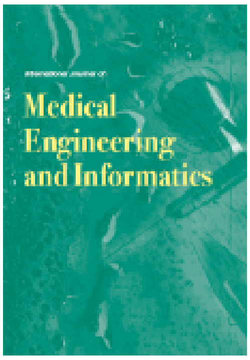

International Journal of Medical Engineering and Informatics

ISSN online: 1755-0661 - ISSN print: 1755-0653
https://www.inderscience.com/ijmei

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DOI: 10.1504/IJMEI.2022.10044040

Article History:

Received:	23 April 2021
Accepted:	12 September 2021
Published online:	22 December 2023

A conceptual model to improve the patient flow during COVID-19

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Abstract: In the COVID-19 context, hospitals across the globe endeavour to manage the unprecedented flow of patients. Challenges are related to the unexpected increase in patients, extra waiting time for cleaning and decontamination of inpatient beds, congested queueing in treatment areas, and waiting time in crowding rooms. This research introduces a new conceptual model to bring a broader, patient-centred, and traceability-based view of patient flow in a clinical setting in the context of COVID-19. The model design opts for four interrelated modes procedural, technical, operational, and contextual. These modes lay the basis of a patient flow solution before starting its development. The feasibility of the proposed model is shown through a usage scenario and developed user interfaces. Results have shown that a knowledge representation of the patient's real-time information can enable better patient flow monitoring. In addition, it would support intelligent healthcare systems that reuse and share pieces of declarative knowledge. Such functionality would enhance the management of patient flow and improve dealing with the patient flow challenges imposed by the COVID-19 pandemic. Moreover, the presented proof of concept laid the ground for future applicability in various clinical settings facing similar infectious disease crises.

Keywords: patient flow; clinical setting; COVID-19; traceability; ontology; artificial intelligence; conceptual modelling; hospital systems.

Reference to this paper should be made as follows: Bougdira, A., Mazti, A., Sedrati, H., Jhilal, F., Amzazi, S., Nejjari, C. and Ghazal, H. (2024) 'A conceptual model to improve the patient flow during COVID-19', *Int. J. Medical Engineering and Informatics*, Vol. 16, No. 1, pp.82–95.

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1 Introduction

Moving patient through a healthcare facility requires the involvement of medical resources, staff, supplies, and internal systems. The patient flow indeed is a description of the entire patient journey within a healthcare facility (admission, hospitalisation, and discharge). Thus, enhanced patient flow means ensuring the patient movement through quick and efficient care pathways (Haraden and Resar, 2004). This throughput should maintain the quality of care and the patients' satisfaction (De Freitas et al., 2018).

During the current COVID-19 pandemic, the patient flow is once again under the spotlight since it is a critical element of hospitals' process management. Besides ensuring capacities to fight COVID-19, hospitals also endeavour to manage the unprecedented flow of patients (thousands of cases in a short period) (Nickbakhsh et al., 2020).

Generally, a poorly or a mismanaged patient flow surely leads to delayed access to medical care and long waiting times in services. Sometimes, such an issue results in adverse health outcomes embodied in increased numbers of re-admissions and mortality (Kreindler, 2017).

In practice, such mismanagement transforms hospitals into overcrowded units where medical staff are stressed and stretched (Saghafian and Traub, 2015). For instance, new admissions could be blocked when inpatients are ready for discharge but are still occupying beds. With this slow throughput and decreased bed capacity, the emergency department boarding time would exceed the acceptable average, also hospitalisation and surgical would be in difficult scheduling (Elder et al., 2015).

The benefits of enhancing the management of patient flow are various and obvious (Winasti et al., 2018). Accordingly, implementing solutions promotes an increased throughput, decreased average length of patient stay, higher patient satisfaction, reduced treatment costs, and ambulance diversions.

We advocate that the tracing and tracking of real-time health data can enhance the management of the patient flow. If one can follow-up instantaneously the patients and events related to them, one could monitor, detect, and intervene to adjust situations (i.e., need an admission bed, oxygenation treatment, or intubation equipment and facilities). Based on this information, a post-analysis could be conducted to detect failure, improve the management ways, and build a predictive model for facing an unknown crisis and expecting complicated situations such as the COVID-19 pandemic.

