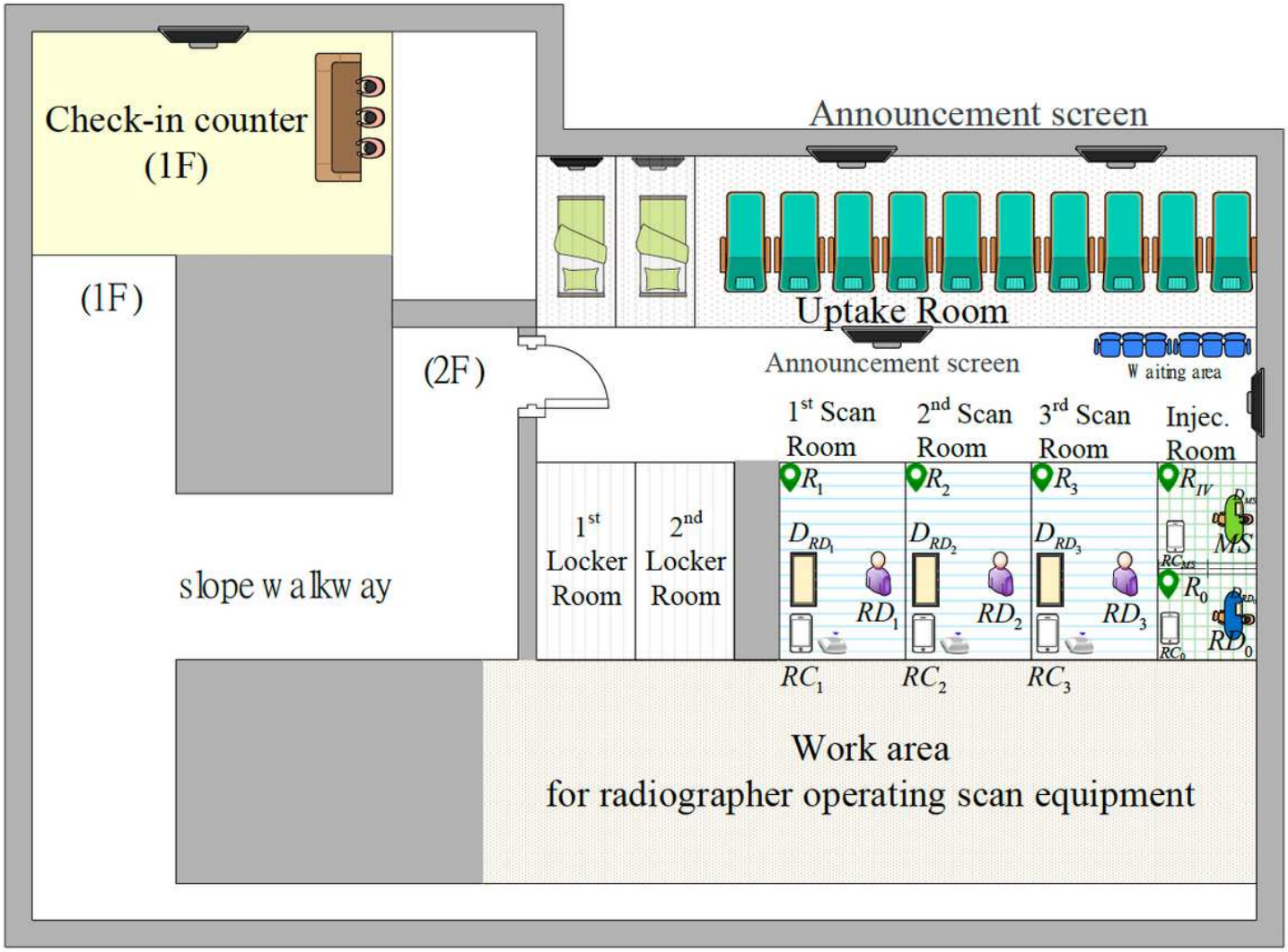


Figure 11

PET outpatient area layout of Linkou Chang Gung Hospital.



Figure 12

Operation screen of patient check-in phase.

