Computed Tomography Process Modelling using Integrated Data in Healthcare: Model Development and Simulation

Dr Premaratne Samaranayake

School of Business, University of Western Sydney, Sydney, Australia

Email: P.Samaranayake@uws.edu.au

Dr Kathryn J Hayes

School of Business, University of Western Sydney, Sydney, Australia

Email: kate.hayes@uws.edu.au

Dr Ann Dadich

School of Business, University of Western Sydney, Sydney, Australia

Email: a.dadich@uws.edu.au

Associate Professor Terry Sloan

School of Business, University of Western Sydney, Sydney, Australia

Email: t.sloan@uws.edu.au

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ABSTRACT

This paper demonstrates a holistic business process reengineering framework. Processes and data are integrated with patient journey modelling and mathematical simulation to support flexible patient scheduling and planning of healthcare operations and logistics to improve patient-flow. The framework is demonstrated through application to computed tomography (CT) services in a hospital. Mathematical modelling and simulation precisely reveal the impact of booking and rebooking on departmental performance. This innovative framework has potential value for other services, within and beyond hospital and healthcare settings.

Keywords: Change management, healthcare innovation, process innovation, technology innovation, service industries

INTRODUCTION

Although many business process re-engineering (BPR) projects seem to provide streamlined business processes through waste elimination, simplification, integration and automation (the four basic principles of BPR Peppard and Rowland, 1995), methods and tools adapted in BPR projects have not been fully exploited to maximise outcomes Clegg (2006) proposes a holonic modeling approach based on the application of systems thinking to designing, managing and improving business processes, while Samaranayake (2009) proposes an enhancement to the Event-driven Process Chain (EPC) methodology of business process modeling to enhance process integration and automation. In this research, the BPR innovation approach is based on improvements in business process modeling for identifying waste in current practices, as well as integrating data structures and document/ information flow for process simplification and integration. It is expected that when re-engineered processes are implemented in a system environment, they are highly integrated not only with data, organizational units and functions associated with the process but also with document and information flow. In this paper BPR innovation is considered as an extension of BPR principles from innovation perspective.

In many Western nations, health services are under increasing pressure to 'do more with less' (Bredenhoff et al., 2010, Fitzgerald et al., 2010).

The limited capacity of health services to meet public health needs can be costly. These costs are evident at the personal, social, organisational, and economic levels. At a personal level, patients are waiting longer to access health services, particularly emergency services (Bureau of Health

Information, 2011), and they are waiting longer to experience improved wellbeing (Rowe et al., 2006); this in turn can strain family and carers (Bishop, 2010), thus implicating social costs (Hill et al., 2011). Organisational costs include increased medical errors (Rowe et al., 2006) and clinician-stress (Bond et al., 2007). Related to these are economic costs, including increased service costs (Huang et al., 2010) as well as costs to recruit and retain staff (Rowe et al., 2006).

The oft-cited inefficiencies of health services have given rise to innovative approaches, which are often the domain of operations management. Lean thinking (Graban, 2009, Ben-Tovim et al., 2008), business process modelling (Kolker, 2008), and BPR (Locock, 2003, Buchanan and Wilson, 1996) have all endeavoured to help improve patient-flow through health service while optimising resource efficiencies. This might partly be explained by government recognition of the importance of patient-flow (NSW Health, nd, NHS Institute, 2008, Wilson et al., 2005) and the potential of these novel approaches (Jones and Mitchell, 2006, NSW Health, 2005).

Guided by BPR principles (Peppard and Rowland, 1995), this paper presents an innovative approach to optimise patient journey. The hospital providing the context for this study is in the early stages of adopting Lean thinking and process re-design (Fitzgerald, Eljiz, Dadich, Sloan, & Hayes, 2011). It is a major metropolitan hospital and a teaching campus for the local university. Although it has less than 500 beds, it had over 55,000 ED presentations in the 2011 calendar year, of which over 14,000 patients were admitted to the hospital. Using computed tomography (CT) services in a hospital as an exemplar, this paper reveals how the inputs, outputs, and control parameters associated with patient bookings and rebookings can be mapped, mathematically modelled, and simulated. However, CT booking and rebooking processes occurred within the broader CT examination process and influenced average times in the CT room and the imaging department – this in turn influenced adjoining departments (e.g., emergency) and patient-flow through the hospital.

The paper commences with a description of the role of CT within hospitals and a review of research on attempts to improve the efficiency and/or effectiveness of CT services. Following this, the framework premised on BPR principles is described and operationalized.

Computed Tomography Services

Since the development of CT in 1972, it has become ‘a permanent feature of medical diagnostics’ (Taner et al., 2012, p. 274), contributing to both the prevention and management of health issues. CT use has increased in recent years (Broder and Warshauer, 2006, Brenner and Hall, 2007, Toms et al., 2001). An examination of national trends within EDs in the United Stated demonstrated a 330 percent increase, from 1996 to 2007 (Kocher et al., 2011). Similarly, another study reported a six-fold increase from 1995 to 2007, which was largely attributed to the increased frequency of CT scanning, rather than increased visits to the ED alone; furthermore, there was no evidence that the increased use of CT was tapering (Larson et al., 2011).

