A Decision Support Visualization Tool for Infection Management Based on BMPN and DMN

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Abstract. The interdisciplinary team of an Antimicrobial Stewardship Program is indispensable to preserve the antibiotic utility and avoid resistance in a hospital. One key duty of this team is the administration behaviour surveillance, which is a complex and tedious issue.

In this work we present a tool to support this supervision by visualising some essential elements of the antimicrobial therapy: patient record, guidelines and key decision actions. The tool uses standardized models of industry (BPMN, DMN) to ease its maintenance in the long term and its interopreability.

1 Introduction

There is an increasing concern worldwide about the loss of efficacy of antibiotics in bacterial infection [12,13,21]. Antimicrobial Stewardship Program teams (ASPs) are the hospital response to global antibiotic resistance, composed of multidisciplinary members. They are aimed to achieve a rational use of antibiotics, improving the collaboration between the hospital departments [3,16]. Data integration, visualization, and clinical decision support systems based on Clinical Practice Guidelines (CPGs) can be helpful tools for ASPs to manage the overwhelming information produced in hospitals [2]. However, most clinicians admit that they do not make an intensive use of CPGs in their daily practice. During the last decades, there are different proposals of automatization and representation in the literature, such as Asbru, GLARE, PROforma and GLIF, among others [17]. Some recent studies have focused on the use of available business process standards, such as the Business Process Model and Notation (BPMN 2.0) or conformance checking [22]. Other improvements to business process technologies might be also useful in medical scenarios, such as the Decision Model Notation (DMN 1.1) [15], a new standard specifically designed for the modelling of decisions.

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In this work, we present a visualization tool to support decisions for ASP teams, according to the needs identified in a previous work [2]. This proposal lies on the use of standardized models of industry to show the current state of the patient, the context of a potential CPG (BPMN) in use and specific medical actions (DMN).

The remainder of this paper is structured as follows: in Sect. 3 we introduce the tool architecture and the details of its implementation. Section 4 describes the results of implementing a specific case of Vancomycin management. Finally, in Sect. 5 we present our conclusions and future work.

2 Related Work

Visualization is a key aspect for clinical decision support systems [5]. The purpose of using visual analysis of data is to exploit human perception as well as to help in the understanding and communication of data and concepts.

The National Research Council of the National Academies [14] diagnosed that the extra time required to introduce data into review systems for decision making is largely owing to the lack of adequate cognitive support when interacting with clinicians. In fact, in 2012, the US Institute of Medicine recommended solving this problem through the use of visualisation models with scenarios of interdisciplinary clinical practice [8].

Visualisation models in the clinical context are mainly focused on two aspects: the custom visualisation of a single patient health record and the visualisation of groups of patients [20].

For example, the goal of IPBC [4] was to improve the therapeutic adjustment in haemodialysis using a three-dimensional visualization. KHOSPAD [18] was designed to identify temporal relationships between primary care doctors, the patient and hospital stays. The objective of KNAVE-II [23] is to visualise oncological treatment information, while the VISITORS system [10] combines intelligent temporal analysis and information visualisation techniques in order to integrate, process and visualise information concerning multiple patients and information sources.

With regard to the visualisation of groups of patients and their characteristics, we can highlight sequence visualisation models such as lifeLines2 [24] and viscareTrails [11], along with techniques based on a single temporal axis like IPBC [4] and InfoZoom [1].

Nevertheless, little attention has been explicitly paid to clinical decision support systems for healthcare associated infection, and very few specific works on the visualisation of epidemiology statistics [7] have been used to detect the outbreak of infections. In [6], a visualization tool is proposed to assist clinicians in the prescription of empiric treatment.

In this work, we propose the use of visualisation techniques combining standard industry models (BPMN and DMN) to guide physicians according to a given guideline.

3 Decision Support Tool

We propose a visualization tool designed to support decisions for antibiotic and infection management embedded in a general platform to support antimicrobial management teams called WASPSS. Our proposal is based on the following aspects:

1. patients: visualization of relevant information of the patient record, using an interactive timeline representation;
2. processes: visualization of the process of potential CPG in use, using standard process models and indicating the current status. We propose the use of BPMN;
3. actions: decision making of specific clinical actions using standard decision models such as using the new DMN model.

