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Abstract

Variations in service delivery have been identified as a major challenge to the success of process improvement studies in service departments of hospital such as radiology. Largely, these variations are due to inherent system level factors, i.e., system variations such as unavailability of resources (nurse, bed, doctors, and equipment). These system variations are largely unnecessary/unwarranted and mostly lead to longer waiting times, delays, and lowered productivity of the service units. There is limited research on identifying system variations and modelling them for service improvements within hospital. Therefore, this paper proposes a modelling methodology to model system variations in radiology based on real time locating system (RTLS) tracking data. The methodology employs concepts from graph theory to identify and represent system variations. In particular, edge coloured directed multi-graphs (ECDMs) are used to model system variations which are reflected in paths adopted by staff, i.e., sequence of rooms/areas traversed while delivering services. The main steps of the methodology are: (i) identifying the most standard path followed by staff for service delivery; (ii) filtering the redundant events in RTLS tracking database for analysis; (iii) identifying rooms/areas of hospital site involved in the service delivery; (iv) determining patterns of paths adopted by staff from filtered tracking database; and, (v) representation of patterns in graph based model called as edge coloured directed multigraphs (ECDMs) of a role. A case study of MR scanning process is utilized to illustrate the implementation of the proposed methodology for modelling system variations reflected in the paths adopted by staff.

Keywords

time, real, locating, information, service, hospital, variations, modelling, delivery

Disciplines

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Modelling Variations in Hospital Service Delivery based on Real Time Locating Information

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Abstract: *Variations in service delivery have been identified as a major challenge to the success of process improvement studies in service departments of hospital such as radiology. Largely, these variations are due to inherent system level factors, i.e., system variations such as unavailability of resources (nurse, bed, doctors, and equipment). These system variations are largely unnecessary/unwarranted and mostly lead to longer waiting times, delays, and lowered productivity of the service units. There is limited research on identifying system variations and modelling them for service improvements within hospital. Therefore, this paper proposes a modelling methodology to model system variations in radiology based on real time locating system (RTLS) tracking data. The methodology employs concepts from graph theory to identify and represent system variations. In particular, edge coloured directed multi-graphs (ECDMs) are used to model system variations which are reflected in paths adopted by staff, i.e., sequence of rooms/areas traversed while delivering services. The main steps of the methodology are: (i) identifying the most standard path followed by staff for service delivery; (ii) filtering the redundant events in RTLS tracking database for analysis; (iii) identifying rooms/areas of hospital site involved in the service delivery; (iv) determining patterns of paths adopted by staff from filtered tracking database; and, (v) representation of patterns in graph based model called as edge coloured directed multigraphs (ECDMs) of a role. A case study of MR scanning process is utilized to illustrate the implementation of the proposed methodology for modelling system variations reflected in the paths adopted by staff.*

1. Introduction

Due to the crucial role that diagnostic imaging plays in contemporary medicine, physicians from virtually all disciplines who care for patients use diagnostic imaging services. Available estimates indicate that over 1.5 billion imaging procedures were performed in the US (Medicare, 2003) and over 33 million clinical examinations were performed with diagnostic imaging in the UK (Healthcare Commission, 2007). Hence, the increasing needs for medical imaging services has created considerable bottlenecks in the service delivery process and resulted in longer patient waiting time in radiology (Hillman & Neiman, 2003). Consequently, many radiology departments are faced with the simultaneous challenges to manage growing demand for scans while reducing wait time for patients seeking access to medical imaging services (Sachs, 2002; Boland, 2006). Furthermore, the prohibitive costs of imaging devices severely restrict radiology departments from purchasing additional equipments in an effort to enhance patient throughput and reduce waiting times. Hence, improving the efficiency of service delivery process is emerging to be a viable step for radiology departments and a priority of healthcare organizations worldwide (US National Research Council, 2009, 2005; UK National Health Services, 2007, 2003, 2005; Crabbe *et al.*, 1994, Reiner *et al.*, 2002).

Improving the efficiency of the service delivery process entails several challenges including optimum allocation and utilization of resources such as medical staffing; reduced non-productive time periods such as patient waiting time; efficiently identifying and eliminating bottlenecks in the service delivery; and streamlining patient flow across the radiology department. The service delivery processes in radiology departments involves a complex interaction between sophisticated medical imaging devices (i.e. MRI, CTs, PET-CT, ultrasounds etc) operated by highly specialized medical staff including radiographers, radiologists, and radiology nurses. General practitioners (GPs) and consultants from different departments of a hospital request patient scans in order to diagnose and treat patients. As a result, a radiology department must deal with a large numbers of patient scan requests on a daily basis.

Radiology department operates solely as a service unit to other departments in the hospital in that it does not treat a particular disease, but rather supports treatment functions in other radiology departments. This result in radiology department being affected by variations that frequently originates in other department as well as compounding its own variations. Increasingly, efforts are made in literature on analyzing the variations sources in service departments thereby streamlining their services (Shukla *et al.*, 2012; Shukla 2012; Meitzner and Trewn, 2006; Roobottom, *et al.*, 1995; Hydo, 1995).

Unwarranted variations are defined as the variations in the utilisation of healthcare services that cannot be explained by variation in patient illness or patient preferences. Current modelling and simulation approaches for healthcare service efficiency and effectiveness improvements in hospitals do not utilise multiple types of heterogeneous service data such as qualitative information about hospital services and quantitative data such as historic system data, electronic patient records (EPR), and real time tracking data for analysing unwarranted variations in hospital. Consequently, due to the presence of large amount of unwarranted variations in the service delivery systems, service improvement efforts are often inadequate or ineffective. For more information about classification of unwarranted variations in healthcare systems refer to Shukla *et al.*, (2012) and Shukla (2012).

The main sources of variations in the service units such as radiology department are due to: (i) variations in clinician practices; (ii) patient characteristics (number of patients, demographics, mix, diagnosis, and severity); (iii) system variations (resource availability variations, patient and staff scheduling, changeovers/setups of complex equipments); (iv) input/output variations (patient scan request arrival variations, discharge variations). These variations in the case of radiology department are illustrated in Fig. 1.

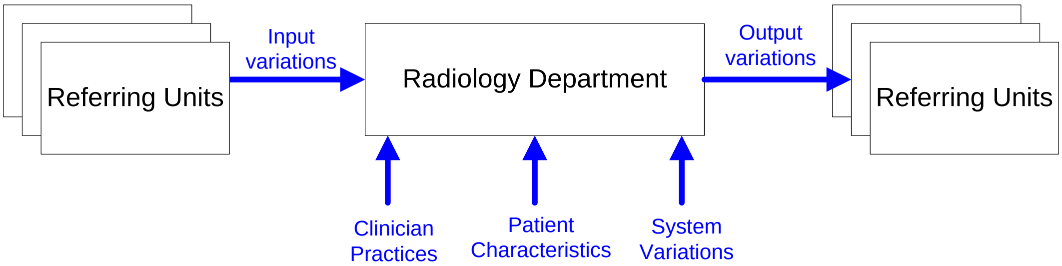


Figure 1: Variations sources in radiology department

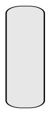
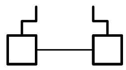
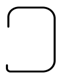
In particular, the variations in clinician practices includes the methods, techniques, experience utilized by the clinicians to deliver services to patients. The variation associated with the patient characteristics can be due to patient related care choices and demographics among other factors. System variations can arise from resource availability (procedure rooms, beds, doctors, nurses, equipments) and changeovers/setups between consecutive patients. Furthermore, the input/output variations in radiology department arise due to the patient arrival patterns, and delivery patterns of the imaging reports.

This paper mainly focuses on system variations, which largely result in unwanted delays, patient and staff waiting, and lowering the productivity of radiology department. Hence, it will be important to identify and understand the sources of these variations. In this paper, the system variations are studied with the help of role activity diagrams (RAD, Ould, 1995, 2005; Shukla, *et al.*, 2009). RADs are based around a graphical view of the process from the perspective of individual roles and focuses on the responsibility of roles and the interactions between them (Ould, 1995; 2005).