The rise in CT use has not always been matched with a rise in efficient or effective service delivery. Despite technological advancements that have greatly improved diagnostic imaging, the orchestration of equipment, personnel – within and beyond imaging departments, information technology (IT), and patients has not kept pace (Taner et al., 2012). For instance, following their examination of hospital radiology departments, Joffe and colleagues (2007) revealed considerable inefficiencies.

Inefficient and/or ineffective hospital CT services represent a significant issue for patients, clinicians, managers, and health services (Joffe et al., 2007). For patients, delayed or inaccurate diagnoses impede access to appropriate and timely healthcare (Kohn et al., 2000, Evans et al., 2011). For clinicians, they denote potential causes for litigation (Pinto and Brunese, 2010). For managers, they can represent wasted resources (including equipment, technical and administrative resources, staff time, as well as funds) and missed opportunities for revenue-raising (Workman-Germann and Hagg, 2007, Joffe et al., 2007). Importantly, inefficient and/or ineffective CT service can create bottlenecks elsewhere, like EDs.

Regardless of how key drivers are defined, it would be naïve to assume no relationship between health services within and beyond the hospital setting. This is supported by a recent study that found a reduced length of hospital stay for patients requiring CT scans following the introduction of technology to improve clinician access to radiology reports and images (Hurlen et al., 2010).

The implications associated with inefficient and/or ineffective hospital CT services might partly explain recent calls for significant reform. International and national bodies recognise that ‘Business as usual for health systems is not a viable option' (WHO, 2008, p. xiv) and 'careful management' (DHA, 2010, p. 26) is required. Sophisticated approaches are therefore required, particularly when 'working hours are fixed and overtime pay is high' (Peltokorpi et al., 2008, p. 70).

To improve the delivery of efficient and effective CT, researchers have peered over the disciplinary fence and borrowed approaches often found within operations management. These includes lean / six sigma methodologies (Workman-Germann and Hagg, 2007, Lodge and Bamford, 2008), simulation modelling to evaluate what-if scenarios (Ramakrishnan et al., 2004), as well as Markov chain models (Wang et al., 2012).

Business Process Reengineering

Despite the potential value of BPR and streamlined processes within health services (Walley, 2007, Bertolini et al., 2011), implementing and testing change can be risky. In the absence of robust evidence, changing processes can needlessly reduce the availability of limited resources, including staff time and the budget; it can also endanger the quality of patient care (Chahed et al., 2011). This might partly explain interest in computer simulation (Siassiakos et al., 2008, Jun et al., 2011).

Simulation is an interactive technique to determine the potential value of reconfigured processes devoid of risk (Siassiakos et al., 2008). Through opportunuties to reproduce and trial different processes, it supports superior operational decision making and planning; these in turn can improve patient care, boost patient satisfaction, and reduce costs (Fialho et al., 2011). Furthermore, when aided by technology, it is possible to capture the complexity of health services and rigorously deduce the consequences of change (Ravn and Petersen, 2007, Fitzgerald and Dadich, 2009).

METHODOLOGY

A holistic approach that brings together processes, data, and patient journey in healthcare service operations into one platform was developed, based on process models using the EPC methodology (Samaranayake, 2009), as well as patient and data models using unitary structuring technique (Woxvold, 1992). Within the context of CT services, the methodology involved:

- Developing a holistic framework of process, data, and patient journey
- Mapping and modelling health service processes
- Modelling the patient journey with associated data elements

- The mathematical modelling and simulation of the patient journey

Holistic Framework

A holistic framework of process, data, and patient journey was developed using a typical scenario from the imaging department (see Figure 1). The broader CT process is initiated by booking, altered by rebooking, and involves a number of sub-processes until the patient leaves the imaging department. Since these processes revolve around the patient journey with various data and organisational units, each element of the framework can be represented by respective models with appropriate connection to the patient journey (Samaranayake and Kiridena, 2011). Furthermore, all individual models associated with this framework can be linked through the associated planning and scheduling methodology and patient-flow routes. In this case, health service processes associated with the selected case can be modelled using EPC methodology, along with data models for planning and scheduling logistics in health service operations (Samaranayake et al., 2010). Additionally, the patient journey is modelled using the unitary structuring technique as the basis for the numerical simulation of patient-flow.

[Insert Figure 1 here]

The CT process is supported by key data and organisational units and is delivered through functional applications in a system environment. For example, as part of overall CT process, CT examination takes input data such as patient history and CT requirements through back office IT systems, and is conducted by designated clinical staff using CT machines, procedures, and diagnostic tests.