Figure 1a shows the general architecture of the tool. The rest of the section describes the components and their implementation in detail.

3.1 WASPSS Platform

The Wise Antimicrobial Stewardship Program Support System (WASPSS) [16] is a technological platform that comprises the integration of hospital departments databases (laboratory, pharmacy, etc.) and the Health Information System (HIS) to support the ASP team activity and to improve the collaboration between the hospital departments. WASPSS also provides basic alerts on administration of antibiotic therapy (prescription and therapeutic limits). Current version of WASPSS is running at the University Hospital of Getafe, Spain. The visualization tool presented is an extension of the current version.

3.2 EHR Interactive Timeline

The linearly organised flow of a timeline provides a great communicative power to easily summarise the current state of the patient record.

The WASPSS system already has a simple timeline chart of several events in a patient's clinical history, such as treatments, cultures and stays. We extend the Electronic Health Record (EHR) visualization of WASPSS, integrating events of the patient's clinical history (antibiotic administration, blood tests, etc.). Moreover, this view enriches the representation of the temporal perspective related to process and decision diagrams obtained from the guideline. Figure 1b (top) shows the implementation of the iteractive timeline: basic information about the patient is displayed at the top of the picture, while the timeline view below shows all the stays, laboratory tests, treatments and cultures performed, including a view of the guideline tasks at the end.