RADs have been shown to be particularly useful in supporting communication. They are easy and intuitive to read and understand. Also, they present a detailed view of the process and permit activities that occur in parallel. The RAD provides a viable opportunity to represent the activities and interactions that are typical in service delivery process in radiology.

Table 1 provides some of the fundamental concepts, general description and examples of RAD concepts in a radiology unit. Additionally, the table also provides the corresponding graphical representation for each of the RAD concepts which is utilized to model the service delivery process in the radiology department.

Table 1: Description of RAD concepts and its graphical representation

S. No.	**RAD concept**	**General description**	**Examples of application in radiology department**	**Graphical notations**
1.	*Role*	Roles consist of actions and interactions that achieve a goal of several goals. Roles are not assumed to be the job titles in the radiology department.	*Clinical consultants, porters, nurses, technicians*	
2.	*Activity*	An activity is a unit of work performed by a particular role.	*Move patient to changing room, position patient on table*	
3.	*Interaction*	People collaborate in order to achieve the service delivery process objective.	*Pass X-ray of the patient from technician to radiology consultant*	
4.	*Part refinement*	The part refinement symbol refers to the work done simultaneously by a role. This is graphically represented by single thread of activity dividing into parallel threads within a role.	*Patient booking, and printing patient non attendance letters*	
5.	*Case refinement*	The case refinement is used to represent decision question and possible outcomes.	Decision question: *Does patient require contrast injection*? Outcome: *Yes*, and *no*.	
6.	*Trigger*	Trigger is an event that starts the activity thread.	*Arrival of patient scan request*	
7.	*State*	A state describes what is true either before or after some actions (actions can encompass activities, interactions, and encapsulated processes).	*Scan is finished, patient can have scan*	
8.	*Loop*	The loop symbol allows a part of a process to be repeated. The iteration starts at the end of an activity and goes back to a prior activity.	*Multiple attempt to give injection*	
9.	*Replication*	This symbol is used to define the nature of the repetition of certain activities in the process.	*Maximum two repeats in giving injections*	
10.	*Encapsulated process*	The encapsulated process allows us to represent complex sub-processes as a separate diagram and indicating it as a symbol in the main diagram	*Perform patient scanning*	

11.	*Start role*	This symbol is used to initiate a transient role in the main diagram.	*Patient scan request vetting by radiology consultant*	
12.	*Other work*	It represents the other work that does not relate to the main process performed by the role.		
13.	*Stop*	This symbol marks the end of one or more threads to indicate the end point of the process.		

RAD is recently identified to be one of the suitable techniques for modelling the process in imaging service delivery process (Shukla, *et al.*, 2009). Shukla, *et al.*, (2009) introduced RAD based modelling methodology which develops the most standard process mapping of the service delivery process. The method utilizes the information gathered from interviews of the staff involved in the service delivery. The resulting RAD model represents the most standard mapping of the service delivery processes without considering the system variations. Therefore, it is necessary to define variations that can be realized based on RADs. Following text details the classification of variations and their types in detail with the help of RADs.

Variations in the service delivery process that can be represented based on RAD concepts are detailed in Table 2. It defines various types of variations based on RAD concepts such as: *role variation*, *path variation*, *activity variation*, *interaction variation*, *decision variation,* and *time variation*. The role variation occurs when there is unavailability of certain types of roles. These variations results in other roles taking up the additional responsibilities leading to unwanted delays in delivery of services. The path variation occurs when a role deviates from normal paths (*i.e.* sequence in which role visit rooms/areas for delivering their share of services to patients). These variations are mainly caused when there is unavailability of certain resources (roles have to look for resources in various rooms/areas). Hence, role variations and path variations are system variations leading to unwanted delays and bottlenecks within service delivery processes.

Table 2: Classification of variations based on RAD concepts

Type	Interpretation	Example in radiology
Role variation	These type of variations occurs when there is a staff unavailability or when there is change in staff within a role	Absence of staff such as radiology nurse, clinical consultants
Path variation	These variations occur when roles traverse different areas while delivering services	Nurse has to traverse different areas when a wheelchair is unavailable
Activity variation	It mainly occurs when one/ multiple activities are changed or not performed while delivering care to patients	Giving sedation injections to claustrophobic patients for calming anxiety
Interaction variation	These variations occur when interactions are not	Radiology assistant not

	done or different interactions are performed	assisting outpatient to get dressed
Decision variation	When different decisions are taken based on the patient conditions	Sedation for the child patients is different from the claustrophobic patients
Time variation	These type of variations occur when the duration of activities are changed	New radiology technologist takes more time for scans

Activity variations, interaction variations, decision variations occur when certain activities, interactions, decisions are changed or not performed. These variations are largely due to varying patient characteristics and clinician practices. Furthermore, time variations are mainly when the durations of the activities or interactions takes longer time than normal. These variations can arise from patient characteristics, clinical practices, and system variations. Hence, the source of time variations cannot be distinguished between clinical practices, patient characteristics, and system variations.

This paper aims at identifying the system variations in a service delivery process, therefore, only role variations and path variations are considered (see shaded cells of Table 2). The role and path variations are mostly reflected in most frequently adopted role paths (*i.e.* sequences of rooms/areas visited by a role for delivering services), which can be electronically tracked, based on the real time locating systems (RTLS). RTLS allows tracking of roles in radiology and storing the tracking events (*tagID*, *roomID*, *time*) in the database which can be analyzed to model role path variations.

A modelling methodology based on graph theory concepts, *i.e.*, edge coloured directed multigraphs (ECDM), is utilized to identify and represent the role and path variations. This modelling method will help to extend the static RAD models to identify and represent system variations occurring in roles and their paths with the help of ECDMs.

The rest of the paper is arranged as follows. In the next section, the literature review on variations modelling in healthcare is reviewed briefly. Section 3 details the background of radio frequency/ infra red (RF/IR) based real time locating system (RTLS) for hospitals. In Section 4, the system variation modelling based on edge coloured directed multigraphs (ECDMs) is discussed in detail. Section 5 discusses the learning algorithm for ECDMs from the RTLS tracking database. Section 6 details a case study of MR scanning process at the radiology department of one large UK hospital. Finally, conclusions are presented in Section 7.

2. Literature review

Realizing improvements in radiology requires modelling and analysis of the service delivery processes. A number of studies have dealt with modelling/mapping issues of the service delivery process based on information gathered through clinician workshops, interviews and discussions aimed at suggesting process improvements (Crabbe *et al.*, 1994; Jimmerson *et al.*, 2005; Dickson *et al.* 2008; Shukla *et al.*, 2009; Patel, 2000; Staccini *et al.*, 2006). These approaches model the most standard process followed while modelling service delivery process. However, modelling the most standard process is useful when the service unit has only one way of performing activities. Such systematic and controlled processes are predominant in manufacturing sector where majority of processes have a specific way of performing activities. On the contrary, a radiology department is usually fast-paced and characterized by uncertainties. There can be several variations in the service delivery process including staff unavailability, medical device breakdown, patient characteristics, and clinical practices for delivering care that are not always transparent. Consequently, any improvement provision must first start with the development of a generic model which can reliably represent process variations in service delivery process.

Table 3 presents the current literature in the area of process improvement applied in various areas including radiology departments. In particular, the approaches used in literature can be broadly grouped under service delivery process modelling for process improvements. The approaches in this category are focussed on modelling the most standard process for service delivery. Furthermore, service delivery process modelling relies on identifying all the steps and decisions in a process in diagrammatic form, which is then used for improvement purposes. It describes the flow of information, patients, and staff; decisions made for delivering services; and the essential inter-relationships and interdependence between the process steps. Commonly used approaches in this category are Flowcharts (Crabbe *et al.*, 1994), Integrated DEFinition (IDEF, Staccini *et al.*, 2006), Value Stream Mapping (VSM, Jimmerson *et al.*, 2005, Dickson *et al.* 2008), and RAD (Shukla *et al.*, 2009, Patel, 2000). All these approaches use different methods for data gathering related *procedural knowledge* (Shadbolt and Milton, 1999), *i.e.*, knowledge about chiefly related to how things are done and *quantitative knowledge* such as time related information about activities. However, these approaches do not consider modelling of system variations for process improvements.