Appointment Bookings and Rebookings

Observations and interviews with staff in the imaging department revealed that the booking and rescheduling process is a core element of the overall imaging process for ultrasound and CT scans. Conversely, x-ray procedures are performed on a first-come-first-serve basis, and no prior booking or rebooking is involved. When emergency patients were brought to the imaging department from the adjacent ED requiring urgent assessment, clinical priorities changed, resulting in frequent patient rebookings and reassignment of resources. The overall process of CT examination is illustrated in Figure 2.

[Insert Figure 2 here]

Since the booking and rescheduling process involves several functions and events, it was mapped separately, using EPC methodology (Figure 3). Data suggest that rescheduling changed the times not just for one patient, but for many patients scheduled for CT scans during that day. However, it was not possible to identify which event(s) caused rescheduling for any particular prior appointment from hospital data as no history of changes to the original schedules was maintained. Here it is assumed that rescheduling was chiefly caused by emergency patients and occasionally by miscellaneous categories. Thus, CT examination records are categorised as rescheduled procedures if one of the following criteria is met: (1) Original booking is changed to a different time due to one of the reasons identified in the booking and rebooking process in Figure 2; (2) No prior booking or pre-booking exists and the request is received on the same day as the procedure; and (3) Any procedure is performed without a pre-booking or an appointment time.

[Insert Figure 3 here]

Although procedures performed without an appointment (the third criterion) do not seem to be directly counted as rescheduled procedures, it is assumed that they cause existing bookings to be rescheduled. Therefore, rescheduling as defined above is broader and covers both rebooked and unbooked emergency procedures. For the purpose of data analysis, each procedure is categorised as: (1) pre-booked procedures that occur as planned; or (2) other (not pre-booked) procedures.

In addition to investigating the impact of booking and rebooking on patient-time in the CT room, patient-time in the imaging department, and patient-flow through the imaging and EDs, the following queries were examined:

- How are rebookings captured and recorded by clerical or medical staff?
- Do current IT systems track changes to schedules?
- Will the proposed scheduling system (based on MS Outlook Calendar) track rescheduling?
- Does a time request of as-soon-as-possible reliably indicate a request from the ED?

The time-stamp measures and staff interviews suggest that not all rescheduled appointments were captured or recorded. The impact of booking and rebooking on CT appointments was investigated using a three-month dataset.

RESULTS

Appointment Bookings and Rebookings

To evaluate the impact of booking and rebooking on overall CT operations, five key variables are identified; namely: Time in CT room; Time in imaging department; Procedure type; Patient type and Mode of inpatient transport.

Based on the two groups of bookings (pre-booking and others), the following measures of key variables in the CT examination process (namely, number of rebooked procedures; patient-time in the imaging department, and patient-time in the CT room) are evaluated: (1) Total percentage of pre-booked procedures; (2) Average patient-time in the imaging department (in minutes); and (3) Average patient-time in the CT room (in minutes).

[Insert Table 1 here]

Of the 624 complete CT scan records analysed, 247 (40%) were pre-booked procedures and 377 (60%) were other bookings, including bookings on the same day and rebookings (category 2). Interviews confirmed this significant rebooking and rescheduling was largely due to emergency requests with the ED the largest user of imaging services. Other users include inpatients and outpatients. To determine whether patient-time in the imaging department is significantly different from patient-time in the CT room – and, if so, the influence of rebooking on this difference - the following variables are considered in subsequent statistical tests: time in imaging department [X]; time in CT room [Y]; time in imaging department for pre-booked patients (category 1) [X1]; time in CT room for pre-booked patients (category 1) [Y1]; time in imaging department for patients not pre-booked (category 2) [X2]; and time in CT room for patients not pre-booked (category 2) [Y2].

Before testing whether rebooking has any significant impact on overall CT operations, it was necessary to test the significance of differences between patient-times within the imaging department and CT room. In this case, the mean times of X and Y (μX and μY) were tested using a *t*-test with 95% confidence levels, revealing that imaging department and CT room times differed significantly.

To test the impact of rebooking patient categories 1 and 2 on patient-times in the imaging department and CT room (including any booking on the day), the following hypotheses were proposed:

Hypothesis 1: There is a difference in the imaging department time between pre-booked and other patients

Null Hypothesis ($H1_0$): There is a significant difference in the imaging department time between pre-booked and other patients. [$H1_0$: $\mu X1 \neq \mu X2$]

Alternative hypothesis ($H1_1$): $\mu X1 = \mu X2$

Hypothesis 2: There is a difference in the CT room time between pre-booked and other patients

Null Hypothesis ($H2_0$): There is a significant difference in the CT room time between pre-booked and other patients. [$H2_0$: $\mu Y1 \neq \mu Y2$]

Alternative hypothesis ($H1_1$): $\mu Y1 = \mu Y2$

The two populations: (i) the difference between imaging department time and CT room time for normally booked patients; and (ii) the difference between imaging department time and CT room time for rebooked patients, are not normally distributed, but skewed to the left. As the sample size is larger than 30, it can be assumed that samples are true representation of the populations.