To that end, we introduce a conceptual model that takes a patient-centred vision to monitor the throughput. The success of this problem-solving strategy is due to the usage of the traceability process. It uses four modes, including procedural, technical, operational, and contextual modes. These modes enable the development of adaptative, customisable, efficient, and scalable solutions for patient flow.

The second section lays the scope of this study and the third one introduces the related work. In the fourth section, the used methods are detailed. In the fifth section, the proposed conceptual model is detailed regarding its four modes. In the sixth section, a usage scenario is conducted. In the seventh section, the theoretical and practical feasibility are discussed before summarising the main conclusions.

2 Scope of the study

The current COVID-19 pandemic is shaping dramatically many aspects of healthcare systems. In case of patient flow, impacts included changes such as postponing many elective cases and cancelling non-emergency ones. Furthermore, healthcare facilities struggle to ensure beds for patients (Nickbakhsh et al., 2020) where some ones remain available only for urgent surgical interventions. For most medical appointments, telemedicine has taken over it, especially for non-priority consultations. In this context, solutions should be introduced to anticipate and mitigate the issue of patient flow under a potential global outbreak (Randelli and Compagnoni, 2020).

3 Related works

The dynamics of the flow of patients can be apprehended by studying strategic departments and seasonal patterns in a hospital (Miranda et al., 2019). Hence, services are evaluated in terms of efficiency to enhance the management system that involves the flow of patients, including the track of outpatients' pathways. In Aguillon et al. (2017), the authors have noticed the patient flow became the issue of all services since it results in crowded emergency departments, waiting for admissions, and inpatients bed issues. Therefore, there is a need for a systems approach that ensures a level of equilibrium between inputs and outputs.

For example, an analysis of primary care clinic with most patients are underserved (Bard et al., 2014) has tried to determine the relationships between individual providers and patient types, length of stay, and the difference between discharge time and appointment time. Another published study (Zafar et al., 2016) tried to quantify pre-procedural patient flow in interventional radiology. The cited work found areas of possible improvement, especially if practices are periodically evaluated to identify inefficiencies.

Efficient patient flow management can be achieved by managing supply and demand for inpatient services across a single system that centralises and integrates bed and case management with transfer centre and patient transport (Lovett et al., 2014).

In contrast to this centralised way, other technological approaches proposed methods to provide dynamic decision support based on the agent-based model to manage hospital resources and predict future resource occupancy (Hutzschenreuter, 2010). According to Drazen and Rhoads (2011), real-time locating systems (RTLS) can play a key role in improving patient flow management. Accordingly, tags are deployed on persons and items. Hence, tracked information can be accessed from a workstation by a staff member who can monitor patients' movement throughout the hospital.

Some research introduced methods that studied and analysed the patient flow using simulation techniques. Such methods combine mining techniques and machine learning with electronic health records (EHRs). Thus, this detailed simulation attempted to improve the patient flow concerning decision making, training, and optimisation (Kovalchuk et al., 2018).

4 Method

The present study on the patient flow in clinical setting opts for a patient-centred perspective (Tan et al., 2013). Hence, we focus on patients as the scientific and medical aspects of patient flow. Moreover, our proposal tries to apply the notion of traceability (Olsen and Borit, 2013), known in other domains such as in food and pharmaceutical industry. Accordingly, this study proposes an adaptation of the main traceability functions for monitoring the patient real-time information. Therefore, we strive to link notions from systems engineering (Laing et al., 2020) for requirements analysis and technological options assessment. Also, we try to establish relationships between operational procedures in terms of integration and implementation.

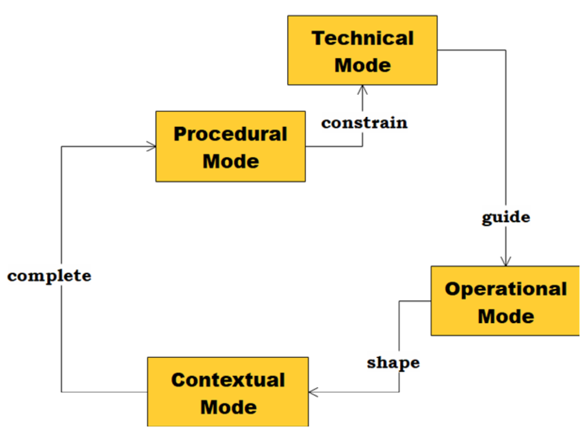
In the healthcare domain, different types of data are used. Due to these heterogeneous data, the current study attempts to face the interoperability challenge and overcome the data integration issue. To that end, we propose the usage of ontology (Yang et al., 2019), which is a part of the broad research field of data integration (Ziegler and Dittrich, 2007). Regarding the context, this work combined mixed methods where data for describing and contextualising the medical domain comes from the literature review, whereas data that is specific to hospitals and processes comes from field investigations.