Table 3: Literature review on the approaches for process improvements

Strategy	Classification			Literature
	Approach	Data gathering		
		Procedural knowledge	**Quantitative knowledge**	
Service delivery process modelling	Flowchart	-	IT systems, manual records	Crabbe *et al.*, (1994)
	IDEF	-	"	Staccini *et al.*, (2006)
	VSM	Workshop discussions	Stop watch	Rother and Shook, (2003), Dickson *et al.* (2008), Jimmerson et al., (2005)
	RAD	Individual interviews	"	Shukla *et al.* (2009), Patel, (2000)
System variation modelling	ECDMs based variation modelling	-	RTLS based tracking data	**Proposed in this paper**

There are research studies that are focussed on identifying the inefficiencies of the nursing care based on time and motion studies (Hendrich *et al.*, 2008, Hendrickson *et al.*, 1990, Quist, 1992). Hendrich *et al.*, (2008) utilized personal digital assistants (PDAs), and radio frequency identification (RFID) tags to record time spent by nurses on several care-related activities. This information was then utilized for improving nursing care in hospitals. These studies illustrate time variations with the nursing care and do not deal with the process modelling aspect. Recently, Value Network Mapping (VNM) has been used in modelling business processes at organizational level (Allee, 2002, 2008). VNM models complex business processes in the form of value chain networks including roles, deliverables, and transactions. In VNM, the process is represented in the form of networks illustrating several interacting roles for creating/adding value to the input. VNM is used to model the macro level business processes involving complex interactions in an organization. Further, VNM has the limitation to represent activities performed within each roles involved within service delivery process. Hence, VNM tries to model complex networks at the macro level of details within organization. Hence, these are not included for classification of the approaches in literature in Table 3.

As described in Table 3, this paper proposes the variation modelling methodology which models role variations and path variations occurring within the service delivery process. The modelling methodology utilizes real time locating system (RTLS) data about paths adopted by roles while delivering imaging services. The background information about RF/IR based RTLS systems and hospital deployment is discussed in detail in Section 3. The paths adopted by roles to perform patient services in radiology can be utilized to identify role and path variations in service delivery. Nevertheless, it is crucial to identify and reduce both system variations which are largely unnecessary and result in longer waiting times and delays. The challenge is to identify unnecessary variations, implement changes to reduce such system variations, and continually improve service delivery.

The methodology proposed in this paper attempts to model role and path variations in medical imaging service delivery process. Largely, these variations are reflected in the form of paths adopted roles while delivering services. The data gathering method used in this process employs radio frequency/infra red (RF/IR) tracking based real time locating system (RTLS) to track roles with room-level accuracy (Kronn, 2008). RTLS typically refers to systems that provide passive (automatic) collection of room level location information in real time. The data gathered by RF/IR-based RTLS system can be utilized to identify patterns of role paths. These patterns in the role paths are represented in a generalized graph based model, *i.e.*, edge coloured directed multi-graphs (ECDMs) where nodes represent the rooms/areas and edges represent movement between nodes (rooms/areas) traversed by an roles. The learning of ECDM from tracking data of radiology staff and patients can be challenging and requires a systematic methodology to identify patterns of role paths. Therefore, an algorithm for learning the ECDM based on tracking data is presented in this paper.

Following section provides the background related to RF/IR based RTLS and discusses their deployment in hospitals.

3. RF/IR based RTLS in radiology unit

This section discusses about RTLS tracking based on RF/IR system and its deployment in a radiology site. RTLS are used to track and identify the room level location of objects in real time using simple, inexpensive tags attached to or embedded in objects and readers that receive the wireless signals from these tags to determine their locations. Recently, a hybrid RTLS solution working on the principle of RF and IR waves have been introduced for hospital asset tracking applications (Krohn, 2008). The characteristics of RF and IR waves are used in order to acquire room level and sub-room level accuracy (Crimmins & Saulnier, 1999). RF/IR based

RTLS are commercially available and are dedicated to provide solutions for patient, medical device, and staff tracking in hospitals.

The main components of the RF/IR based RTLS are tags, monitors, stars and communication mechanism. The details about the working of these components are presented below:

Tag: It is a battery powered RF/IR tag that can be attached to the object that needs to be tracked in real time (see Fig. 2). Tags observe their environment for incoming IR signals with the help of infra-red sensors and periodically report both its own unique code and IR location ID. The IR code represents the area or location where the tag is identified. This communication protocol allows the usage of multiple tags for real time tracking. The tags are also equipped with on-board motion sensors, which allow tags to operate at two different rates: slow when the tag is stationary and fast when the tag is in motion. This provides a method for locating tagged assets with room-level accuracy. The tags have four switches which can be customized for the different applications. For example, switches can be used to trigger an alert to indicate tampering if a tag is removed from the object.

Monitor: It is an IR signalling unit which spreads the IR waves to provide a method of locating tagged objects (see Fig. 2). Each monitor transmits an IR pulse pattern containing a unique location code. The IR coverage zones are limited by solid physical structures such as walls. A monitor spreads the IR waves, which bounce off effectively from structures and walls to the cover entire room including locations that are not in the direct line of sight to the monitor. Tags in the room having a monitor receive the IR location ID and communicates periodically about its position. The tag's communication is then processed to locate and identify tagged objects within the room. Monitors in RF/IR based RTLS can also communicate with RF waves. This enables monitors to have constant communication with the stars using RF waves. Monitors communicate with the stars periodically to report the status of their batteries.

Star: The star interprets and reports RF messages emitted by tags and monitors at larger distances (see Fig. 2). Stars communicate the data received from tags to the server running the tracking software interface. The communication between a star and the server is done by using Ethernet. Tag transmissions are processed to track tagged objects in the software. The star allows tracking of large number of tags distributed in several areas.

Figure 2: Tag, Monitor, Star used in RF/IR based RTLS

Communication Mechanism: The basic mechanism of communication between RF/IR based RTLS can be summarized in Table 4. As shown in Table 4, monitors transmit their location ID using IR and the tag receives the location ID via IR. The location ID and tag ID are then sent to stars via RF which further communicates received data to the server.

Table 4: Communication among the RTLS components

	Tag	**Spider**	**Star**	**Server**
Tag	-	IR waves	RF waves	N/A
Spider	IR waves	-	RF waves	N/A
Star	RF waves	RF waves	-	Ethernet
Server	N/A	N/A	Ethernet	-

In order to illustrate the deployment of the RF/IR RTLS system, a MR scanning site of the radiology department is considered. Fig. 3 illustrates the deployment of tags, monitors, and stars in MR scanning site of radiology unit.