Testing Null Hypotheses using *t*-Tests

The means of imaging department times, between categories 1 (pre-booked) and 2 (other) are significantly different at the 95% confidence level; thus, the null hypothesis $H1_0$ is accepted and alternative hypothesis $H1_1$ is rejected. This means rescheduling impacts imaging department times between pre-booked and booked otherwise (all other bookings). It is evident from the mean times of the imaging department for categories 1 and 2 (36 mins and 24 mins) that pre-booked patients spend more time in the imaging department than those booked.

Similarly, the means of CT room times, between categories 1 and 2, are significantly different at 95% confidence level. Therefore, null hypothesis $H2_0$ is accepted and the alternative hypothesis $H2_1$ is rejected. In this case, the mean CT room times are 16 mins and 12 mins for pre-booked procedures and other bookings, respectively. Although the difference between CT room times is statistically significantly different, there is only a 4-minute difference. This suggests less variance of patient-times within the CT room between two categories and less impact of booking and rebooking on the CT examination. Thus, rescheduling impacts CT procedures, particularly imaging department times.

Mathematical Models and Simulation

The three functional areas of the imaging department – namely, sonography, CT, and x-ray, are now considered for mathematical modelling and simulating patient-flow. Process models of the CT functional area, using EPC methodology, form the basis for the mathematical models and simulation of patient-flow. Details of CT processes, including rescheduling, are depicted in Figures 1 and 2.

Illustrated in the process models (Figures 2, 3, and 4) are the key variables and parameters involved in each function. Variables associated with booking, rebooking, time-stamp measures, and time calculations associated with key events are considered for mathematical models first. Next, those variables and their values (based on collected data) are used to simulate patient-flow. Once mathematical models for CT processes are developed, they can be linked with models for sonography and x-ray processes to form a complete model of the imaging department. In this case, a process model of x-ray can be used (see Figure 4).

[Insert Figure 4 here]

Apart from the CT process model using EPC methodology and the mathematical models of patient-flow simulation, the patient journey associated with CT is modelled using unitary structuring technique (Woxvold, 1992, see Figure 5).

[Insert Figure 5 here]

The formalism adopted in the unitary structure (Woxvold, 1992) uses the icons M, A, R and S (outer line) to denote 4 data elements, as represented by the first letter of the words Material, Activity, Resource, and Supplier, respectively. In addition to original data elements of the unitary structure, the patient journey model depicted in Figure 5 incorporates Patient (represented by the letter P) at various points of the structure. The formalism also allows three forms of relationships between these data elements to be represented as follows:

- Vertical MRP bills of materials (parent-child relationships)
- Horizontal PAC operations routing (standard sequences)
- Arbitrary CPM activity network (precedence relationships)

Because the three techniques – MRP, PAC, and CRP – are merged into a single integrated structure, some of the functionalities of the individual techniques are not retained in their original form. For example, unlike with conventional MRP, materials had no intrinsic lead-time because timing data are incorporated into the corresponding activity data element within the unitary structure. Resources are associated with individual activities and represent human (labour) and machine categories required to execute the activity. Therefore, details of each unitary structure data element, including the scheduling paths (Samaranayake, 1998) required for planning and scheduling of components and patient journey simulation are presented in Table 2.

[Insert Table 2 here]

Numerical simulation of the patient journey model, as illustrated in Figure 5, can be performed using scheduling paths (the preceding and following sequences), the explosion of the structure for determining exploded material quantity, as well as activity durations. Exploded material quantities can be determined using the requirement of each material and the number of elective surgeries scheduled for the planning duration. Furthermore, the exploded quantity of each material (M1-M3) is based on BOM explosion, while exploded activity duration of each activity (A1-A9) is a combination of setup, labour, and machine times. In this case, the duration of each activity is estimated using average activity times over a period of time. For the simplicity of modelling the patient journey, it is assumed that there is only one resource unit per activity. Therefore, total resource requirements are the same as those for activity duration. The exploded activity duration can be calculated by:

$$Total\ \ Activity\ Duration = \left\{ \begin{array}{l} Setup + \left(\dfrac{Assembly\ Qty}{Base\ Qty} \right) * \\ Max\{ (Machine\ Time / Unit)\ or\ (Labour\ Time / Unit) \} \end{array} \right\}$$

In this case, the base quantity of any material is number of units required for one patient involved in the process. Material quantities and activity durations can be determined using the average times of each activity. Thus, the numerical simulation of the patient journey in the CT process, based on the planning and execution method developed earlier (Samaranayake and Toncich, 2007) is performed with the following data and input parameters:

- Working Monday to Friday between 09:00 hours and 17:00 hours, with no break
- A schedule of patients based on the averages determined earlier
- Activity times using the average times derived from 3 months of time-stamp data

- Assumption of 100% availability of all medical supplies before each activity

Assuming only one critical resource unit per activity, resource requirements for each activity are the same as those of activity duration.