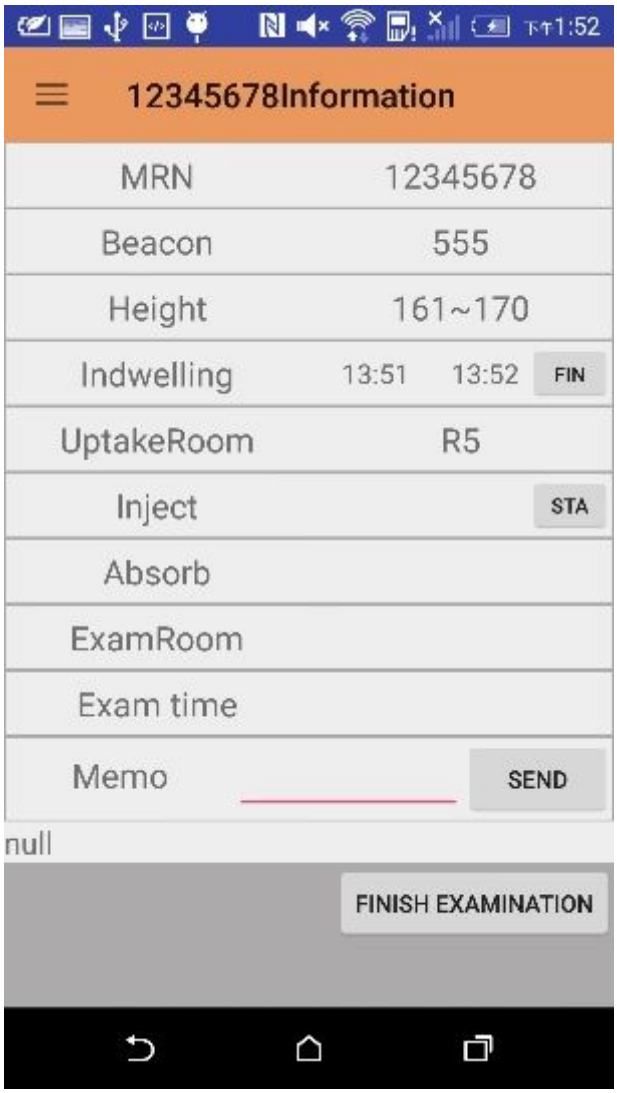


Figure 13

Interface for indwelling needle and injection phase.