In a nutshell, we applied the traceability's functions to tackle the patient flow issue in a clinical setting. We use a context-modelling approach (ontology-based) to face the interoperability challenge and overcome the patient data integration issue. The user interfaces are developed using OWL, Protégé 5.5.0, Jena API, and the J2EE environment.

5 Conceptual model

The core idea of the conceptual model is the ability to monitor the patients' movement. Hence, the proposed model takes a patient-centred vision in which the monitoring of the throughput is a key element in the success of the solving strategy of flow's issues. Therefore, the development of a solution revolves around four modes that interact between them to generate an adaptative, efficient, and scalable solution. These modes can be illustrated as in Figure 1.

Figure 1 Main elements of the proposed conceptual model (see online version for colours)



5.1 Procedural mode

As indicated above, the procedural mode is based on the main traceability functions, including identifying, tracking, and tracing (Olsen and Borit, 2018; Bougdira et al., 2019a). The identification process should allow choosing how to identify the targeted entity. It should be determined by the type and structure of the identifier. In traceability, an entity is a traceable resource unit (TRU) (Moe, 1998).

In this paper, the identifier is the patient identifier (PI) that can be permanent (remains valid during consecutive hospitalisations) or changes with each hospitalisation. The identification mechanism should assign a unique ID to patients when they first come to the hospital. It should allow associating the identifier to the patient's information.

The tracking process refers to the localisation of the targeted entity along with the entire throughput. Therefore, the tracking activity enables users to follow the patient geographically. One could see exactly where a patient came from and went (indoor within the hospital, or if possible, outdoor location). This continuous tracking is related to the notion of real-time locating systems (RTLS).

Regarding the tracing process, it enables to record and retrieve information about a patient. This information might include profile data (i.e., patient name, address, and ID), medical data (i.e., test results, condition, and medical history), and device data (i.e., ambient and environmental parameters coming from temperature and humidity sensors).

5.2 Technical mode

In a general way, the technical mode allows developers to adapt tools to deploy a solution functionality. The implementation requirements dictate which technology could be used.

In case of identification, one can use a paper-based technique (i.e., a badge of patients) or an automatic technique [e.g., radio frequency identification (RFID), near field communications (NFC), and quick response (QR)-code]. For example, RFID enables an automatic identification of patients using a system of reader/tags. This contextual information is transferred when a patient is detected by a reader.

In the case of tracking, the position of patients changes throughout many stages. Therefore, the need for real-time localisation requires a combination of indoors (i.e., RFID) with outdoor positioning techniques (GPS). This monitoring requires RTLS technologies. Information can be accessed anywhere and anytime. Such a strategy can involve various positioning data (i.e., RFID, sensor networks, and GPS).

For tracing, two specifications should be considered heterogeneous data and the way of managing and integrating this data. This issue is from data-integration field where various techniques can be used (Ziegler and Dittrich, 2007).