Based on the scheduling paths (the preceding and following sequences) and the associated planning and scheduling algorithm (Samaranayake and Toncich, 2007) using integrated data structures, the patient journey model can be simulated. The numerical simulation suggests that each component of the structure can be planned and scheduled, with scheduled and start times for activities and operations, and finite loading of required resources. Additionally, the simulation reflects patient-flow with required materials (medical supplies, medication, drugs, etc.) as required by imaging processes in real-time, when implemented in a system environment, with links to the patient record system. In this case, the critical path of the patient journey is represented by a combination of materials, activities, and resources. Details of numerical simulation are not provided here since it is beyond the scope of this paper.

Based on the process models and the preliminary data analysis, the following variables are identified as key variables for the mathematical modelling and simulation of patient-flow in the CT department:

Procedure type; Procedure time; Travel time from the ward or ED to CT reception and CT room; Patient type; Number of CT rooms; Number of CT operators and Time in the imaging department

Depending on outcomes from the statistical analyses discussed earlier, it is possible that simulating patient-flow can be modelled with varying CT room and department times, comparing rebooked procedures to normally booked and performed procedures. Tables 3 to 5 summarise the descriptive statistics of the key variables, calculated using data hospital data collected March, 17 2009 to June, 15 2009.

[Insert Table 3 here]

[Insert Table 4 here]

[Insert Table 5 here]

Because the sample size of some of the aforesaid procedures is less than 30 – the minimum required for statistical analyses – these procedures (namely, XBC, XCAC, XNPC, XCA, XEX, and XL) are aggregated into the Miscellaneous category. The descriptive statistics for the Other category with all those procedures are tabulated below.

[Insert Table 6 here]

It should be noted that the total count of records used for descriptive statistics were well below the total procedures identified earlier, due to incomplete data on CT room times.

DISCUSSION

This paper has presented a holistic BPR framework of process and data integration with patient journey modelling and mathematical simulation to optimise efficiencies and effectiveness within a health service. The potential value of this framework was illustrated through application to hospital CT services. This involved:

1. Mapping the end-to-end CT service using EPC methodology, connecting the booking and rescheduling process and its associated functions and events with logical operators
2. Measuring the impact of rescheduling average patient-times in the CT room and total patient-times in the imaging department
3. Identifying key input and output variables as well as control parameters of time measures (including procedure time, department time, and travel time), procedure and patient type, as well as resources (for example, CT rooms and operators)
4. Evaluating the impact of rescheduling on overall operations by combining descriptive statistics of key variables with statistical data analysis

This process unveiled key issues and facilitated the mathematical and simulation modelling of patient-flow, within and beyond the imaging department. Specifically, CT times were found to be significantly greater for pre-booked patients who experienced longer total times on average. Further, although CT room times between pre-booked and other patients were significantly different, booking and rebooking had little impact on actual procedure times. As illustrated, emergency patients are experiencing shorter waiting times for CT scans, but this desirable state is potentially being achieved at the expense of scheduled patients. There will always be compromises between the need to accommodate emergency cases and efficient scheduling this paper illustrates a method of investigating the extent of these compromises and exploring ways to reduce the impact of rescheduling decisions.

Replication of the research at a site with historic data that explicitly identifies CT patients that necessitate rebooking and 'shuffling' of other patients scheduled that day will provide opportunities to quantify and ameliorate the impact of rebooking.

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Table 1: Descriptive Statistics of Imaging Department and CT Room Times

	Imaging Department	CT Room
Mean	28.8	13.5
Median	20.0	10.0
Mode	15.0	10.0
Standard Deviation	28.0	14.3
Minimum	3.0	2.0
Maximum	405.0	142.0
Number of Records	624.0	624.0

Table 2: Unitary Structure Components and Scheduling Paths

Sequence Number	Component Type & ID	Component Name	Preceding Sequence Number	Following Sequence Number
10	P (IP)	Inpatient	-	20
20	M (M1) / S (S1)	Medication/Drugs Pharmacy/Supplier	10	30
30	A (A1) / R (R1)	Preparing patient for transport Hospital Staff/Nurse	20	40
40	A (A2) / R (R2)	Patient transport from ward to ID Hospital staff / Bed / WC	30	50
50	P (IP)	Inpatient	40	70
60	P (OP)	Outpatient	-	70
70	M (M2) / S (S2)	Medical supplies for CT Pharmacy / Supplier	50, 60	80
80	A (A3) / R (R3)	Transport patient to CT CT Staff / Bed / WC	70	90
90	A (A4) / R (R4)	Preparing patient for CT CT Staff / CT Scanner	80	110
100	A (A5) / R (R5)	PR update and paper work Hospital staff	90	110
110	P (P)	Inpatient or Outpatient	90, 100	120
120	M (M3) / S (S3)	Medical supplies for CT Pharmacy / Supplier	110	130
130	A (A6) / R (R6)	CT examination CT Staff / CT Scanner	120	140
140	A (A7) / R (R7)	Reconstruction of images CT Staff	130	150
150	A (A8) / R (R8)	Analysing and report writing CT Staff	140	-
160	P (P)	Patient (inpatient or outpatient)	130	170
170	A (A9) / R (R9)	Discharge / Transport patient Nurse / ID Staff	160	-

