Developing an emergency department -crowding dashboard: a design science approach

N. Martin, J. Bergs, D. Eerdekens, B. Depaire, S. Verelst

ABSTRACT

The phenomenon of emergency department (ED) crowding is often experienced by healthcare professionals and studied in literature. As an 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 also be provided in an intuitive way. In this respect, this paper describes the development of a dashboard which provides real-time information regarding ED crowding. Using a modified Delphi study, a series of desirable crowding indicators are identified. Providing these measures, together with general patient flow statistics, enables ED staff to proactively judge whether corrective actions are required.

KEYWORDS

- emergency department
- crowding
- dashboard
- data analysis
- design science research

1. INTRODUCTION

The fact that most emergency departments (EDs) are often crowded is well known amongst healthcare professionals and repeatedly described within the literature (Boyle et al., 2012; Pines et al., 2011; Pitts et al., 2012; Verelst et al., 2014). Emergency department (ED) crowding has also become a public concern. The latter is reflected by the increased media attention. This attention is not unjustified, given the significant consequences for both patients (e.g. mortality and morbidity) and caregivers (e.g., work related stress and burnout) (Johnson and Winkelman, 2011).

Although the recognition of the ED crowding problem began at least a decade ago, many unanswered questions remain. When considering these questions, one might wonder — how it is possible that we are able to treat complex diseases, yet not able to prevent a simple queue?

The ED crowding problem is, in essence, a classical economical problem — a discrepancy between supply and demand. Despite the large number of publications describing the consequences, there is however little consensus on a definition of ED crowding. The simplest of definitions states that "*crowding occurs when the identified need for emergency services exceeds available resources for patient care in the ED, hospital, or both"* (Hoot and Aronsky, 2008 p.126). Notwithstanding the lack of a standard criterion definition, the literature is replete with efforts to measure crowding (Hoot et al., 2007; McCarthy et al., 2011). The criteria used to validate these crowding measures include: clinician opinion, consensus panel, ambulance diversion, patients left without being seen, times to care, and forecasting. Nevertheless, the lack of an unambiguous definition is a first hurdle in finding appropriate solutions. As without a clear definition it is difficult to describe what actually needs to be solved.

The current research paradigm is, predominantly, preoccupied 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 placed within Asplin's model (Asplin et al., 2003). This was 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) (Chinnis and White, 1999). The ED is a complex macroscopic collection of partially connected micro-structures (agents), formed in order to adapt to the changing environment, so 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. It is the peculiar structure of those critical networks that allow macroscopic "avalanches" to take place. In the context of ED crowding this means full waiting rooms and unsafe conditions. It seems clear that the behaviour of such a complex adaptive system is hard to predict and control. Therefore, it has been suggested to alter the research paradigm towards analysing and managing (Bergs et al., 2016). Analysing refers to the use of continuously gathered data. The introduction of information and communication technology (ICT) tools, electronic patient tracking, electronic patient files and so on, has provided us a mass of data (e.g., data on occupancy, waiting time and other relevant operational measures and indicators) (Ryu and Song, 2014). 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 (Kamal, 2014). It is important to realise that these data are the reflection of a process, which is executed for each case. Gaining useful insights requires analytical techniques that consider and exploit the process dimension within the data. More specifically, the analytical approach should be able to deal with choice and concurrency in the process, i.e. not every patient receives the same treatment and the order of certain activities can change arbitrarily. 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. To support analysing and managing of ED operations, we need a system that presents data in an intuitive way. Therefore, the aim of this paper[1] is to describe the development of a dashboard designed to deliver real-time information regarding ED crowding.

2. METHODS

This section outlines the methods used in the study, i.e. design science research is described in Section 2.1 and the modified Delphi study is discussed in Section 2.2. The last subsection, Section 2.3, focuses on ethical considerations.

2.1 Design science research

The research project underlying this paper follows the principles of design science research (DSR). DSR involves the development and study of artefacts, which are human-made objects that aim to solve a generic problem experienced in practice (Johannesson and Perjons, 2014). In this paper, the artifact corresponds to the dashboard, which addresses the need to have a workable process monitoring tool for the ED in response to the crowding problem. While natural sciences tend to focus on problem understanding and explanation, the central goal of DSR is problem solving (Niehaves, 2007). This does not imply that its outcomes are only related to one particular case as DSR should also generate abstract knowledge that is applicable to a set of problem instances (Goldkuhl and Lind, 2010). For a detailed discussion on DSR, the reader is referred to, e.g., Johannesson and Perjons (2014), Wieringa (2014) and Dresch et al. (2015). The remainder of this section focuses on how the DSR principles can be operationalized for the problem at hand.