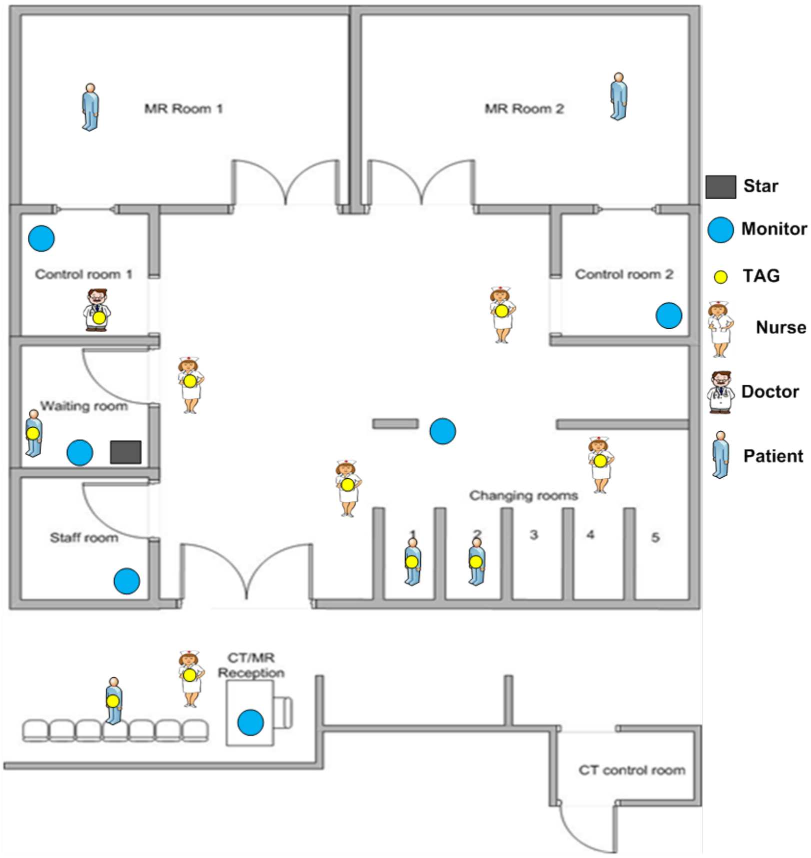


Figure 3: Deployment of RF/IR based RTLS in MR scanning site of radiology unit

The deployment illustrates the placement of monitors, and star within different areas of the hospital layout. The tags are attached to patients, nurses and doctors for their real time tracking. Monitors are placed in areas such as waiting room, reception, changing area, and control rooms 1 & 2. These monitors spread the IR waves in their respective areas. These IR waves are correspondingly received by tags attached to patients, doctors and nurses. A tag then transmits its unique ID and IR location ID to a star via RF waves. Subsequently, the tracking information is received periodically by the RTLS and is recorded in the server.

The RF/IR based RTLS tracking solutions are recently introduced and are used in large hospitals for people and equipment tracking and management (Centrak, 2009). So far there are no studies indicating any effect of these systems on patient health. However, care must be taken while using these systems around medical imaging equipment. The RF/IR tags contain metallic batteries to communicate with the monitors and stars for RTLS. Hence, the use of tags has to be avoided when around imaging equipments. This is done by removing the tags from staff and patients before they enter the scanning rooms and then placing the tags back on them again when they egress the scanning rooms.

The tracking data obtained from RF/IR based RTLS includes crucial information about roles such as (*tagID, roomID, time*). This information is utilized to model frequently occurring patterns in role paths. Following section details the methodology to model role and path variations arising from radiology service system.

4. Modelling the system variations in radiology

This section details the graph based modelling method to represent the system variations that occur in the radiology department in form of role and path variations. The main motivation for developing the graph based model is to represent paths adopted by roles while service delivery. Different rooms/areas within the service delivery site are represented as nodes of the graph based model. In addition, set of directed edges is used to represent role paths. Further, in order to represent various patterns of role paths, concept of coloured edges is utilized. Hence, the patterns in role paths are represented in form of edge coloured directed multi-graphs (ECDMs).

A simple illustration of ECDM is shown in Fig. 4. The nodes numbered from 1 to 9 represent the rooms/areas of the service delivery site and each set of distinct coloured directed edges represent paths adopted by a role for delivering service. The ECDM illustrated in Fig. 4 shows three patterns of role paths, *i.e.*, I, II, and III having green, red, and blue directed edges. The main challenge in modelling patterns is to have a formal and mathematical representation of ECDMs. Hence, the following text is dedicated to provide mathematical representation of ECDM.

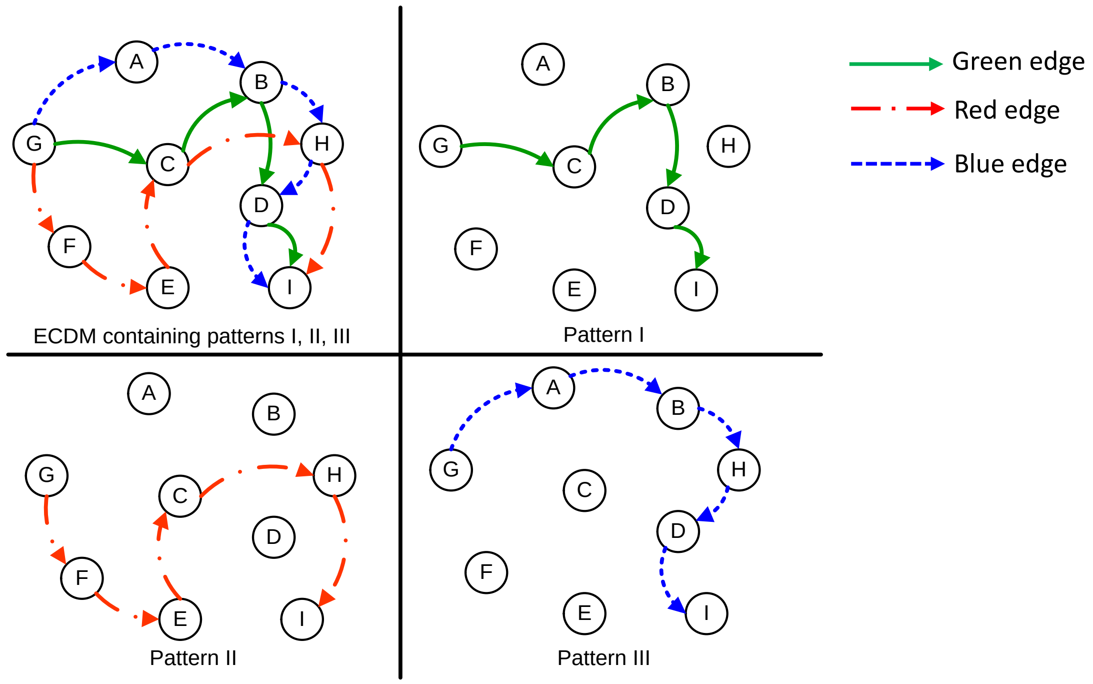


Figure 4: Example of ECDM representing patterns I, II, and III, each pattern represents role paths within service delivery site

The modelling based on ECDM is based on the generalized graph theory concepts. Hence, the graph based models existing in literature are reviewed and suitable graph based model is selected for ECDM. Recently, McGuffin and Schraefel, (2004) introduced new types of generalized graph based models and compared them based on their capability to be used for information navigations representation. The purpose for the development of these models was to generate flexible models which can be used to efficiently and effectively analyze complex and multi-dimensional information. One of the graph based models defined under this category is the zzstructure, which can represent or subsume multiple instances of other graph based representations. Zzstructures generalize various data structures such as lists, 2D arrays, and trees. Zzstructures are directed multigraphs which can have multiple edges between pair of nodes and each edge has associated colour and direction. In addition, zzstructure must also satisfy the following restriction:

Restriction R: each node in a zzstructure may have at most one incoming/outgoing edge of each colour.

Due to restriction R in zzstructure, each coloured role paths should form path that do not intersect within same colour. However, in a healthcare setting, patterns of role paths can violate restriction *R* as they can visit one room/area more than once in the service delivery path. Hence, zzstructures without restriction '*R*' are used for modelling ECDMs. This enables the ECDMs to represent multiple complex role paths. Following text details the mathematical representation of ECDMs.