Table 3: Casemix of CT Procedures

CT Procedure	Frequency	%
XB	765	42.69
XAPC	284	15.85
XSPA	155	8.65
XAP	97	5.41
XNPC	50	2.79
XCAC	47	2.62
XEX	35	1.95
XBC	37	2.06
XCA	26	1.45
XFNA	20	1.12
XL	19	1.06
Other	257	14.34
Total	1,792	100.00

Table 4: Mode of Internal Transport

Mode of Transport	Frequency	%
Bed	814	45.42
Wheelchair	259	14.45
Walk	56	3.13
No record	661	36.89
Other	2	0.12
Total	1,792	100.00

Table 5: Descriptive Statistics of CT Procedure Time (Y) by Individual Procedure (*n* = 685)

	CT Procedure: XB	CT Procedure: XAPC	CT Procedure: XSPA	CT Procedure: XAP	CT Procedure: XBC	CT Procedure: XCAC	CT Procedure: XNPC	CT Procedure: XCA	CT Procedure: XEX	CT Procedure: XL	CT Procedure: Miscell. (excl. XL)
Mean	10.81659	13.74214	16.81944	10.65909	12.7619	11.14286	12.1	18.53333	11.72727	10.72727	22.41558
SD	0.65465	0.793213	2.490304	1.800559	1.360855	1.165549	1.017996	6.313151	2.397313	1.440271	2.852093
Median	10	10	10.5	8	12	10	12	10	10	10	15
Mode	10	10	10	10	15	10	15	5	10	15	10
SD	9.906647	10.00203	21.13093	11.94356	6.236223	5.341214	4.552616	24.45073	7.950986	4.776838	25.02701
Sample Var.	98.14165	100.0407	446.5162	142.6485	38.89048	28.52857	20.72632	597.8381	63.21818	22.81818	626.3513
Kurtosis	17.17011	7.276273	18.98607	24.3261	2.102169	1.248811	-0.87161	5.006989	1.677443	-1.44539	9.386917
Skewness	3.648313	2.306274	4.193987	4.523813	1.238395	1.100499	0.184588	2.408764	1.27912	0.313876	2.909687
Range	70	63	127	76	25	22	15	83	27	13	137
Min	2	2	3	2	5	3	5	5	3	5	5
Max	72	65	130	78	30	25	20	88	30	18	142
Sum	2477	2185	1211	469	268	234	242	278	129	118	1726
Count	229	159	72	44	21	21	20	15	11	11	77

Table 6: Descriptive Statistics of Other CT Procedures including all Samples < 30

Mean	17.01705
SD	1.432292
Median	10
Mode	10
SD	19.0015
Sample Var.	361.0569
Kurtosis	17.71232
Skewness	3.863971
Range	139
Min	3
Max	142
Sum	2995
Count	176