[1] This paper builds upon the master thesis project of the third author.

In literature, several methodological 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 (2014), which is based on the work of Peffers et al. (2007). The framework describes five DSR activities, which can be revisited at any stage of research. Firstly, the problem at hand needs to be studied and its relevance has to be shown. The importance of additional efforts to support EDs in dealing with the crowding problem is summarized in the introduction of this paper. Secondly, the artifact that will be developed is defined, and its requirements are identified. These requirements for the dashboard, which is the proposed artifact, are outlined in Section 3. Thirdly, the artifact needs to be created, as outlined in Section 4. Fourthly, the developed artifact is applied to a specific problem instance to demonstrate its feasibility. To this end, Section 5 outlines the dashboard's operations using a real-life dataset of an ED. Finally, the artifact is evaluated by determining the degree to which it meets the requirements, which is the topic of Section 6.

2.2. Modified Delphi study

This study utilises a modified two-round Delphi technique to establish consensus amongst a panel of nurses and clinicians drawn from an ED background, with experience in operational managing. The technique is used to select the most desirable crowding indicators, which are included in the dashboard. The Delphi technique is a well-established hybrid research method that combines both qualitative and quantitative approaches (Keeney et al. 2001). The central premise of the Delphi is founded upon the assumption that collective group opinion is more valid than personal opinion alone (Hasson et al. 2000). Consensus is reached through successive survey rounds whereby panelists are requested to generate and reassess findings. The Delphi technique was chosen as a method to develop consensus from a group who would reflect national ED management.

2.3. Ethical considerations

The study was conducted according to established ethical protocols. The need for ethical approval was waived by a Belgian Higher Education Institute, research ethics committee. All participation was voluntary and participants were made aware of their right to withdraw from the study at any point without explanation. Participant anonymity was assured via the anonymous online data collection tool. The act of completing each questionnaire was interpreted as consent to participate in the study.

3. REQUIREMENT SPECIFICATION

The dashboard's central goal is to provide an overview of the current situation of the patient flow at the ED. Using this information, staff members can proactively judge whether corrective actions are required to avoid or tackle crowding. To operationalize this goal, requirements are specified. Consistent with Johannesson and Perjons (2014), a distinction is made between functional and non-functional requirements. While the former specify the functions that the artefact needs to provide, the latter are related to the artifact's structure and its environment.

Two functional requirements for the dashboard are put forward:

- The dashboard should represent and visualize the degree of crowding on the ED in a non-binary way such that the user can judge the current situation.
- The dashboard has to provide real-time information.

Besides these functional requirements, four non-functional requirements are also specified:

- The dashboard needs to present its content in a clear and concise way. Even though the dashboard has to provide a complete view on the ED status, staff members should be able to analyze the provided information in a short time span.

- The dashboard should be usable in multiple EDs and, hence, has to be generic and standardized. In this way, it can be implemented in another ED with minimal adjustments.
- The dashboard has to provide information unambiguously. When visualizations are used, these should not be prone to misinterpretations.
- The information that is used and the visualizations should adhere to privacy regulations.

The requirements outlined above will guide the dashboard's development (Johannesson and Perjons, 2014). The extent to which the dashboard is consistent with the requirements will be discussed in Section 6.

4. DASHBOARD DESIGN AND DEVELOPMENT

This section outlines the design and development of the dashboard. The dashboard's use case is described in Section 4.1. Section 4.2 describes the modified Delphi study that is used to select the most desirable crowding indicators based on insights from the working field. The structure of the dashboard and its implementation is discussed in Section 4.3.

4.1. Dashboard use case

Given the dashboard's goal to provide ED staff with comprehensive patient flow information, Figure 1 visualizes the dashboard's use case. The user interacts with the dashboard by consulting it and receiving real-time information. Based on this information, the user can determine the extent to which the ED is crowded and decide whether corrective actions are required. When measures are taken, this will impact the dashboard as they aim to influence patient flow. The dashboard can be used to evaluate the effect of the corrective actions to determine whether further adjustments are required.