An ECDM can be defined in terms of graph theory as $\mathbf{G} = (\mathbf{V}, \mathbf{E})$, where **V** is the set of areas (i.e., nodes) in the service delivery site defined as $\mathbf{V} = (v_1, v_2, v_3, \ldots, v_n)$. **E** is the set of directed edges or individual movements, *i.e.*, $\mathbf{E} = (e_1, e_2, e_3, ...)$ between areas in **V**. The l^{th} edge (e_l) of **G** is equivalent to $v_i \rightarrow v_j$, *i.e.*, directed from area v_i to v_j. The direction and the edges associated with each pair of area (v_i, v_j) is denoted by the adjacency matrix $\mathbf{A}$. The attribute value $\{a_{ij}\}$ of $\mathbf{A}$ is the number of edges with source area v_i and target area v_j. Mathematically,

$$\{a_{ij}\} = \#\,\text{of edges from}\, v_i \,\text{to}\, v_j \qquad \forall (v_i, v_j) \in \mathbf{V} \tag{1}$$

A function $f(.)$ is defined for mapping the edges to the colours or patterns of role paths such that:

$$f : \mathbf{E} \rightarrow \mathbf{C} \tag{2}$$

where, **C** is defined as the set of '*K*' frequent patterns of role paths $(c_1, c_2, c_3, \ldots c_K)$ for an ECDM. The k^{th} pattern of a role will have a set of edges which are to be represented by colour c_k. Therefore, the attribute value a_{ij} of **A**, representing edges from v_i to v_j, is divided into *K* patterns of role paths. In particular, the division of a_{ij} classifies edges into different patterns of role paths. The division of a_{ij} edges into colours defined by **C** is such that:

$$a_{ij} = \sum_{k=1}^{K} q_{ijk} \tag{3}$$

where, q_{ijk} is the number of edges originating from the i^{th} area and terminating on the j^{th} area of c_k^{th} colour or belonging to k^{th} pattern of role paths. The division of a_{ij} classifies all the edges into respective variation patterns of role paths. However, the sequences of the role paths are represented mathematically. Therefore, let us consider $\mathbf{S}^k$ which represents the sequence of edges that is represented by the c_k colour. The sequence $\mathbf{S}^k$ comprises the order of nodes $v_i \ \forall v_i \in \mathbf{V}$ traversed by a role. Therefore, for all patterns of role paths are represented by colours in **C**, there is a sequence of the edges represented mathematically by $\mathbf{S}^k$. Hence, the aforementioned formulation represents the patterns of role paths mathematically in the form of

ECDMs. Considering the above mathematical notations, the restriction '*R*' of zzstructure can also be formulated as:

$$R :\rightarrow 0 \leq q_{ijk} \leq 1 \qquad \forall (v_i, v_j) \in \mathbf{V}, c_k \in \mathbf{C} \tag{4}$$

This represents that a area can have at most one incoming and one outgoing edge. However, the above restriction is not present in ECDMs and therefore these are utilized to represent variations in role paths adopted for service delivery.

The tracking data gathered by RTLS is utilized for learning of ECDMs. The learning of ECDMs involves an algorithm which can analyse tracking database to elicit patterns in role paths. The next section provides information about the development of a learning algorithm for ECDMs.

5. Learning algorithm for ECDM

This section details the algorithm proposed for learning ECDM from the tracking database. A properly learned ECDM represents paths adopted by a role in the service delivery process. It is necessary to develop an effective learning algorithm for constructing ECDMs from the tracking database. The analysis conducted using inadequately learned ECDMs will provide misleading results that do not reflect accurate information on role paths. The tracking database obtained by deploying the RTLS system (tags, monitors, stars) generates large amount of events data which is in the form of tuple (*tagID*, *roomID*, *time*). These events reflect the location of individuals performing particular role while delivering patient services. This information about the process can be utilized to construct ECDMs by defining a formal algorithm for learning from events database. The overall methodology for learning ECDMs is illustrated in Fig. 5.

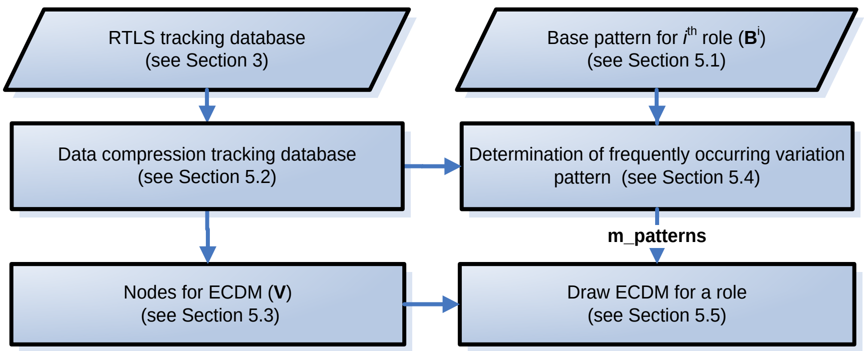


Figure 5: Flowchart of the overall learning methodology for ECDM

Following paragraphs discusses the steps involved in the learning algorithm which identifies patterns of the role paths.

5. 1 Determining standard role path for service delivery

The initial step for the learning algorithm is to gather information about the standard path of roles, which are most commonly adopted for delivering patient services. This information can be gathered from discussions with senior clinicians involved or by observation and discussions with the relevant staff. The RAD model developed in Shukla, *et al.*, (2009) can also be used for eliciting standard paths together with location information.

An Activity-Location-Role table can be constructed to relate locations (rooms/areas) with the service delivery activities for a particular role (see Table 5). As per definition, roles can be radiographer, radiology nurse, receptionist, radiologist. Table 5 is used to get standard paths for each role, which will be utilized in next steps to elicit other patterns from the tracking database.

Table 5: Activity-Location-Role table for i^{th} role

Locations / Activities	A	B	C	D	E
Activity (*i*, 1)	1	0	0	0	0
Activity (*i*, 2)	0	0	2	0	0
Activity (*i*, 3)	0	0	0	0	3
Activity (*i*, 4)	4	0	0	0	0
Activity (*i*, 5)	0	0	0	5	0
:	:	:	:	:	:

An Activity-Location-Role table relates activities of i^{th} role with the areas within service delivery site. While relating the activities with locations, the sequence of activities is also defined to get the standard or base pattern (for example, the base pattern for receptionist can be Reception, Patient Changing Area, Control Room, Patient Changing area, and Reception). Now onwards, the standard path is referred in this paper as base pattern $\mathbf{B^i}$ of i^{th} role. The structure of the table is shown by an example in Table 5. The rows represent activities (for example, register patient on arrival, go to control room, forward scan request to radiographer, return back to reception) and columns represent the locations (for example, Reception, Patient Changing Area, Control Room, Waiting Room). Activity (*i*, 1) denotes the 1^{st} activity performed by i^{th} role in service delivery process. Based on the attribute value of the table it is possible to create base pattern of a role. For example, the base pattern for the example shown in Table 5 is $\mathbf{B^i} = (\mathrm{A, C, E, A, D})$. The base pattern obtained in this step is used together with the RTLS tracking database for modelling and analysis.

5.2 Filtering the tracking database

The initial data obtained from the tracking database can contain erroneous, incomplete, and redundant data which must be screened and filtered out. Similar to all other RTLS, the RF/IR system generates a stream of events data of the form (*tagID, roomID, time*) where *tagID* is the unique code associated with the Tag which is attached to the individuals performing particular roles. RoomID is the code of the monitor under which the tag was identified, and time represents the time at which a tag was identified. If all the events associated with a particular *tagID* are sorted on time scale and grouped, they will form a pattern of the role paths. Hence event are grouped into stages which can be represented in the form of (*tagID, roomID; time in, time out*). In order to study the patterns of role paths, the absolute time can be discarded and only relative duration can be utilized. Hence, the movement stages can be developed in form (*tagID, roomID, duration*). This procedure greatly reduces the number of redundant events in the database and helps to focus on patterns.

5. 3 Identifying number of areas involved in service delivery

This step details the identification of areas $\mathbf{V} = (v_1, v_2, v_3, \ldots, v_n)$ for ECDM. It is the main element to construct the ECDM. In RF/IR based RTLS, the monitors which are installed in different areas of the service delivery site are considered to be the nodes for ECDM. These areas are represented as nodes in ECDM. The patterns of role paths between nodes will have to be defined to develop the ECDM. Following subsection discusses about determining the patterns of role paths from tracking database.