Figure 1: Framework of Process, Data and Patient Journey

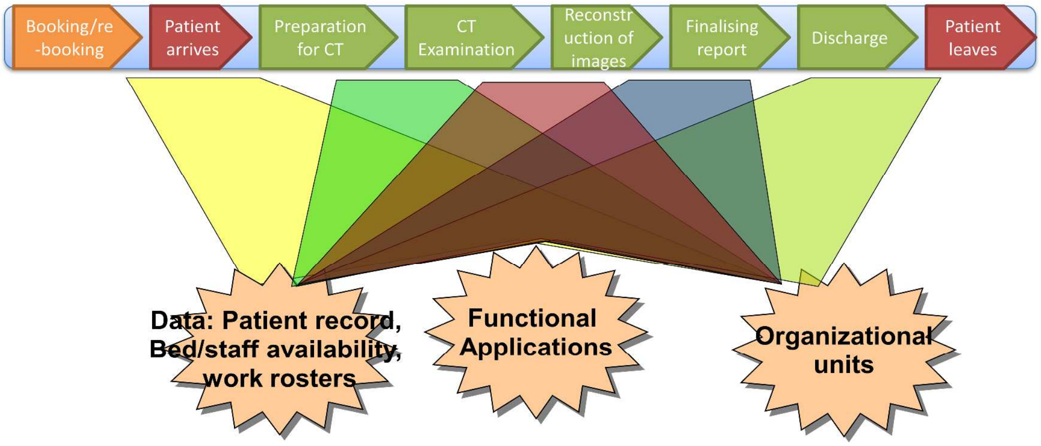

Figure 2: CT Examination Process in the Imaging Department

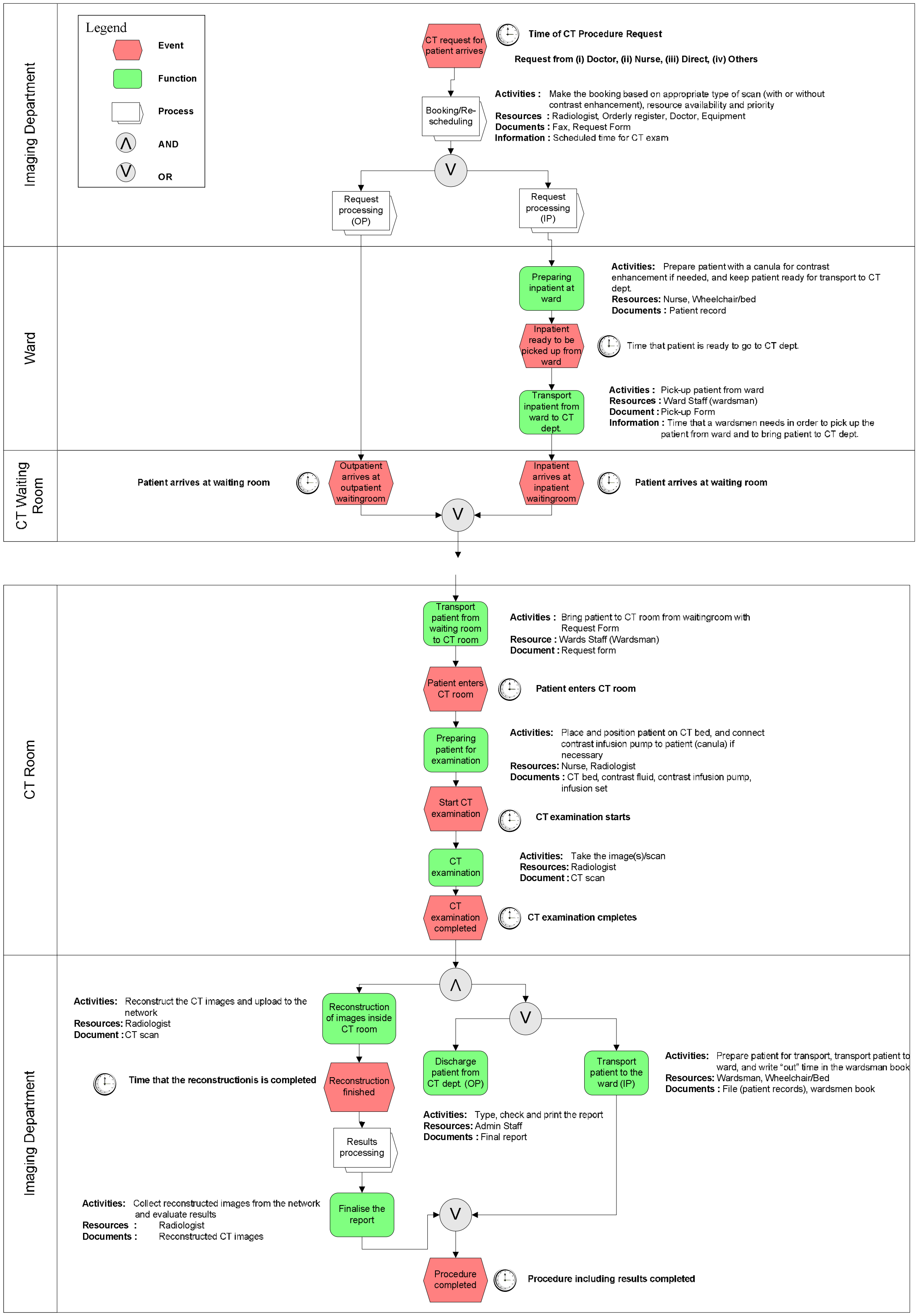

Figure 3: Booking and Rebooking Process in the Imaging Department