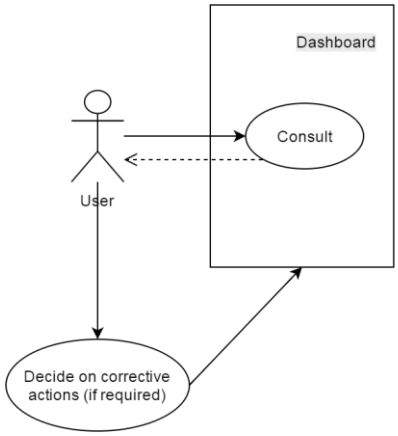


Figure 1: Use case diagram

4.2. Dashboard structure and implementation

4.2.1. Dashboard structure

The general structure of the dashboard is presented in Figure 2. From this diagram, it follows that the dashboard requires a limited number of settings and provides information divided in seven content tabs. A screenshot of the dashboard's layout is provided in Figure 3, where three parts are distinguished using rectangles with rounded corners. In the top left part (red rectangle), the user has to specify some settings such as the number of nurses, the number of doctors and the number of available beds. The lower left part (green rectangle) lists the tabs that are available and from which the content is visualized at the right (blue rectangle).

Using the results of the modified Delphi study as an input, the dashboard's content tabs are defined. The remainder of this subsection will provide a brief overview of these content tabs.