5.4 Determination of patterns of role paths

This step extracts frequently occurring patterns of role paths from the RTLS tracking database. The frequently occurring sequences of areas in tracking database are defined as patterns of role paths. The frequently occurring patterns different from base pattern characterizes that system variation occurs while delivering services. The events obtained from subsection 5.3 comprise of three attributes – *tagID*, *roomID, duration*. Since, in this paper we are interested to identify various patterns occurring within the process, therefore, only *tagID, roomID* is utilized for analysis.

Let us consider, **L** to be a set of distinct *roomID*s and pattern **E** is a nonempty subset of **L**. That is

$$\mathbf{E} \neq \phi; \mathbf{E} \subset L \tag{5}$$

There are N of events (or *roomID*s) in the tracking database for a particular *tagID*. The tracking database can be defined as $\mathbf{D} = \{D_i\}_{i=1}^{N}$, where the i^{th} event $D_i \in \mathbf{L}$. The dataset **D** is constructed by extracting the *roomID*s corresponding to a particular *tagID*. Based on base pattern defined in subsection 5.1, $\mathbf{B}^{\text{i}}$ for the i^{th} role is used to construct the ECDM for the i^{th} role. $\mathbf{B}^{\text{i}}$ is utilized to extract the patterns of role paths from **D**. The events in $\mathbf{B}^{\text{i}}$ is termed as base events. Patterns in **D** which are similar to the base pattern $\mathbf{B}^{\text{i}}$ are identified. Three types of variations in base pattern that can be extracted by the proposed algorithm are as follows:

A. Variation type 1: These variations are due to random events that occur between two consecutive base events in $\mathbf{B}^{\text{i}}$. The number of events that can be tolerated in between two consecutive base events are restricted by threshold α. This is done to restrict the size of pattern in the search space otherwise the search space will increase exponentially. The patterns crossing this threshold are infeasible and are not considered further. This is due to the fact that if a role is being interrupted during its designated activities it will be reflected by some events occurring between two consecutive base events. On the other hand, if the number of in-between events is large then it is assumed that the role has started performing new activities that is not reflected in base pattern.

B. Variation type 2: These represent variations in patterns signifying that a role has either missed some of the activities to be performed in the rooms defined in base pattern by missing base events or has done those activities in different rooms. The missing of base events is also restricted by threshold β. It is assumed that if a role is missing more than β base events in a pattern then the role is following completely different path and hence is not included as frequently occurring pattern.

C. Variation type 3: These are represented by deviation in the base patterns due both types of variation, i.e., variation 1 and variation 2. These patterns are restricted by thresholds α and β.

The steps in an algorithm based on $\mathbf{B}^{\text{i}}$, α, β, and **D** has been defined below. The steps are as follows:

Step 1: Get the information about tracking database **D**, base patterns ($\mathbf{B}^{\text{i}}$) for all roles, α, and β.

Set $i = 1$.

Step 2: For i^{th} role do following sub-steps:

Step 2.1: Call function *extract_patterns* with attributes **D**, $\mathbf{B}^{i}$, and α .

//*This is done to extract patterns corresponding to Variation type 1* //

Step 2.2: Assign extracted patterns to $\mathbf{m\_patterns}$

Step 2.3: Generate pseudo base patterns based on $\mathbf{B}^{i}$ and having maximum of β missing base events.

Step 2.4: Assign all the pseudo base patterns to $\mathbf{pseudo\_B} = \{\mathbf{P}_1, \mathbf{P}_2, \mathbf{P}_3 ...\}$

Step 2.5: For each $\mathbf{P}_j$ where, $j \in (1, 2, \ldots, |\mathbf{pseudo\_B}|)$ do

Step 2.6: Call *extract_patterns*(**D**, $\mathbf{P}_j$, α) considering base pattern to be $\mathbf{P}_j$.

//*This is done to extract the patterns defined by Variation type 2 & 3. That is, the patterns extracted in this step can have at the most* β *missing base events and* α *random events in between base events* //

Step 2.7: Append the extracted patterns to $\mathbf{m\_patterns}$

End For

End For

Step 3: For m^{th} pattern in $\mathbf{m\_patterns}$, where $m \in (1, 2....|\mathbf{m\_patterns}|)$ do

Step 3.1: Call function *frequency* with $m\_pattern_m$ to evaluate the significance of the variation pattern

Step 3.2: Assign the frequency of the pattern to f_m

Step 3.3: If $f_m < F$, then discard the $m\_pattern_m$ in $\mathbf{m\_patterns}$.

End If

End For

Step 4: Output the $\mathbf{m\_patterns}$ as qualified variation patterns

Step 5: $i = i + 1$ and Goto Step 2 until $i > |\#roles|$

In the above steps, two additional functions *extract_patterns* and *frequency* have been used to illustrate the methodology for indentifying frequently occurring patterns of role paths from tracking database. The steps involved in *extract_patterns* function are detailed as follows:

Step 1: Get the input $\mathbf{D} = \{D_i\}_{i=1}^{N}$, $\mathbf{B} = [b_1, b_2 ... b_k ... b_{|\mathbf{B}|}]$ (base pattern) and α as the argument to the function

Step 2: Set $c = 1$ and $k = 1$

Step 2.1: For all $i \in \{1, 2....N\}$ set $index = 0$

Step 2.2: If $(D_i = b_k)$

THEN $k = k + 1$

ELSE $index = index + 1$

End If

Step 2.3: If $index \leq \alpha$

THEN $candi\_pattern(c) = D_i$ and $c = c + 1$

ELSE $k = 1$, $c = 1$, $index = 0$, and CLEAR *candi_pattern*

End If

Step 2.4: If $k = (|\mathbf{B}| + 1)$

Output *candi_pattern*

CLEAR *candi_pattern*

$c = 1$, and $k = 1$

End If

End For

Step 3: End *extract_pattern* function

The steps for the *frequency* function are straight forward and hence are not detailed. The output of frequency function is to provide the number of times each pattern in $\mathbf{m\_patterns}$ exist in database **D**. The output is stored in the vector $\boldsymbol{f}$ having the frequencies of each of the patterns in database **D**.

The output of the above algorithm is the **m_patterns** which comprise of the patterns of role paths.

5.5: Constructing the ECDM for a role

The frequently occurring patterns (**m_patterns**) identified in subsection 5.4 is utilized for constructing the ECDM of a role. Each movement pattern in **m_patterns** is represented by different edge colours $c_k \in \mathbf{C}$ in the ECDM. The movement patterns in **m_patterns** can be directly mapped to the sequence of edges defined by $\mathbf{S}^k$ in the ECDMs of c_k colour (see Section 3). As per the definition of ECDM, the patterns of role paths are a set of coloured edges between different nodes or areas (obtained in subsection 5.2). The values of q_{ijk} for all *i, j,* and *k* are also identified based on the **m_patterns**.

Section 6 presents a case study of MR scanning process of the radiology department where variation modelling methodology has been applied. The RF/IR tracking was done in the MR scanning site and the data gathered was utilized to implement the proposed methodology. The following section details the application of the proposed methodology.

6. Case Study

The case study involves the Magnetic Resonance (MR) scanning service in the radiology department at a large hospital in UK. The radiology unit has three MR scanners to deal with patient scan requests that generate from different departments in the hospital. Radiographers and radiologists with the help of radiology assistants, receptionists, and porters provide MR imaging services to patients. Each of the MR scanners is assigned two radiographers to scan patients and one radiology assistant to prepare patients for scanning. Several IT systems such as radiology information system (RIS), picture archiving and communication system (PACS), and clinical reporting system (CRS) are used to schedule patient appointments, archive patient scan images, and review patient scan reports.