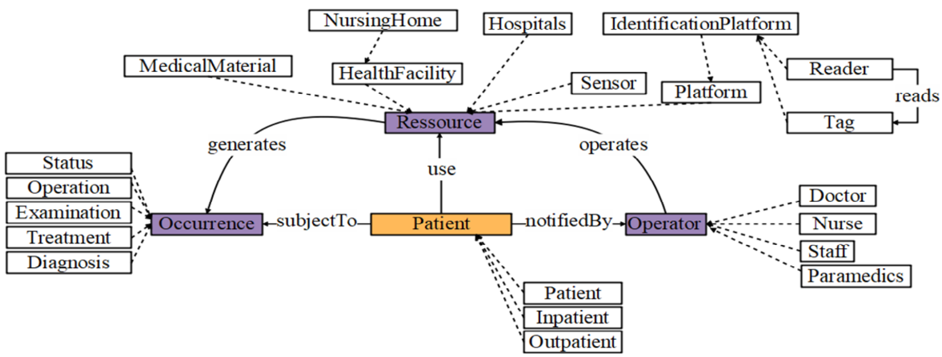
5.3 Operational mode

The operational mode should focus on patients and their movement through different services (i.e., emergency department and radiology). Thus, each time a patient undergoes an examination, moves into or out of service, changes its status, the procedural mode enables to follow-up the patient and its information. The representation of operational mode should be the most possibly general and inclusive, and it should take a broader picture of the throughput. Ideally, it should combine field observation and literature review, including recommendations by the World Health Organization (WHO) (2020, 2021).

5.4 Contextual mode

Based on the context-modelling, a knowledge representation would be built to formalise the most noticeable data necessary for monitoring the patient flow. This context-modelling is indeed derived from intelligent traceability ontology (ITO) (Bougdira et al., 2019b) and the modelling of traceability in industry 4.0 (Bougdira et al., 2019c). A patient can refer to inpatient, elective or acute case. The medical context is described as *operator*, *resource* and *occurrence* (Figure 2).

Figure 2 Patient and the medical context (see online version for colours)



Such formalisation considers the patient and its surroundings (operator, resource, and occurrence). Using these initial concepts, one can extend this representation by adding more subclasses and sub properties of objects and data. In the medical field, 'operator' can be a doctor, surgeon, physician, nurse, paramedics, and caregivers. 'resource' can involve health care facilities, hospitals, services, emergency departments, medical materials, and platforms (e.g., identification with RFID technology). In this context-modelling, 'occurrence' is an event that could be an examination, test results, a doctor's report, a biology test, a patient status, or treatment procedure.

For example, a doctor (*operator*) operates an ultrasound (*resource*) that generates an image that is interpreted into a medical report (*occurrence*). During the monitoring of patient flow, this information is associated with its identifier as the patient moves into the throughput.

Using the first-order logic (Diekert et al., 2008), the defined concepts allow building logical statements. Other inferential evidence can be derived using the semantic web rule language (SWRL). Typically, this modelling lays the basis for developing ontologies that use web ontology language (OWL) and resource description framework (RDF).

6 Case study

A simulation scenario is conducted to address the functioning way of the conceptual model explicitly. As a testing case, a brief description of the steps for model application is provided. The simulation is conducted in Hassan II University Hospital, Fez, Morocco, which provides tertiary care, acute care, and hospitalisation. It is also a centre for professional education and healthcare research and training.