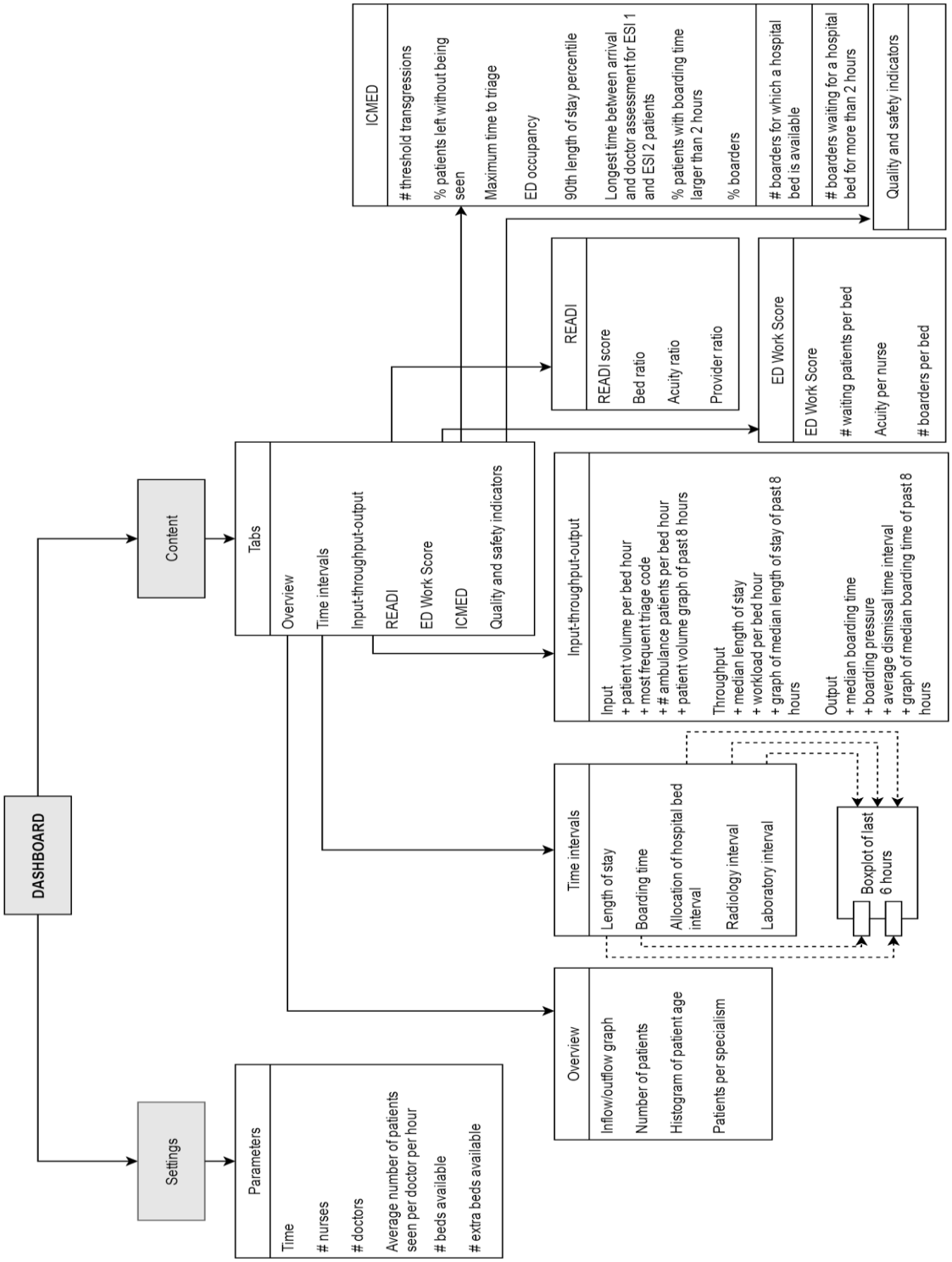


Figure 2: Diagram of dashboard structure



Figure 3: Screenshot of dashboard structure

1. Overview tab

The overview tab, which is opened in Figure 3, is composed of three graphs which present an overview of the current situation at the ED. The upper graph shows the evolution of patient in- and outflow on the current day with a one-hour interval. While patient inflow is visualized by a stacked bar chart with triage code as a grouping variable, patient outflow is represented using a line. The two graphs at the bottom provide insight in the composition of the patient population by representing their age and the ED unit to which the patient is assigned. As is the case for the in- and outflow graph, colors reflect the composition of a patient group in terms of triage code.

2. Time interval tab

The first round of the modified Delphi study shows that not all time intervals defined by Wiler et al. (2015) are judged equally desirable. Consequently, five time intervals, all scoring above 5.5 on a 7-point desirability Likert scale on average, are selected for inclusion in the time interval tab. These are the length of stay, boarding time, the time until the allocation of a hospital bed, the radiology interval and the laboratory interval. As such time intervals tend to have a positive skew, both the mean and median are included in the dashboard. Compared to the mean, the median is influenced less severely by outliers. Besides presenting the mean and median values for the current situation, the dashboard also depicts the evolution in the time interval values. By clicking on one of the intervals, one-hour boxplots are shown for each of the past six hours. This is illustrated in Figure 4, where length of stay is selected.

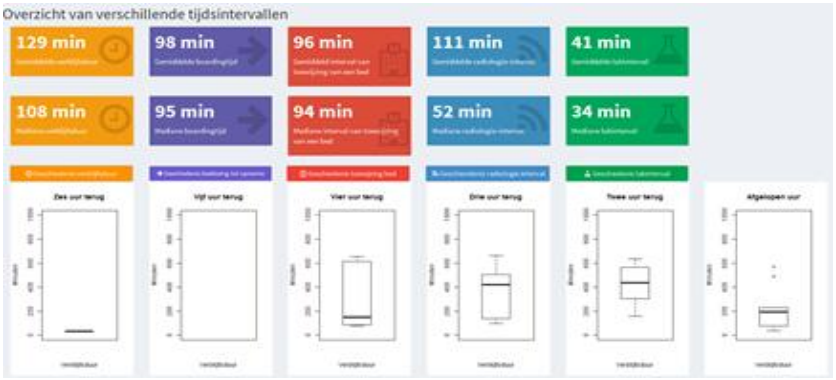


Figure 4: Screenshot of the time interval tab

3. Input - throughput - output tab

The input-throughput-output tab, of which a screenshot is provided in Figure 5, contains eight measures formulated by Solberg et al. (2003). The patient volume standardized by the number of bed hours, the most frequently occurring triage code and the number of ambulance patients per bed hour are included as input measures. The two throughput measures are the median length of stay and the workload per bed hour. Three output measures are included: the median boarding time, the boarding pressure and the average discharge time interval. All the selected measures have an average score above 5.5 on a 7-point Likert scale of desirability during the first round of the modified Delphi study. For the patient volume per bed hour, the median length of stay and median boarding time, graphs are included depicting the evolution of these measures' values during the past eight hours. This can be seen at the bottom of Figure 5.

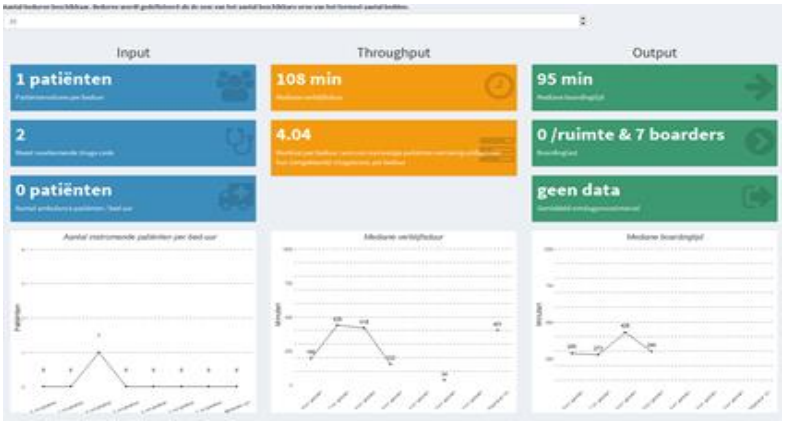


Figure 5: Screenshot of the input-throughput-output tab

4. READI tab

Of all quantitative crowding measurement scales, READI (Hoot et al., 2007) achieved the highest desirability score in the first round of the modified Delphi study. Even though an expert expressed doubts regarding the use of READI as a predictor of crowding in the second round, it is still included in the dashboard given the strong support during the first round. As shown in Figure 6, the READI tab contains both the READI score and its building blocks, i.e. the bed ratio, the acuity ratio and the provider ratio.