The main areas of the MR scanning service delivery site are CT/MR reception area, changing area, waiting room, control room 1, MR room 1, control room 2, and MR room 2 (see Fig. 3). Radiographers, receptionist, radiology assistant has to move between different areas to deliver imaging services to patients. The MR scanning is primarily a medical imaging technique most commonly used in radiology to visualize the structure and function of the body. The patient scan helps the radiologist to monitor and assess patient medical condition. This is sometimes also referred to as diagnostic imaging. The process starts when a patient scan is requested by a consultant from other departments of the hospital. The request contains some questions on patient health that are to be answered by the radiologist. The radiologist answers the questions with the help of patient MR scan and medical data available in hospital information systems.

General practitioners (GP) from different departments request MR scans for their patients from the radiology department. The receptionist schedules the patients for scan procedures on MR machines, each of which has fixed appointment time slots of 20 minutes per area for patients between 9AM – 5PM (excluding one hour of lunch). The area of the patient indicates a class of scan, *i.e.*, head, heart, abdomen, knee, and others. Due to the large demand for scans from different departments and limited number of available patient appointment slots on the three MR scanners, patients are expected to wait. According to nationally recommended patient care guidelines in UK, no patient should wait more than 18 weeks from GP appointment until their treatment (Department of Health, 2006). Imaging services for patients is identified as a major element in the 18 week care pathway. Therefore, the radiology department is under tremendous pressure to meet the targeted wait time guidelines by reducing unnecessary variations in the process. The variations modelling methodology is used to model system variations which are reflected in paths (sequences of rooms/areas) adopted by the roles in the MR scanning process.

The RF/IR based RTLS was deployed in the MR scanning site of the radiology unit (the RTLS deployment is same as illustrated in Fig. 3). The main areas to be tracked are CT/MR reception area, changing area, waiting room, control room 1, MR room 1, control room 2, and MR room 2. Monitors are installed in each of the areas except MR room 1 and MR room 2 to ensure proper scanning procedures and to ensure patient and staff safety as discussed in the previous sections. Hence, five monitors are installed in CT/MR reception area, changing area, waiting room, control room 1, and control room 2. These monitors spreads IR signals within each area which is picked up by tags associated with staff performing roles to communicate their position to the star which receives information about the location of tags and communicates that to the server which stores the information as events database. In order to ensure the highest level of safety, the monitors were installed after conducting a site analysis to adjust IR power levels to the MR scanning site requirements. Furthermore, project staff with the help of hospital officials made an arrangement to prevent the entrance of staff and patients having tag to the MR rooms to ensure safety procedures.

To ensure smooth data collection, the star and server workstation was installed in waiting room of the MR scanning site. Tailored information sheets about the study and type of RF/IR based data gathering procedures were circulated among radiology staff and patients to inform them of the study and also to seek their voluntary participation. The radiographers, receptionist and radiology assistant who were willing to participate in the study were provided tags at the start of their shift each day to track their paths. Receptionist is informed about the type of study and was asked to provide information sheets inviting patients to the study when registering them on arrival. Patients willing to voluntarily participate in the study were provided tags by project staff.

Project staff were at hand at all times to remove and collect tags from MR scanning staff and patients before they entered the MR scanner rooms (MR room 1 and MR room 2). The tags were given back to staff upon egress from the MR rooms. All tags were carefully collected from patients when they egressed the MR scanning site after examination and from staff at the end of their shifts. This process of data gathering was conducted over a period of one week to gather sufficient information about the paths adopted by staff within MR scanning site. The data was continuously recorded in the workstation placed in waiting room in the form of events comprising of attributes such as (*tagID, roomID, time*). In order to model system variations in the MR scanning process of the radiology department, the proposed variations modelling methodology based on ECDM is applied.

6.1 Determining base pattern for role

The roles involved in MR scanning process are receptionist, radiographers, and radiology assistant. These roles are required move between different areas of MR scanning site in order to deliver services to patients. The base pattern of radiographer role is identified based on their involvement in MR scanning process. The RAD model of the MR scanning process is utilized together with locations information for identifying base pattern of the role. More information about the MR scanning process is discussed in detail in Shukla, *et al.*, (2009). This is done to develop Activity-Locations matrix for radiographer role (see Table 6). These matrices also define the precedence relationship among locations (rooms/areas) and activities performed by radiographer role.

The base pattern of the radiographer based on Table 6 can be identified to be **B** = (D, B, F, D) or (E, B, F, E). The radiographer (positioned at location D & E) collects patients from the changing area and performs final check about patient consenting in changing area. Then patient is taken to the MR scanner room where the scanner table is positioned and setup operation corresponding to the type of scan is performed in MR scanner room. Finally, radiographer sets up various scan sequences to run on scanner in control room 1. The base pattern is utilized by the learning algorithm to analyse the tracking database obtained by deploying RF/IR based RTLS.

Table 6: Activity-Locations-Role matrix for radiographer role

Activities \ Locations	A	B	C	D	E	F	G
Check patient arrival list	0	0	0	1	0	0	0
Collect patient from the changing area	0	2	0	0	0	0	0
Perform final check about consenting	0	2	0	0	0	0	0
Position and setup MR scanner for patients	0	0	0	0	0	3	0
Start various scan sequences to run on patients	0	0	0	4	0	0	0

A = CT/MR reception; B = Changing area; C = Waiting room; D = Control room 1; E = Control room 2; F = MR room 1; G = MR room 2

6.2 Compressing the tracking database

The events data for all the radiographer tags are extracted from the tracking database. The events data is stored in form of (*tagID, roomID, time)*. The tracking database is then compressed by grouping the similar events data as (*tagID, roomID, duration*) (see subsection 5.2). Since the proposed variations modelling methodology based on ECDMs deals with the rooms/areas visited by a role, therefore, the database containing a list of the rooms visited by staff performing radiographer role are considered in this case study. The compressed database is represented as **D**, which contains the list of *roomID*s traversed by each tags associated with the staff performing radiographer role.

6.3 Identifying nodes for ECDM for radiographer

The nodes of the ECDM for radiographer role are determined by identifying distinct *roomID*s present in the compressed database obtained in subsection 6.2. For current example, the distinct nodes for ECDM are identified as ‘A’, ‘B’, ‘C’, ‘D’, ‘E’, ‘F’, ‘G’.

6.4 Determination of role and path variations in radiographer role

The path variations are identified based on the base pattern ($\mathbf{B}$) and tracking database (**D**) for radiographer role identified in subsection 6.1 and subsection 6.2. The threshold parameters for extracting the variations 1, 2 and 3 is $\alpha = 3, \beta = 1$ and the threshold parameter for qualifying the pattern, *i.e.*, $F = 15$. The pattern identification for radiographer role is defined as follows:

Step 1: Input **D**, base pattern $\mathbf{B} = (\mathrm{D}, \mathrm{B}, \mathrm{F}, \mathrm{D})$ & (E, B, F, E), parameters $\alpha = 3$ and $\beta = 1$.

Set $i = 1$

Step 2: For the clinician do following sub-steps:

Step 2.1: Call *extract_patterns*(**D**, **B**, α).

Step 2.2: Assign extracted patterns to $\mathbf{m\_patterns}$

Step 2.3: Pseudo base patterns having at most $\beta = 1$ missing base events in $\mathbf{B} = (\mathrm{D, B, F, D})$ is generated, *i.e.*, (D,B,F,D), (B,F,D), (D,F,D), (D,B,D), and (D,B,F).

Step 2.4: Assign all five pseudo base patterns to $\mathbf{pseudo\_B} = \{\mathbf{P}_1, \mathbf{P}_2 ... \mathbf{P}_5\}$

Step 2.5: For each $\mathbf{P}_j$, where, $j \in (1, 2, \cdots, 5)$ do

Step 2.6: Call *extract_patterns*(**D**, $\mathbf{P}_j$, α)

Step 2.7: Append the extracted patterns to $\mathbf{m\_patterns}$

End For

Step 3: For m^{th} pattern in $\mathbf{m\_patterns}$, where $m \in (1, 2, ..., |\mathbf{m\_pattern}|)$ do

Step 3.1: Call *frequency*($m\_pattern_m$)

Step 3.2: Assign the frequency of the pattern to f_m

Step 3.3: If $f_m < F$, discard $m\_pattern_m$ in $\mathbf{m\_patterns}$.