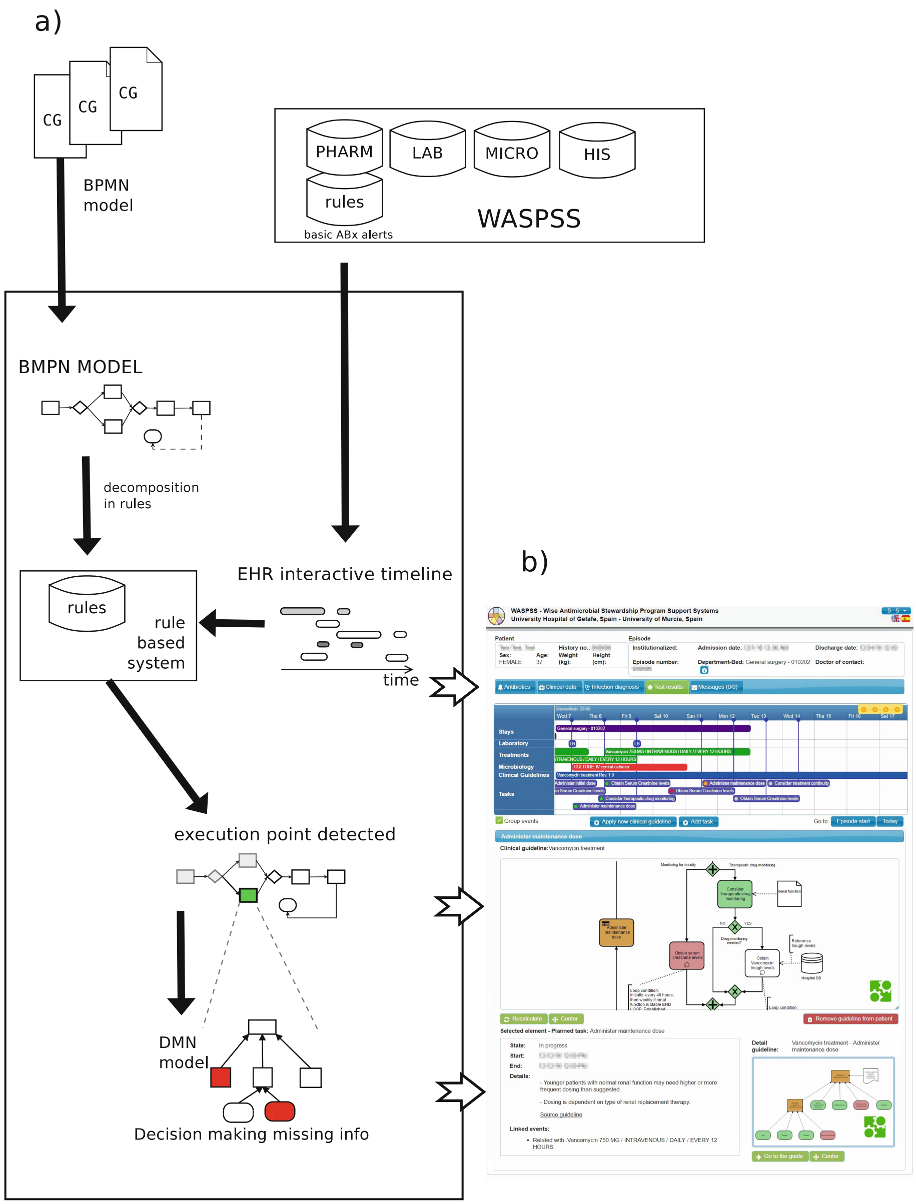

Fig. 1. Tool architecture (a) and snapshot of current implemented version (b). (Color figure online)

3.3 Guideline and BPMN Model

In this work we shall focus on the CPG knowledge components that support the following decisions:

1. the recommended steps to follow to treat infections and
2. decision rules regarding the antibiotic to be applied according on certain symptoms.

We consider that the use of generally accepted standards in industry for process design, since it provides solid technology for long-term maintenance. To this end, key knowledge from guidelines is obtained, under medical supervision, using a semi-automatic process using technology available in the market. In particular, this tool version implements the standard notation currently used for business process modelling (BPMN 2.0) to model procedural aspects of clinical guidelines.

The knowledge extracted from the guidelines refers to clinical processes coordinating people, resources and information dealing with patients. A process is composed of activities (tasks), events and splitting/merging points, and can be considered and managed by using suitable approaches such as BPMN.

3.4 Rules: Excecution Point

The second goal of our proposal is to put the patient record into the context of a CPG that might be followed by the clinician. Our tool aims to visualize the all steps (using the BPMN graph) of the recommendation process, indicating which might be the current step, called the execution point. However, detecting the current execution point of a CPG for a given patient is a complex issue. Our approach consists in checking for every BPMN task whether it is either in progress, completed or omitted.

From the computational point of view, this problem means to deal with the automatic map of each BPMN task with the elements of the patient record. The key issue is the way the current status of each task is inferred in the BPMN. In our proposal, we decompose the whole BPMN process in a set of production rules. Therefore, a rule-based system is implemented according to the following aspects:

1. the input is the current state of the patient (visualised in the timeline),
2. the knowledge base has the rules extracted from the BPMN,
3. and a forward-chaining reasoning engine is used. Its outcome is an inferred fact for each task (or several, if the task is inside a loop) containing the status inferred.

The implementation has been carried out by using Drools [19] as a rules engine, a consolidated solution in industry that is easy to integrate with Java code. Figure 1b (middle) shows the BPMN process and the execution point.

3.5 DMN: Decision Support

The last goal of this tool is to support a specific set of decisions of antibiotic therapy. Unlike indicating the execution point of the CPG, a general set of recommendations, the tool aims to visualize the elements required to deal with some clinical actions. We propose the use of a new standard, the Decision Model and Notation (DMN 1.1) [15], to represent process-related decision making. This notation makes it possible to model complex decisions by depicting the data requirements and the previous decisions that must be considered to obtain the final recommendation.

Similarly to the execution point, we use production rules to make knowledge represented in DMN executable. Detailed explanations about any decision status are possible using rule-based inference. All the rules include metadata regarding their origin (guideline, task, etc.) and all the facts generated include, in a human-readable way, the complete history of rules launched to generate them. Clinicians may therefore check each suggestion made by the system and validate its foundation. DMN visualization and suggestions are shown in Fig. 1b (bottom). If the box representing the decision is green, this means that all the required input data are available, and the user can then request a suggestion about the decision based on available knowledge. These rules will subsequently be fired to generate the suggested decision.