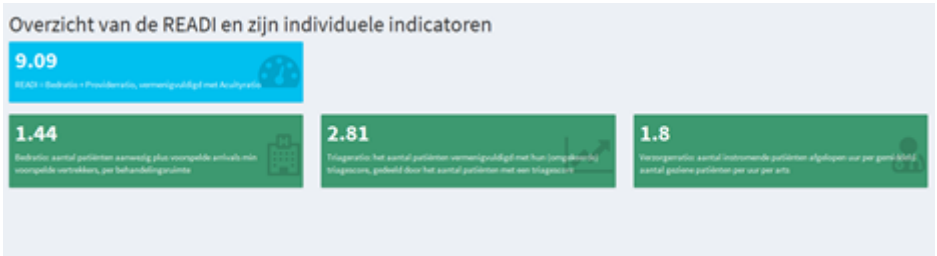


Figure 6: Screenshot of the READI tab

5. ED Work Score tab

The ED Work Score (Epstein and Tian, 2006) also received a high desirability score in the modified Delphi study. The layout of the corresponding dashboard tab is similar to the structure of the READI

tab as it also depicts the aggregated ED Work Score and its individual indicators. These individual indicators are the number of patients waiting per bed, the acuity per nurse and the number of boarding patients per bed. A screenshot of the ED Work Score tab is provided in Figure 7.



Figure 7: Screenshot of the ED Work Score tab

6. ICMED tab

Based on the results of the modified Delphi study, ICMED (Boyle et al., 2013) should not be included in the dashboard with a mean desirability score of 5. This might be attributed to the fact that it is proposed quite recently. As ICMED refrains from making a binary judgment on whether or not the ED is crowded, it is included in the dashboard. As shown in Figure 8, the ICMED tab includes the indicators in the middle and the number of threshold transgressions at the top. At the bottom of the tab, the number of boarders for which a hospital bed is available and the number of boarders that is waiting for a bed for over two hours are shown. These values are added as they can be more informative than the associated ICMED indicators which are expressed as percentages.



Figure 8: Screenshot of the ICMED tab

7. Quality and safety indicator tab

The analysis of ED's operations currently focuses on quantifying the degree of crowding. Finding appropriate measures for this purpose has proven to be a challenging task. Quality of care and patient safety can also be influenced by crowding. However, quality and safety indicators still need to be developed. Moreover, the influence of ED occupancy on these indicators needs to be measured to determine the required ED capacity and, consequently, a threshold for crowding (Bergs et al., 2016). The critical importance of quality of care and patient safety requires their inclusion in a dashboard that aims to provide comprehensive support to ED staff. Following this line of reasoning, a quality and safety indicator tab is already added in the dashboard's conceptual overview in Figure 2.

4.2.2. Implementation

The dashboard structure, discussed in Section 4.3.1, is implemented using the *Shinydashboard* package in R. R[2] is an open source software language which provides extensive functionalities for data manipulation, data analysis and the creation of graphs. *Shiny*[3] is an open source web application framework which enables users to transform their analyses into interactive web applications. The *Shinydashboard* package[4] builds upon these foundations and has a special focus on dashboard development using *Shiny*.

5. DASHBOARD DEMONSTRATION

The dashboard is designed to provide real-time patient flow information to ED staff. For the purpose of this paper, real-time behavior is simulated using a real-life dataset. By selecting a particular moment within the timespan of this dataset, it can be handled as if it was real-time information. A brief description of the dataset is included in Section 5.1, after which the application of the dashboard is outlined in Section 5.2.

5.1. Dataset description

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 last 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 last triage code;
- 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 hospital);
- The time at which a patient leaves the ED.

Until now, all fields focus on one particular patient. The dataset also includes data on the average number of patients that is present in the ED during the x-th hour of presence of this patient, with x ranging from 1 to 8. This provides insight in the pressure on the ED during the stay of a particular patient.