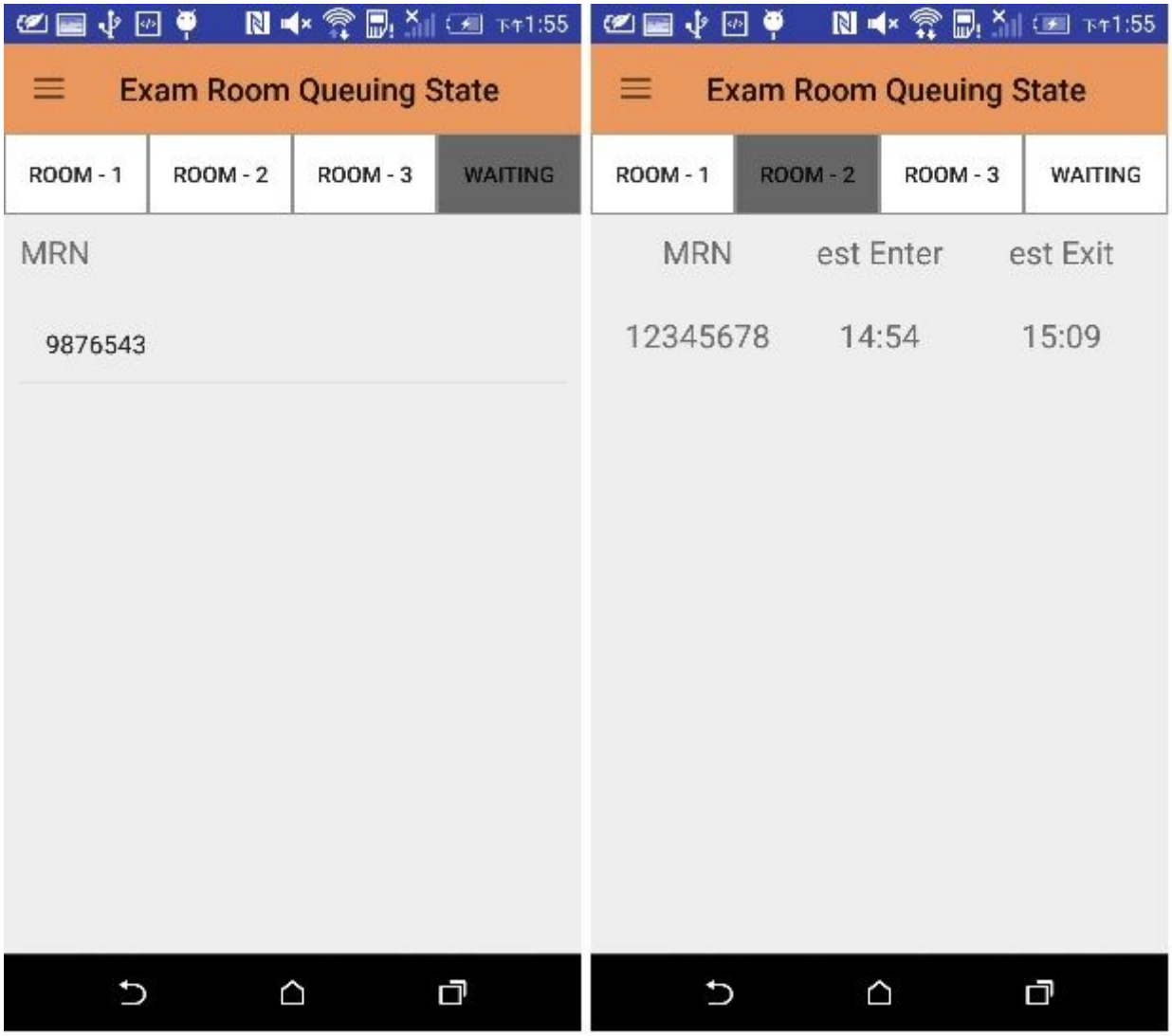


Figure 14

Waiting list for scan rooms and patient queues for each scan room.



Figure 15

Total queue list interface.

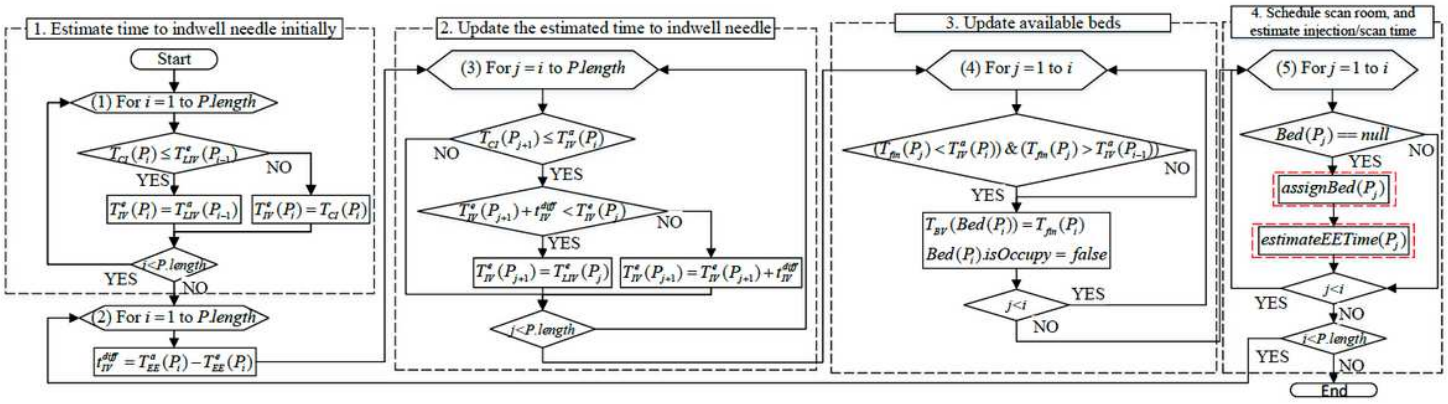


Figure 16

Experimental group data output flow chart.