4 Case of Use: Vancomycin

The survey of Vancomycin administration is essential due to its resistance to many health-care associated strains. In this case of study, we propose BPMN and DMN models of the public guidelines for the Vancomycin treatment proposed by the Johns Hopkins Hospital [9].

- Firstly, we face the modelling of CPG using BPMN. Usually, two main objectives can be pursued when creating a computer-interpretable model from a CPG. On the one hand, the model should be as detailed as possible, in order to cover as many aspects from the CPG as possible. On the other hand, the model should be as simple as possible for fostering interpretation by domain experts. Unlike current computerized CPG methodologies, which are based on a comprehensive description, we present the modelling of those parts that are critical for decision-making and for which we have sufficient data to provide proper decision support.
  We propose a BPMN diagram (Fig. 2) representing the main steps to be performed during the treatment. Only the main tasks are modelled, and we focus on the need to carry out periodic controls so as to ensure the appropriate dosage of antibiotics. Activities are represented by means of rounded-corners rectangles. Gateways are used to define splitting/merging points, and are represented as diamonds with a "+" for parallel branching points, and an "×" for that data-based branching points where it is needed to choose an exclusive path. The decision activities are represented using activity rectangles but

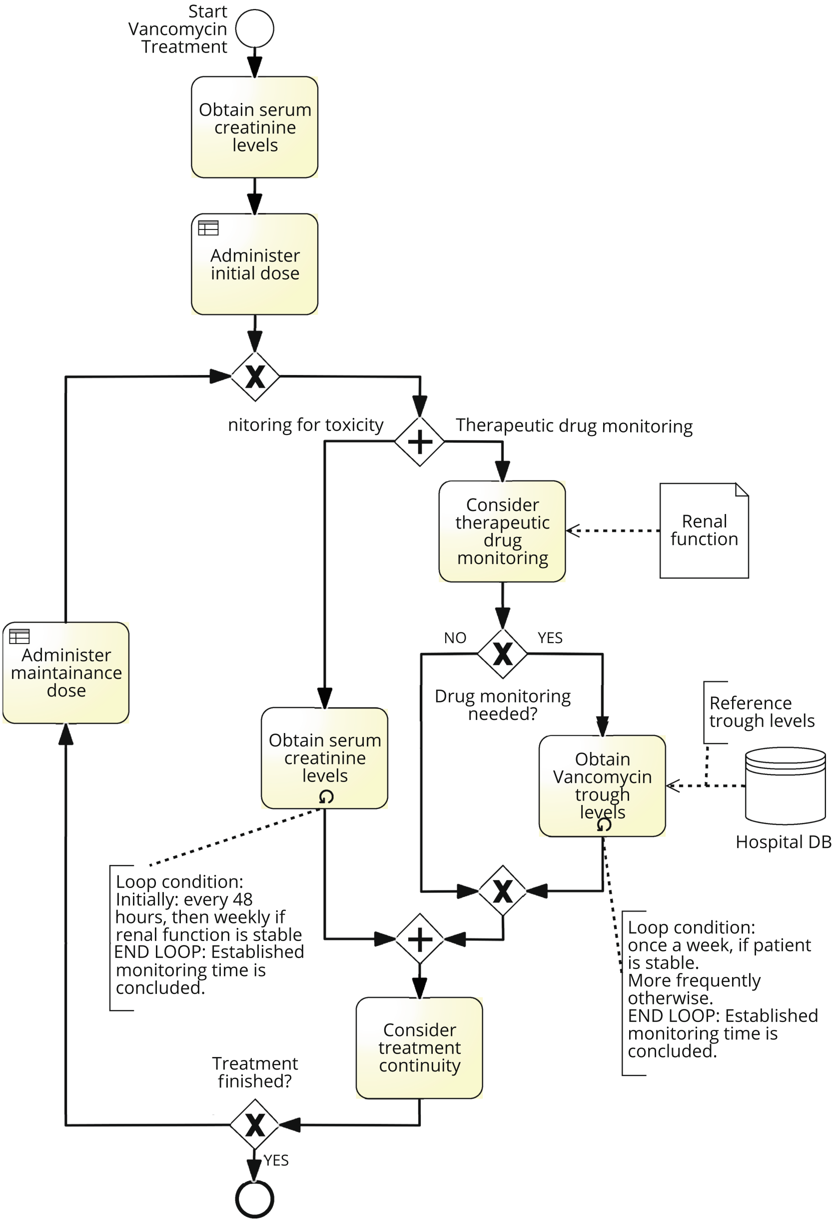

Fig. 2. Example of Vancomycin treatment: BPMN

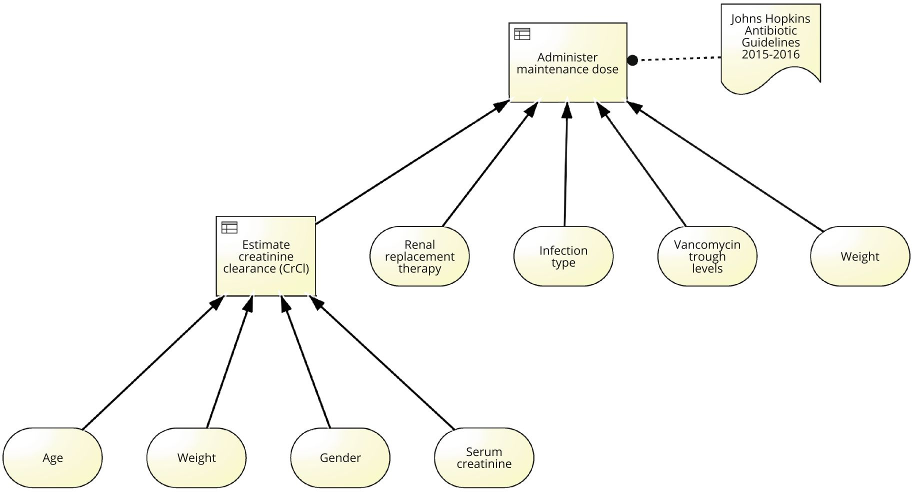

Fig. 3. Example of Vancomycin treatment: DMN model.

including an specific mark (a small table) located at the up-left. As shown in Fig. 2 the represented part of the CPG is a simple BPMN diagram composed of 5 activities and 2 decision activities.