5.2. Dashboard application

To simulate real-time support, the dashboard was initialized on April 1st, 2011 at 7pm. The number of nurses and doctors are set to 12 and the number of beds equals 25. While a detailed description of all indicators is beyond the scope of this paper, this section aims to demonstrate the applicability of the dashboard in a real-life context.

---

[2] https://www.r-project.org

[3] http://shiny.rstudio.com

[4] https://cran.r-project.org/web/packages/shinydashboard

Given the settings outlined above, the overview tab of the dashboard indicates that 60 patients are present at the ED. As shown in Figure 9, the overview tab highlights that arriving patients are primarily of triage codes 3 and 4. Moreover, the age histogram indicates that mainly geriatric patients are present. The histogram at the bottom right shows that ED units with code IAL and TRH have to deal with the highest number of patients.

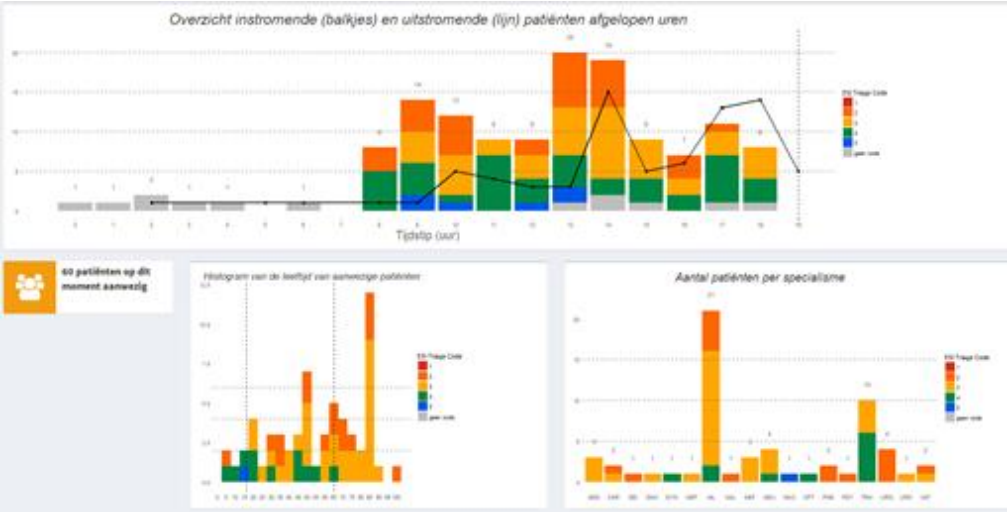


Figure 9: Screenshot of overview tab on April 1st, 2011 (7pm)

The input-throughput-output tab in Figure 10 indicates that the throughput in the ED and the transfer to the hospital are troublesome with a median length of stay of 272 minutes and 30 boarders. The fact that hospital transfers pose a problem is confirmed by the ICMED indicators, as shown in Figure 11. 93% of all boarders are waiting over 2 hours to be transferred to a hospital ward. Moreover, for 18 of the 30 boarders, a hospital bed is already available. Note that the ICMED indicators indicate an crowded ED as 6 threshold transgressions are observed. A similar conclusion is reached in the READI and ED Work Score tab.

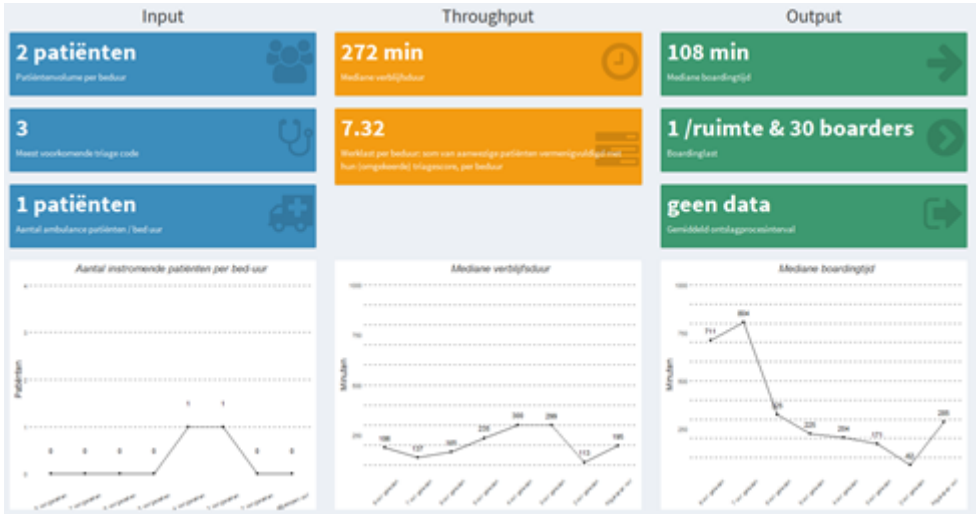


Figure 10: Screenshot of input-throughput-output tab on April, 1st (7pm)

