International Emergency Nursing xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Emergency Nursing

journal homepage: www.elsevier.com/locate/aaen

Developing an emergency department crowding dashboard: A design science approach

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ARTICLE INFO

Article history:
Received 9 November 2016
Received in revised form 22 June 2017
Accepted 3 August 2017
Available online xxxx

Keywords:
Emergency department
Crowding
Dashboard
Data analysis
ED management
Design science research

ABSTRACT

Background: As an emergency department (ED) is a complex adaptive system, the analysis of continuously gathered data is valuable to gain insight in the real-time patient flow. To support the analysis and management of ED operations, relevant data should be provided in an intuitive way.
Aim: Within this context, this paper outlines the development of a dashboard which provides real-time information regarding ED crowding.
Methods: The research project underlying this paper follows the principles of design science research, which involves the development and study of artifacts which aim to solve a generic problem. To determine the crowding indicators that are desired in the dashboard, a modified Delphi study is used. The dashboard is implemented using the open source *Shinydashboard* package in R.
Results: A dashboard is developed containing the desired crowding indicators, together with general patient flow characteristics. It is demonstrated using a dataset of a Flemish ED and fulfills the requirements which are defined a priori.
Conclusions: The developed dashboard provides real-time information on ED crowding. This information enables ED staff to judge whether corrective actions are required in an effort to avoid the adverse effects of ED crowding.

1. Introduction

1.1. Research problem

The fact that most emergency departments (EDs) are often crowded is well known amongst healthcare professionals and repeatedly described in literature [1–4]. Emergency department (ED) crowding has been linked to negative consequences for both patients (e.g., mortality and morbidity) and caregivers (e.g., work related stress and burnout) [5].

The current research paradigm is concerned with predicting and controlling — predicting when crowding happens and controlling the causal factors to prevent crowding from happening. To predict the occurrence of crowding, researchers have tried to single out the most important causal factors — often positioned within Asplin's model [6], followed by intervention studies seeking to control aspects of ED operations in order to prevent crowding from happening. However, the context in which ED crowding takes place is characterised by a complex adaptive system (CAD) [7]. The ED is a complex macroscopic collection of partially connected micro-structures (agents), formed in order to adapt to the changing environment, such that its survivability as a macro-structure increases. The system is complex in the sense that it is a dynamic network of interactions, in which the relationships compel more than aggregations of individual static entities. The system is adaptive in the sense that the individual and collective behaviour mutates and organises itself according to the change-initiating micro-event or collection of events. Microscopic impulses at the level of the individual agent can generate macroscopic effects. The adaptive character of the system can be powerful if it is sufficiently sensitive to anticipate upon changes in the environment. However, the peculiar structure of critical networks can allow macroscopic "avalanches" to take place. In the context of ED crowding this means full waiting rooms and unsafe conditions.

As the behaviour of such a complex adaptive system is hard to predict and control, it has been suggested to alter the research paradigm towards analysing and managing [8]. Analysing refers to the use of continuously gathered data. The introduction of

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http://dx.doi.org/10.1016/j.ienj.2017.08.001
1755-599X/

information and communication technology (ICT) tools, electronic patient tracking, electronic patient files and so on, has provided us a mass of data related to occupancy, waiting time and other relevant operational measures and indicators [9]. These data should be analysed in order to create questions and answers that really matter and to gain insight into what is happening without relying on proxy measures, predicted outcomes, or gut feeling [10]. It is important to realise that these data are the reflection of a process, which is executed for each patient. Gaining useful insights requires analytical techniques that consider and exploit the process dimension within the data. Managing refers to the proactive management of the system in order to prevent devastating "avalanches". Instead of waiting until the ED is crowded and patients need to be placed in the hallway, changes in indicators must be recognised and managed accordingly to prevent situations of poor quality and safety. This requires a systems approach, which, besides changes in the basic structure of the organisation, also comprises continuous analysis, ad hoc adaptations of procedures, and adjustments to reduce the effect of causal factors.

1.2. Study purpose

The rationale behind this study is situated in the aforementioned need for real-time information regarding ED crowding. More specifically, the purpose of the study is the development of a dashboard designed to provide this information. This will increase the sensitivity of the ED as an adaptive system and enable staff members to proactively judge whether corrective actions are required. By supporting ED analysis and management, it is an asset towards achieving higher levels of quality and safety.