End If

End For

Step 4: Output **m_patterns=** $(\mathrm{D, A, B, D, B, F, D});(\mathrm{E, A, B, E, B, F, E})$ as qualified patterns of role paths.

Step 5: End

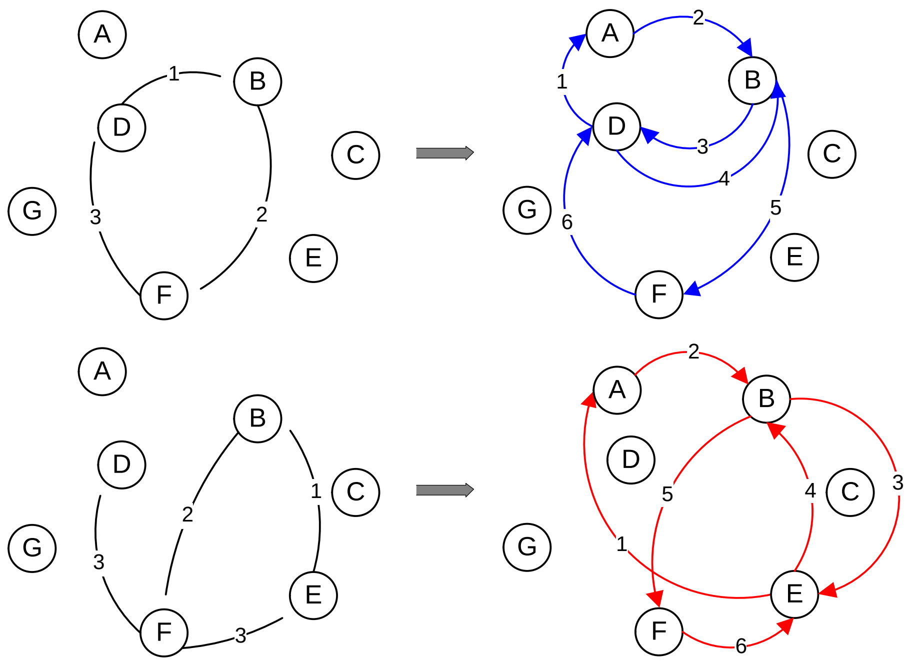
The variation pattern obtained by the proposed methodology is **m_patterns** = (D,A,B,D,B,F,D); (E,A,B,E,B,F,E). It illustrates that there are variations in the involvement of radiographer role in MR scanning process. The pattern identified by the proposed algorithm illustrates that there are areas such as A, B, D which is frequently adopted by the radiographers in order to perform MR scanning. Therefore, the path variation in the radiographer role is to be analysed by constructing ECDM for radiographer path patterns.

6.5 ECDM representation for radiographer

The path variation obtained in the form of movement patterns **m_patterns=** $(\mathrm{D, A, B, D, B, F, D});(\mathrm{E, A, B, E, B, F, E})$ is represented by obtaining the sequence ($\mathbf{S}^k$). The movement pattern of the radiographer in **m_patterns** is represented as *blue* and *red* coloured edges in ECDM. Hence, the sequence is represented as:

$$\mathbf{S}^{blue} = (\mathrm{D, A, B, D, B, F, D}) \quad \mathbf{S}^{red} = (\mathrm{E, A, B, E, B, F, E}) \tag{6}$$

The base pattern and the pattern for the radiographer role are represented in Fig. 6 in the form of ECDM.



a. Base pattern b. Pattern in radiographer paths

Figure 6: ECDM showing base pattern and frequent patterns in paths adopted by staff performing radiographer role

The overall application of the methodology on the case study is illustrated in Fig. 7. The radiographers have to frequently visit additional areas such as A, B, D or A, B, E apart from base pattern (D, B, F, D) or (E, B, F, E). The main reason for this variation in the radiographer movement can be explained by the fact that the radiographers were performing the activities defined for the radiology assistants, who were not present. The radiology assistants have to take patients from CT/MR reception area (A) to the changing area (B) where they perform consenting procedure about the presence of metallic objects in patient body. Patients are advised to change into a hospital gown only after completing the consent form indicating that they have met the requirements to proceed with their scanning appointments. The radiology assistant moves back to the control room 1 or 2 (D or E). In contrast, radiographers have to perform these activities when there are no or shortage of radiology assistants. In effect, radiographer has to perform the additional tasks, which are defined for radiology assistant. This leads to the unnecessary delays and increases waiting time for patients requiring MR scans. Radiographers are required to concentrate on MR scanning performed on patients, recording patient medical condition on radiology information system, and allocating the resulting images to the specialist radiologists. Hence, when radiographer takes up additional responsibilities such as of the radiology assistant, it delays the process and patient to patient time increases. Usually, radiographers remain in the control rooms (D, E) and are responsible for taking patients, prepared for scan, from the changing area (B) or waiting area (C) to the MR rooms (F, G) for performing the MR scanning. Hence, the variations modelling methodology was able to identify the path variations in the radiographer role. The variations in radiographer paths are studied in detail with the staff performing radiographer role. This led to the identification of reasons for variations in radiographer role.

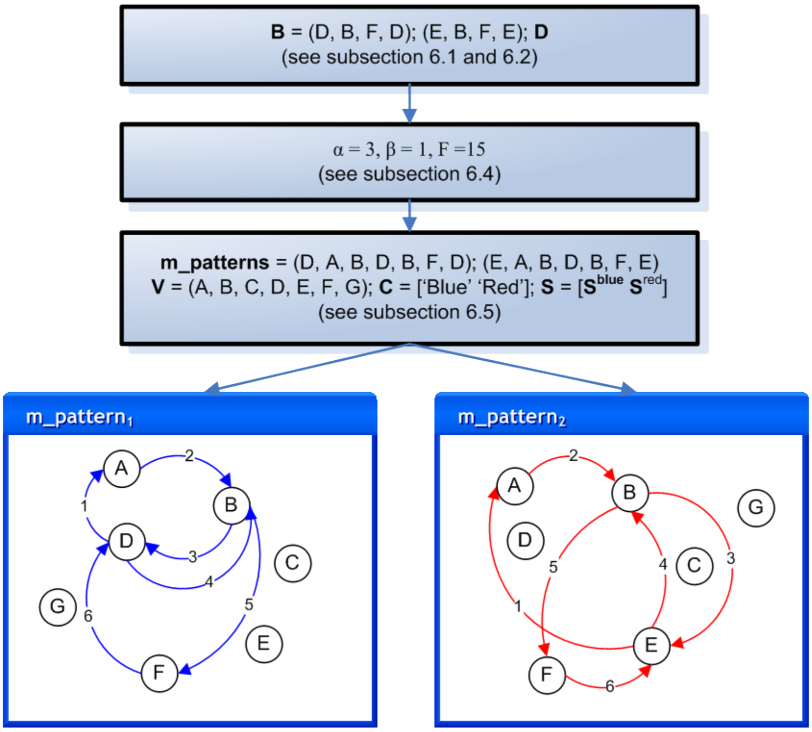


Figure 7: Proposed variations modelling methodology on radiographer role in MR scanning process

Thus, the proposed methodology is able to identify and represent the path variations in the roles. The variations are represented in form of ECDMs which is analysed to identify the root causes of the problems such as shortage of radiology assistants.

7. Conclusion

This paper presents a methodology for modelling the system variations occurring in the radiology department based on the RF/IR based RTLS. The methodology models the system variations in form of patterns of role paths involved in the service delivery process. The patterns are represented in ECDMs, which are generalized representation technique in graph theory. The system variations such as role and path variations are identified with the help of this methodology. These variations lead to unnecessary delays, waiting, lowering of patient throughput in the radiology. Future studies can focus on other variation types under the category of system variations in service systems by considering time, activity, interaction, decision variations.

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