- Secondly, we model the decision of *administer maintenance dose* using DMN. This decision depends on available information (e.g. renal replacement therapy or patient weight) and *estimation creatinine clearance*, a second decision to me made. Figure 3 shows a DMN decision requirements diagram for the main decision *administer maintenance dose*. As shown, decision activities are represented as rectangles and are related to the needed information, that are depicted as rounded rectangles. Other knowledge sources, such as authority and related published documents, are shaped as wavy-sided rectangles.
- Figure 4 shows how the tool supports a decision for *Administer maintenance dose* using DMN visualization. The first component visualizes the DMN model. In green the available components are highlighted. For example, the *Age*, *Weight*, *Gender* and *Serum creatinine* components are available and, therefore, *Estimate creatinine clearance (CrCl)* is possible. The second component of the tool shows the DMN selected element, in this case *Administer maintenance dose*, and the information available in the health record (e.g. timestamped 12/18/2016 12 pm). The third module helps the physician by providing a suggestion. In this example, the tool, according to the guideline, suggest an initial Vancomycin dose of 1000 mg.
- Finally, Fig. 1b depicts a real example of a ICU patient for the Vancomycin problem and how the visualization tool aims to support decisions. The interactive timeline shows the current state of the patient, indicating the Vancomycin details (750 mg every 12 h, intravenous). The BPMN panel depicts the current guideline execution modelled in Fig. 2. The *Administer maintenance dose* task has been selected, and the interface therefore shows a detailed