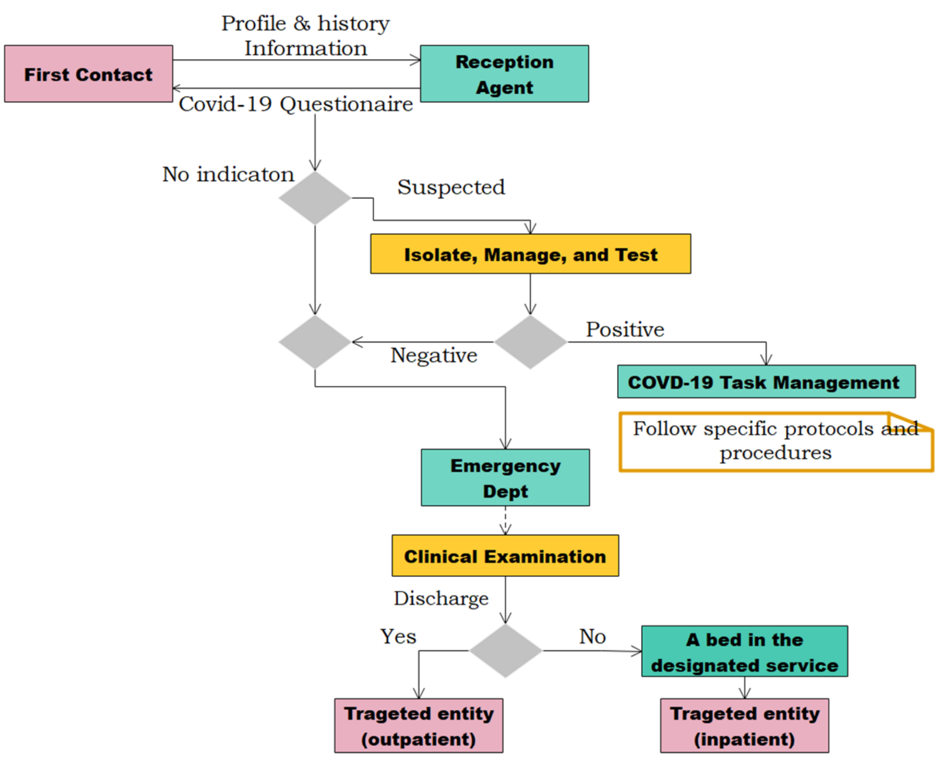
6.1 Implementation's steps

First, we set the needed activities for implementing and executing identification, tracing, and tracking (procedural mode) (i.e., instructions to follow for recording patient's data and the persons authorised to access data). Next, we choose RFID technology (technical mode) since it allows both automatic patients' identification and indoor localisation.

6.2 Flow diagram

For the operational mode, the flow of patients is represented in a general way (Figure 3). This representation tries to adapt to the constraints and changes imposed by the COVID-19 outbreak. In practice, a patient is contacted by a nurse or a care coordinator assistant. Here, profile information (i.e., name, address, and phone number, insurance ID, and medical history) are requested. With the COVID-19, a questionnaire about symptoms is also required.

Figure 3 General representation of the patient's flow in a clinical setting within a COVID-19 context (see online version for colours)

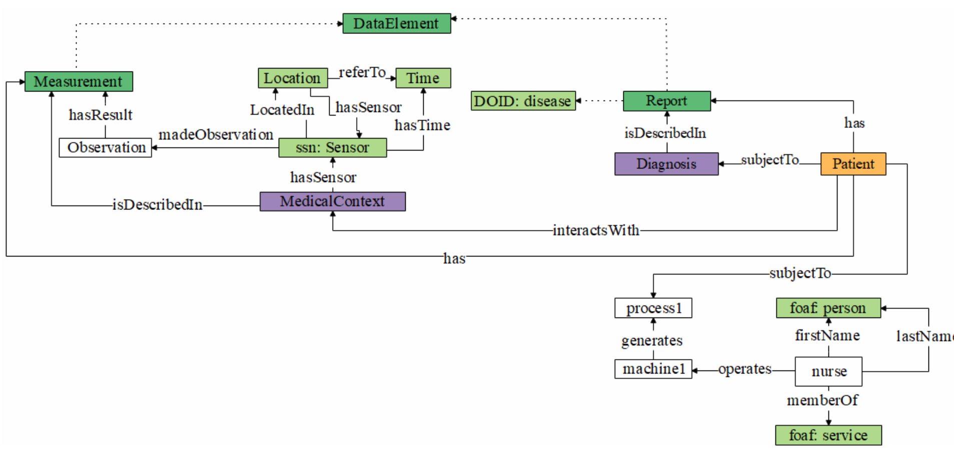


6.3 Context's external relationships

The context-modelling can describe external interactions with existing standards and ontologies. In the medical domain, we mention unified medical language system (UMLS) (Bodenreider, 2004), health level 7 standard (HL7) (Orgun and Vu, 2006), and human disease ontology (Schriml et al., 2019). Here, the UMLS would help to promote standardised vocabularies and terminology. In the case of HL7, the suggested modelling takes into consideration the importance of exchanging and retrieving the electronic health information (HL7RIMLib is stored in the RDF/RDFS format).

In the case of human disease ontology (ODID), one can find information about a disease in a patient's diagnosis. In general context, we can cite semantic sensor network (SSN) (Compton et al., 2012), friend of a friend and (FOAF) ontology (Brickley and Miller, 2014). The data is related to sensing and observations from the SSN ontology. In the case of RFID technology, the patient ID and its location are considered as RFID-measurement data. In the case of FOAF ontology, the proposed contextual mode can get information from this ontology (i.e., first/ last name of the nurse involved in the treatment of a patient). All these relationships with externals ontologies are illustrated in Figure 4.