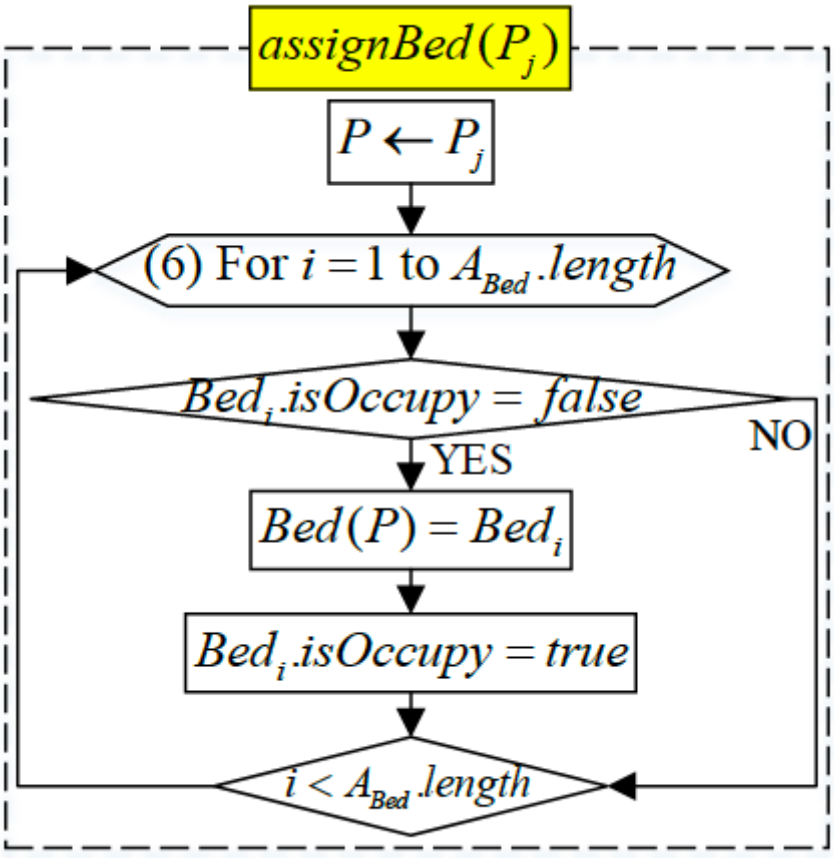


Figure 17

Flow chart for arranging beds.

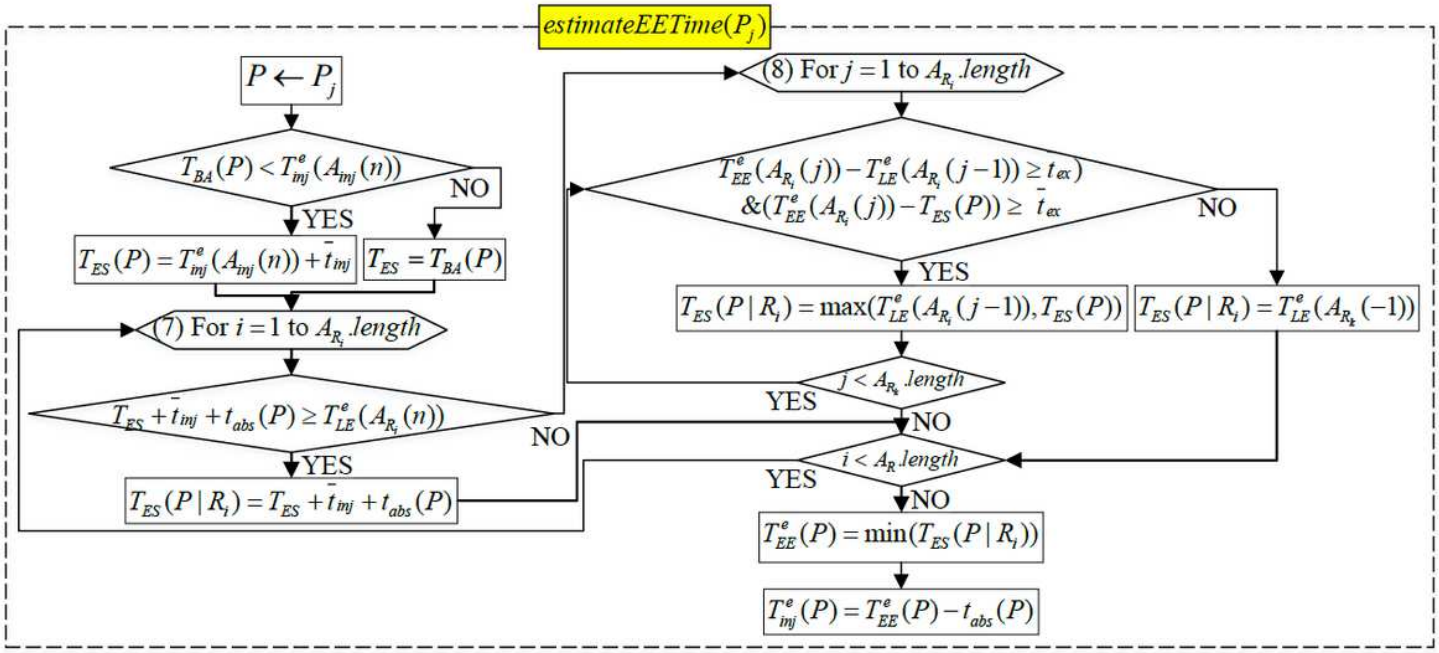


Figure 18

Flow chart of estimating injection time and scan time.