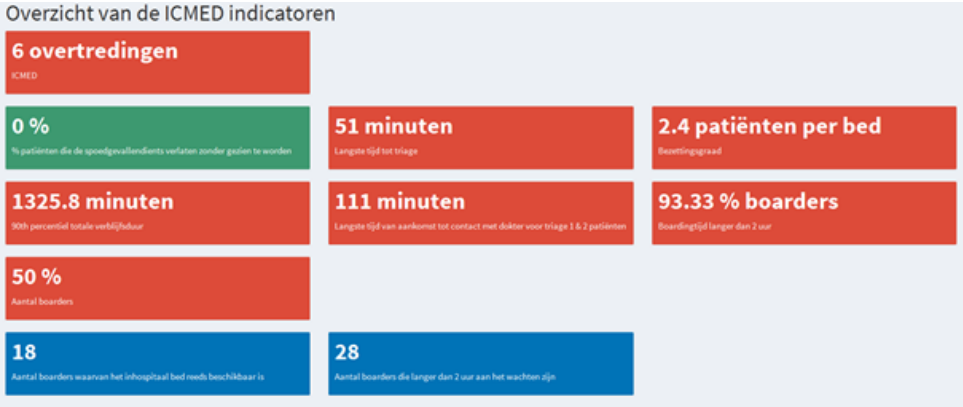


Figure 11: Screenshot of ICMED tab on April, 1st (7pm)

6. DASHBOARD EVALUATION

In DSR, evaluation comes down to the determination of the degree to which the developed artifact meets its requirements (Johannesson and Perjons, 2014). This section outlines the extent to which the presented dashboard meets the requirements formulated in Section 3.

The first requirement indicates that the degree of crowding should be represented and visualized in a non-binary way. The proposed dashboard fulfills these conditions as it includes a series of crowding indicators defined in literature. Moreover, the values of these indicators are given, without a value judgment. Consequently, no binary assessment on ED crowding is made as the interpretation of the numeric values is left to the user.

The second requirement relates to the real-time character of the dashboard. Depending on the time at which the dashboard is consulted, the indicators and graphs will be adjusted to reflect the ED status at a particular point in time. This is also simulated for demonstration purposes in Section 5. As a consequence, the dashboard has the capacity to provide real-time support when real-time information is inserted to the data table underlying the dashboard.

Requirement 3 stipulates that information needs to be provided in a clear and concise way. The dashboard presents a limited number of crowding indicators, which are grouped in tabs. From the wide range of measures defined in literature, the most desirable ones are selected by means of a modified Delphi study. Moreover, the overview tab allows the user to quickly gain insight in the status of the ED. Therefore, it can be concluded that the dashboard presents its content in a clear and concise way.

The fourth requirement states that the dashboard should be sufficiently generic such that it can be used in multiple EDs. The dashboard's reusability is ensured by the settings that the user can specify, such as the number of nurses and the number of beds. Using these settings, the calculation basis of the crowding indicators can easily be adjusted to the specificities of an ED. Regarding the dashboard's content, it should be noted that all indicators originate from literature and the included measures are selected using a multi-centric modified Delphi study.

Requirement 5 indicates that information should be provided unambiguously. For graphical visualizations, the lie-factor of Tufte (2001) can be considered, which is calculated by dividing the effect size in the visualization by the effect size in the data. When the resulting value lies between 0.95 and 1.05, the graph can be deemed to be free from distortions as the latter can be misleading for the user. Within the proposed dashboard, no differences are present between the effect sizes in the data and the visualizations. Consequently, the lie-factor conditions are satisfied. Besides graphs, the dashboard only provides numerical values as the user is responsible for their interpretation.

Consequently, all information is presented in an unambiguous way, which minimizes the risk for misinterpretations.

The final requirements demand adherence of privacy regulations. The dashboard does not require personal information or medical details of identifiable patients, as shown in its demonstration using an anonymized dataset. Moreover, the dashboard is composed of aggregated information and does not allow for the identification of individual patients.

Based on the discussion outlined above, it can be concluded that the proposed dashboard fulfills the formulated requirements. However, additional evaluation efforts can increase the support for the dashboard. The dashboard might for instance be used in practice, after which the users can be queried on their experiences with respect to the requirements.