Figure 4 Proposed context and its relationships with externals ontologies (see online version for colours)



6.4 Usage scenario

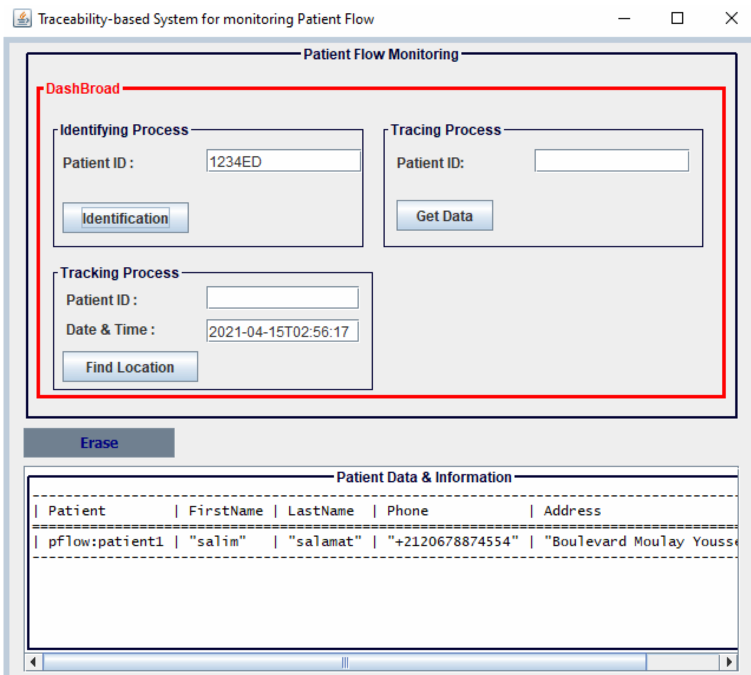
The following user interface shows the possible outcomes of the model applicability. These user interfaces are developed using tools like OWL, Protégé 5.5.0, Jena API, and J2EE environment.

Supposing a patient, namely, patient1 is being unable to orientate within the hospital. A nurse tried to help him, by entering the patient identifier, the nurse can verify the patient identification (i.e., whether the patient is registered, when he was registered, and his profile information) (Figure 5).

Moreover, the nurse can view which service the patient was assigned to and how long the patient has been waiting for a given service. This tracing information would help to direct the patient to the next step and efficiently organise and optimise the throughput.

In case of losing track of a patient, a care coordinator can use the tracking process to determine the patient location. For example, one can deduce the patient location through its last-known status. The patient's record and the patients' tags show that mammography has been taken, therefore the patient can most be likely found in the radiology department.

Figure 5 Identification process with information of patient 1 (see online version for colours)



7 Discussion

The conceptual model involves a traceability-based approach that is more required than ever due to the COVID-19 context (i.e., need for quick and efficient responses to sudden and drastic changes). The conceptual framework represents the patient's information and its surroundings in the same context-modelling. However, this suggested context-modelling still needs enhancements and more mapping onto the medical domain [i.e., electronic health record, health level seven (HL7) standards, and open biomedical ontologies]. Practically, the proposed model solution might be combined with other strategies like reviewing the patient flow process and its relationships, or specific tools that track patient's data according to sub-specialists (Newman et al., 2020). Moreover, the proposed method must learn from others' existing solutions centred on improving care coordination for an optimal health outcome.

8 Conclusions

In this paper, a conceptual framework for developing a patient flow solution in the clinical setting has been proposed. The model tried to take into consideration the challenges of the COVID-19 pandemic, such as the unexpected increase in patients and the extra waiting time for cleaning and decontamination of inpatient beds. Therefore, the suggested model involves procedural, technical, operational, and contextual modes. These modes help to lay the basis of a patient flow solution before starting its development. Such an approach enables to set more adaptive, efficient, scalable, and customisable solutions. Studying the theoretical feasibility and conducting a case scenario showed the importance of the model application. Such results laid the ground for future works regarding the model deployment.

Author statement

Authors have no special considerations regarding their submission. There are no related papers by any of the authors already published or under consideration for publication. There are no previous communications with any of the editors.

Acknowledgements

HG is a recipient of a grant from NIH through the H3 African Bioinformatics Network h3abionet/H3Africa.

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