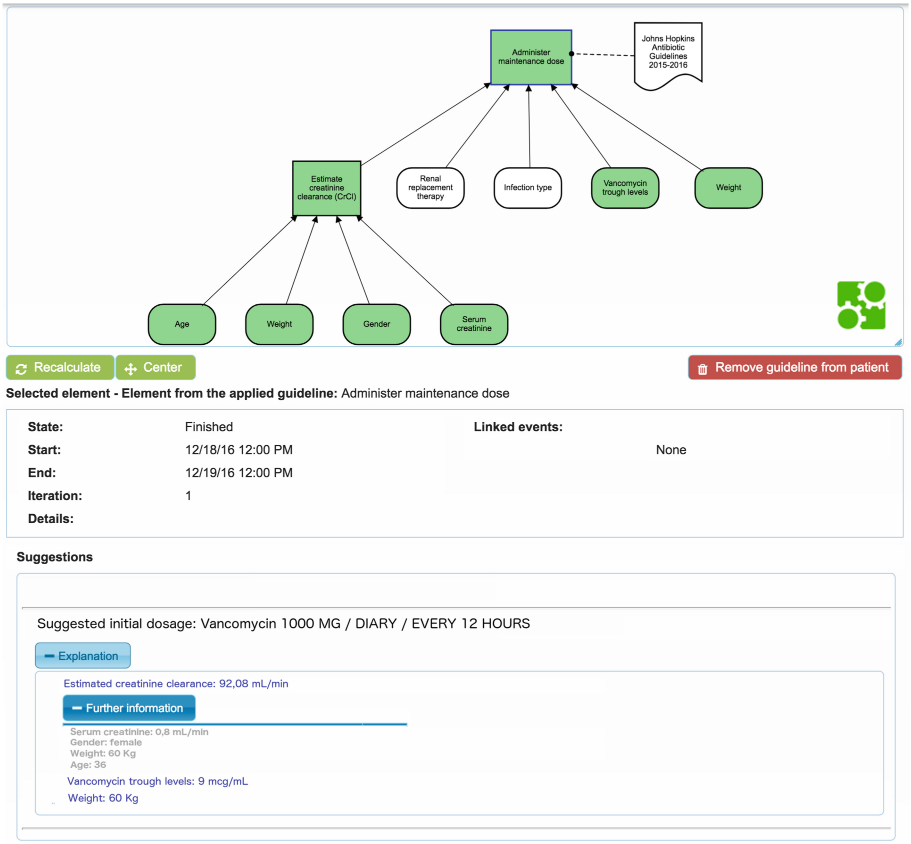

Fig. 4. Visualization tool snapshot: decision supported using DMN. (Color figure online)

description (including the linked DMN model), showing the missing information to make a decision.

The supervision of Vancomycin using our visualization tool is currently under evaluation by the ASP team of the University Hospital of Getafe.

5 Conclusions

In this work we propose a tool to support decisions for infection management considering the visualization of: the current state of the patient, the context of a potential CPG in use and specific medical actions.

There is a myriad of models to approach this problem. However, part of the originality of this work relies on the assumption of using solid technologies tested in the industry, avoiding unstandardized models, in order ease its integration in hospital systems and to assure its maintenance in the long term.

The presented tool is integrated the WASPSS platform [16] and patient information is visualized using an interactive timeline, a simple and widely extended model.

We use the BPMN to model processes contained in the CPGs and the novel DMN model to represent decision tasks. We also use BPMN/DMN for visualisation when a CPG is applied to a specific patient, colouring the elements of the model in different ways depending on its adherence. We use production rules to: (1) provide the user the context of a adherence of a CPG by inferring the state of each task of the CPG (in progress, completed or omitted) and (2) support decision based on the tasks modelled by DMNs. On the one hand, the BPMN and DMN provide a standard formalism to express and share different types of task process and rationale. On the other hand, production rules are widely used antibiotic recommender systems in the industry. Its use also allows us to infer helpful information for the physician to make a decision.

The tool is currently under evaluation in a hospital to assess on the management of Vancomycin therapy, and we plan to incorporate mechanisms with which to facilitate the linking of tasks and data.

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