7. CONCLUSION

This paper presents a dashboard providing real-time information on patient flow in an ED. Besides general statistics on the patients currently present at the ED, a series of crowding indicators are provided. To maintain the dashboard's clarity, the most desirable indicators are selected using a modified Delphi study. The provided information will enable staff members to proactively judge whether corrective actions are required to avoid and to tackle crowding. The dashboard is developed using the principles of design science research, which provides a solid methodological underpinning for the research process. Future work can improve the information value of the current dashboard by, e.g., including color schemes which reflect positive or negative evolutions in an indicator's value. Moreover, further evaluative efforts can provide additional support for the importance of the proposed dashboard. These evaluative actions can include its use in practice, which would stress the dashboard's contribution to ED practice. While the previous recommendations are situated within the scope of the current dashboard, the functionality scope can also be extended. In this respect, integrating prediction and real-time simulation in the dashboard are promising directions. This can enable the dashboard to provide recommendations on potential courses of action to improve patient flow in an crowding situation.

REFERENCES

Bergs, J., Vandijck, D., Hoogmartens, O., Heerinckx, P., Van Sassenbroeck, D., Depaire, B., Marneffe, W., Verelst, S. Emergency department crowding: time to shift the paradigm from predicting and controlling to analysing and managing. International Emergency Nursing. 2016; 24:74-7.

Boyle A, Beniuk K, Higginson I, Atkinson P. Emergency Department Crowding: Time for Interventions and Policy Evaluations. Emergency Medicine International. 2012;2012(2):1–8.

Boyle, A., Coleman, J., Sultan, Y., Dhakshinamoorthy, V., O'Keeffe, J., Raut, P., Beniuk, K. Initial validation of the International Crowding Measure in Emergency Departments (ICMED) to measure emergency department crowding. Emergency Medicine Journal. 2013; 32:105-8.

Dresch, A., Lacerda, D.P., Antunes, J.A.V. Design science research. Heidelberg: Springer, 2015.

Epstein, S.K., Tian, L. Development of an emergency department work score to predict ambulance diversion. Academic Emergency Medicine. 2006; 13(4):421-6.

Goldkuhl, G., Lind, M. (2010). A multi-grounded design research process. Lecture Notes in Computer Science. 2010; 6105:45-60.

Hasson F, Keeney S, McKenna H. Research guidelines for the Delphi survey technique. Journal of Advanced Nursing. 2000; 32(4):1008–15.

Hoot, N.R., Zhou, C., Jones, I., Aronsky, D.. Measuring and forecasting emergency department crowding in real time. Annals of Emergency Medicine. 2007; 49(6):747-755.

Johannesson, P., Perjons, E. An introduction to design science. Heidelberg: Springer, 2014.

Keeney S, Hasson F, McKenna HP. A critical review of the Delphi technique as a research methodology for nursing. International Journal of Nursing Studies. 2001; 38(2):195–200.

Niehaves, B. On epistemological diversity in design science: new vistas for a design-oriented IS research?. Proceedings of the 2007 International Conference on Information Systems. 2007.

Peffers, K., Tuunanen, T., Rothenberger, M. A., Chatterjee, S. A design science research methodology for information systems research. Journal of Management Information Systems. 2007; 24(3): 45-77.

Pines J.M., Hilton J.A., Weber E.J., Alkemade A.J., Shabanah Al. H., Anderson P.D., et al. International Perspectives on Emergency Department Crowding. Academic Emergency Medicine. 2011; 18(12):1358–70.

Pitts SR, Pines JM, Handrigan MT, Kellermann AL. National trends in emergency department occupancy, 2001 to 2008: effect of inpatient admissions versus emergency department practice intensity. Annals of Emergency Medicine. 2012; 60(6):679–686.e3.

Solberg, L.I., Asplin, R., Weinick, R.M., Magid, D.J. Emergency department crowding: consensus development of potential measures. Annals of Emergency Medicine. 2003; 42(6):824-834.

Tufte, E.R. The visual display of quantitative information. Graphics Press: Cheshire, 2001.

Verelst S, Wouters P, Gillet J-B, Van den Berghe G. Emergency department crowding in relation to in-hospital adverse medical events: a large prospective observational cohort study. The Journal of Emergency Medicine. 2015; 49(6): 949–61.

Wieringa, R. Design science methodology. Heidelberg: Springer, 2014.

Wiler, J.L., Welch, S., Pines, J., Schuur, J., Jouriles, N., Stone-Griffith, S. Emergency department perfoamnce measures updates: proceedings of the 2014 emergency department benchmarking alliance concensus summit. Academic Emergency Medicine. 2015; 22(5):542-553.