1.3. Research question

As a first step in a project aimed to improve quality and safety in an ED, a system was needed that delivers real-time information regarding ED crowding. To this end, it needs to be investigated how a system fulfilling this need should be developed. This paper describes the development of such a system, which should present the information deemed desirable by ED staff in an intuitive way.

2. Methods

From a methodological perspective, this study follows the principles of design science research (DSR). DSR involves the development and study of artifacts, which are human-made objects that aim to solve a generic problem experienced in practice [11]. While natural sciences tend to focus on problem understanding and explanation, the central goal of DSR is problem solving [12], which underlines its relevance for the topic of this paper. In this paper, the artifact corresponds to the dashboard, which addresses the need to have a workable process monitoring tool to gain real-time insight in ED crowding.

In order to select the crowding indicators that need to be included in the dashboard, a modified two-round Delphi study is used. The central premise of Delphi is founded upon the assumption that collective group opinion is more valid than personal opinion alone [13]. The Delphi technique was chosen as a method to develop consensus in a group who would reflect national ED management. In the first round, a questionnaire is distributed to the heads of department of all Flemish EDs. The responses are summarised and presented to experts in the second round, which explains the modified character of the Delphi study. Consultation of experts is likely to improve the quality of the received feedback for the purpose of the study.

2.1. Design science research

The research project underlying this paper follows the principles of design science research (DSR). For a detailed discussion on DSR, the reader is referred to, e.g., Johannesson and Perjons [11], Wieringa [14] and Dresch et al. [15]. In literature, several frameworks have been proposed which outline the key activities that need to be conducted when performing DSR. Given its clear structure, this paper uses the framework of Johannesson and Perjons [11], which is based on the work of Peffers et al. [16]. The framework describes five DSR activities, which can be revisited at any stage of research: (i) problem explication, (ii) artifact and requirement definition, (iii) artifact design and development, (iv) artifact demonstration and (v) artifact evaluation. Each of these five activities will be briefly discussed within the problem context under consideration.

Firstly, the problem at hand needs to be studied and its relevance has to be shown. From the introduction, it follows that a shift towards analysing and managing an ED as a complex adaptive system requires the presence of real-time information on ED crowding. Moreover, it should be determined which crowding measures are deemed desirable by ED staff.

Secondly, the artifact that will be developed is defined, and its requirements are identified. The artifact that will be developed is a dashboard containing real-time general patient and patient flow statistics and a set of crowding indicators. To select the most desirable crowding indicators, a modified two-round Delphi technique is used to establish consensus amongst a panel of nurses and clinicians drawn from an ED background, with experience in operational managing. The Delphi technique is a well-established hybrid research method that combines both qualitative and quantitative approaches [17]. As indicated in the introduction, a questionnaire is distributed in the first round to the heads of department of all Flemish EDs (February 2016). The input obtained from 26 questionnaires is summarised and presented to 6 experts in the second round (March 2016). Based on their input, the measures that are included in the dashboard are selected. The results of the modified Delphi-study are also used to specify requirements for the artifact, which are listed in the results section.

Thirdly, the artefact is designed and developed. The dashboard is implemented using the *Shinydashboard* package [18] in R [19]. R is an open source software language which provides extensive functionalities for data manipulation, data analysis and the creation of graphs. *Shiny* [20] is an open source web application framework which enables users to transform their analyses into interactive web applications. The *Shinydashboard* package builds upon these foundations and has a special focus on dashboard development using *Shiny*.

Fourthly, the developed artifact is applied to a specific problem instance to demonstrate its feasibility. To this end, the results section outlines the dashboard's operations using a real-life dataset of an ED. The available dataset contains anonymized data of 4451 patients, recorded by the information system of a Belgian ED in April 2011. Besides basic personal information such as gender and age, the dataset also contains medical information such as the triage code, the ED unit to which the patient is assigned and an indication of whether the patient is discharged at the ED. Moreover, dates and times are included for: the assignment of a treatment room; the triage code assignment; the request of the first lab test; the delivery of the first lab result; the delivery of the last lab result; the request of the first radiological examination; the execution of the first radiological examination; the delivery of the first radiological report; The delivery of the last radiological report; The retrieval of drugs from the electronic cabinet; the request of a hospital bed (in case of admittance to the hospital); the assignment of a hospital bed (in case of admittance to the

Please cite this article in press as: Martin N et al. Developing an emergency department crowding dashboard: A design science approach. Int. Emerg. Nurs. (2017), http://dx.doi.org/10.1016/j.ienj.2017.08.001