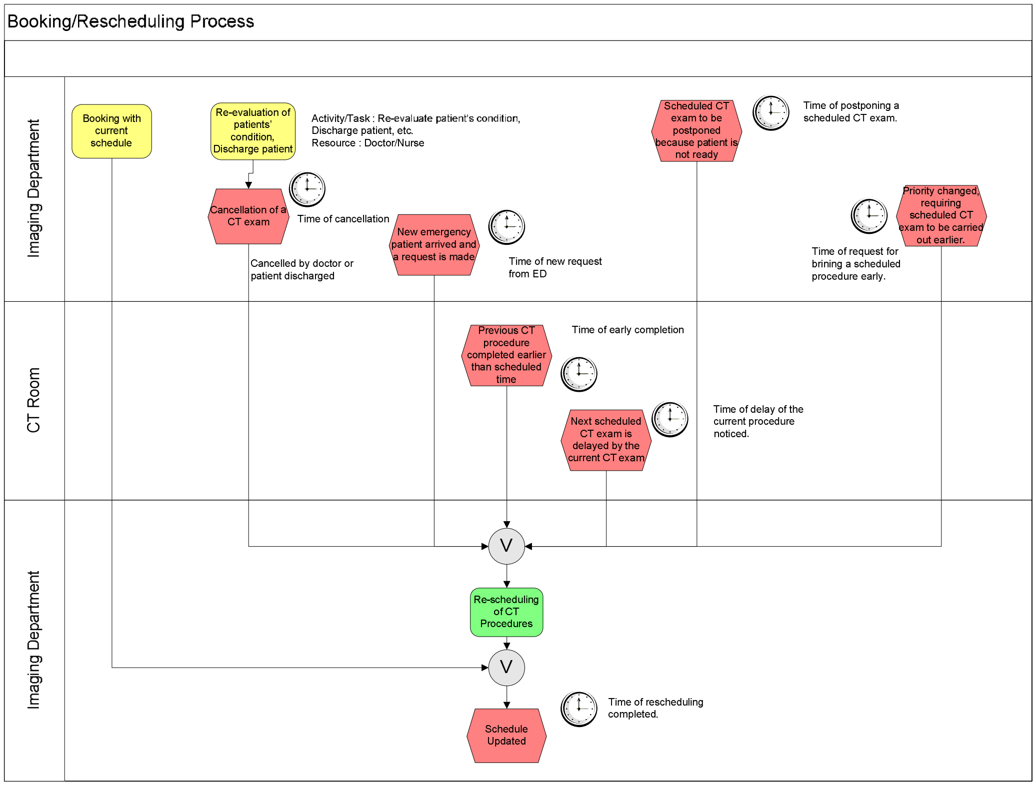

Figure 4: X-Ray Procedure in the Imaging Department

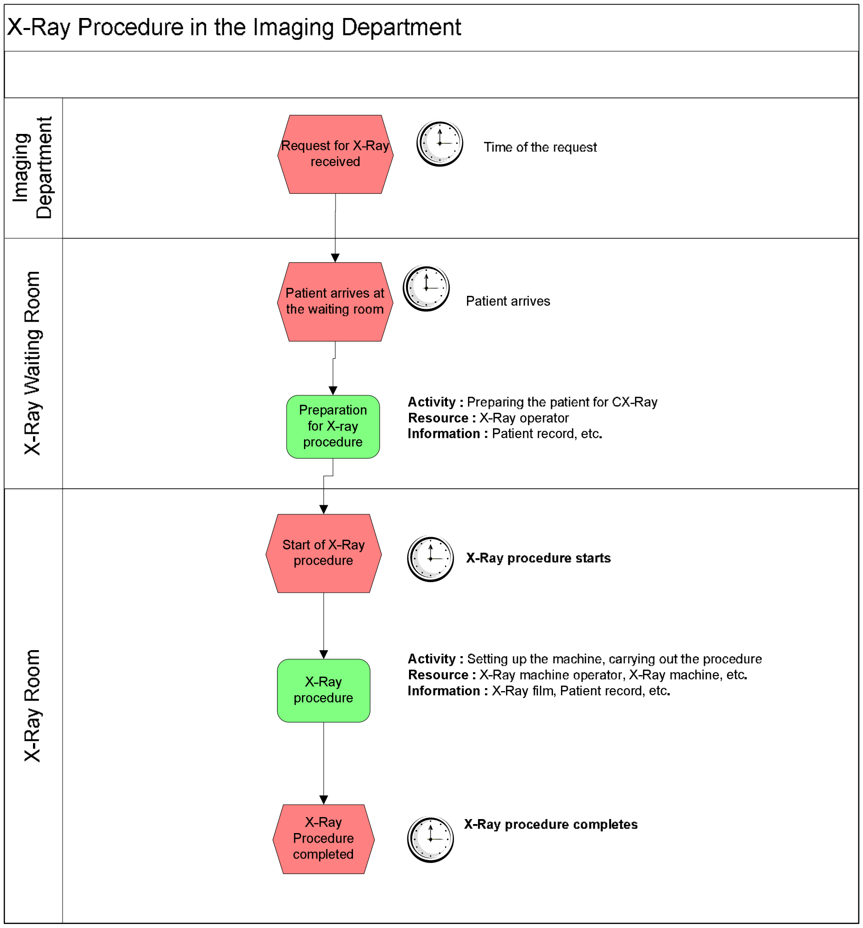

Figure 5: Patient Journey Model of CT Examination in Imaging Department