Exploring the Use of Context-Awareness in Scheduling Methods to Approach the Patient Planning Problem

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***Abstract*—Lately, in literature, a few papers have been published on methods for solving patient planning problems involving uncertainty. Most authors consider very simple recourse actions, typically only counting the extra overtime resulting from unexpected delays. This is not very realistic in a real world setting, since one in practice wants to dynamically reschedule as unexpected events occur. To be able to perform as such, a scheduling system must address three main challenges: (1) enlarge its scope; (2) plan for uncertainty; and (3) solutions approach. In this paper, is discussed how the context-aware methodology can contribute as a solution to this problem, by enabling process support.**

Keywords-scheduling; context-aware; healthcare; workflow

I. INTRODUCTION

The majority of the hospitals use a so-called block-booking system when planning surgeries. In this system, a medical specialty is assigned to blocks denoting a specific amount of time, e.g., a day, in one Operating Room (OR). These blocks can be combined into cyclical Master Surgery Schedules (MSS), where every block is repeated after a fixed cycle. At the strategic level of block-booking system, the number of blocks assigned to the specialties and emergencies during a MSS cycle is determined. At the tactical level, OR-days are allocated to specialties in an MSS, such that the strategic allocation is met.

In recent years, approaches to solve MSS have become more complex, in the sense that they started to consider multiple resources and tackle uncertainty more accurately.

Uncertainties might come from different sources, such as processing times, demand/patient arrivals, no-show ups, personnel availability, etc.

Clearly, MSS affects the patient flow to downstream inpatient care units. Surgeries performed in each block of the MSS create a flow of patients through the Intensive Care Unit (ICU) to the ward, or directly from the OR to the wards, before they leave the hospital. The post-anesthesia care unit might be part or not of the OR department.

The development of an MSS module must address three main challenges:

1) Enlarging the scope of the MSS: MSS approaches embedded in commercial software consider only the impact of the MSS on operating theatre and operating staff; the goal here is to enlarge the scope to down-stream resources, such as the intensive care unit ICU and the general wards required by the patients. The solution module should be flexible enough to cope with different features that appear in different hospitals that interfere with the planning activities.

2) Planning with uncertainty: Surgical management processes are subject to high variability resulting in significant deviations between intended and actual performance of surgical plans. For instance, when surgeries take longer than predicted or emergency patients arrive, it often results in overtime and possible cancellation of surgeries. When planning at an aggregate level, uncertainties are usually neglected. The challenge is to anticipate the uncertainties and incorporate them during the MSS decision-making.

3) Solution approaches: The problem cannot be totally described in mathematical programming terms. The volatility of information (see previous point) makes it difficult to incorporate all uncertainty in a single solid deterministic model.

To tackle such challenges, a MMS module has to enable a fast and automated, fully context dependent, scheduling. In such scenario, context-aware systems present themselves as a promising approach.

This paper is divided in four section. In Section I, are presented the major challenges regarding scheduling in healthcare environments. In Section II, is presented a brief literature review on evidence that some of the health IT, currently implemented in clinical practice, lacks process support. In Section III, is presented the context-aware methodology, and, in Section IV, is discussed how this methodology can contribute to process support, and improvement of operational management. Section V concludes the article providing some ideas for future work.

II. BACKGROUND

A few papers have lately been published on methods for solving patient planning problems involving uncertainty. Significant improvements can be attained by doing this [1]-[4]. Exact methods, such as stochastic programming [1][2], or robust optimization [2] seem unable to solve problems of a realistic size within reasonable time. For this reason, some authors apply a "Sample Average Approximation" (SAA) approach, to speed up the calculation of recourse costs (i.e., the cost of handling unforeseen changes in the scheduling problem) [3][5]-[7]. Even more pragmatic approaches use

 ISBN: 978-1-61208-618-7

Column generation [6], simple heuristics [2], local search [8], or meta-heuristics like Simulated Annealing [5][8] or Tabu search [5]. These can be applied either to the original problem, to the SAA simplified problem, or to a modified problem including hedging on resource demand or availability [8].

Most authors consider very simple recourse actions, typically only counting the extra overtime resulting from unexpected delays. This is not very realistic in a real world setting, since one in practice wants to dynamically re-schedule as unexpected events occur. Only very few authors consider more advanced recourse actions [4][9].

Very little work has been done for integrated planning and scheduling under uncertainty for planning that covers more than a week into the future. The vast majority of hospitals do not consider data uncertainty at the planning level. However, such an approach can have substantial negative impact at the operational level and result in a suboptimal use of OR's.

For obtaining robust schedules, that will anticipate possible disruptions, OR's planning should consider uncertainty. Bruni et al. [4] use stochastic programming to model uncertainty associated with arrival of emergency patients and duration of surgery. The authors also presented some recourse strategies that model reactive scheduling policies.

The problem of optimizing the assignment of surgeries and sufficient planned slacks to the operating days such that the risk of working overtime is minimized, no surgeries are cancelled and operating room utilization is improved is addressed by [8]. The problem is solved by Local Search and improvement heuristics.

Other models, that create MSSs with levelled bed occupancy in downstream units, are presented in [10][11]. Both the number of patients and the length of stay in the hospital are assumed to be stochastic. Beliën and Demeulemeester [10] aim to minimize the expected bed shortage. The problem is solved by mixed-integer programming and Simulated Annealing. Fügener et al. [11], concentrate on inpatient flow and define a model to calculate, for a given MSS, the expected distributions of recovering patients in the downstream units. Based on this, it is proposed an approach for planning the MSS with the objective to minimize downstream costs by levelling bed demand and reducing weekend bed requests. The main distinction between the two papers is that [10] only allows one downstream resource, while [11] models multiple downstream units.

A multistage stochastic mixed-integer programming formulation for the assignment of surgeries to operating rooms over a finite planning horizon is proposed in [12]. Demand for and the duration of surgery are random variables and the objective is to minimize expected cost of surgery cancellations, patient waiting time, and operating room overtime.

It should be emphasized again, that the master surgery schedules are usually performed manually at the hospitals, without any type of systems to support the decision making. It should be performed with a given periodicity. The underlying method to generate MSS that levels the workload and increases the efficiency of the surgical nursing wards, without deteriorating the OR department's efficiency, is based on simulation-optimization.

The above-described work identifies common signs that the implemented technology lacks process support. To complete care processes, health personnel work as a team, performing high risk tasks under uncertainty, and time pressure, dependent on a wide and reliable communication infrastructure for exchanging different kinds of data, such as patient reports, lab tests and working shifts, together with text, voice and alarm services. The management of this information is difficult and requires considering a wide variety of problems that should be avoided in order to properly meet the needs of hospital professionals. Context-awareness can provide the necessary knowledge for health IT to reduce inefficiencies and manage complexity.

III. MATERIALS AND METHODS

Let us start by defining "context". To define "context", some of the definitions given by the research community [13]-[17] over the years were investigated, and it is concluded that the most suitable definition for our research is [18]:

"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant for the interaction between a user and an application, including the user and applications themselves."

This definition shows the importance of which information is relevant or not in a context-sensitive system. A context-sensitive system could, therefore, be defined as a system allowing interactions between multiple entities using relevant information. Abowd et al. [18], state that: "*A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task".* This definition shows that a context-sensitive system can change its behavior and send some relevant information according to the context, which reflects our view.

The trend in the health IT field has been to push as much information as possible to the users, in order to provide more sophisticated and useful services while, at the same time, making users more available. During a preliminary research study on the AwareMedia system [19], a classification that splits the above listed information along three main axes is suggested:

- Social awareness: `where a person is', `activity in which a person is engaged in', `self-reported status';

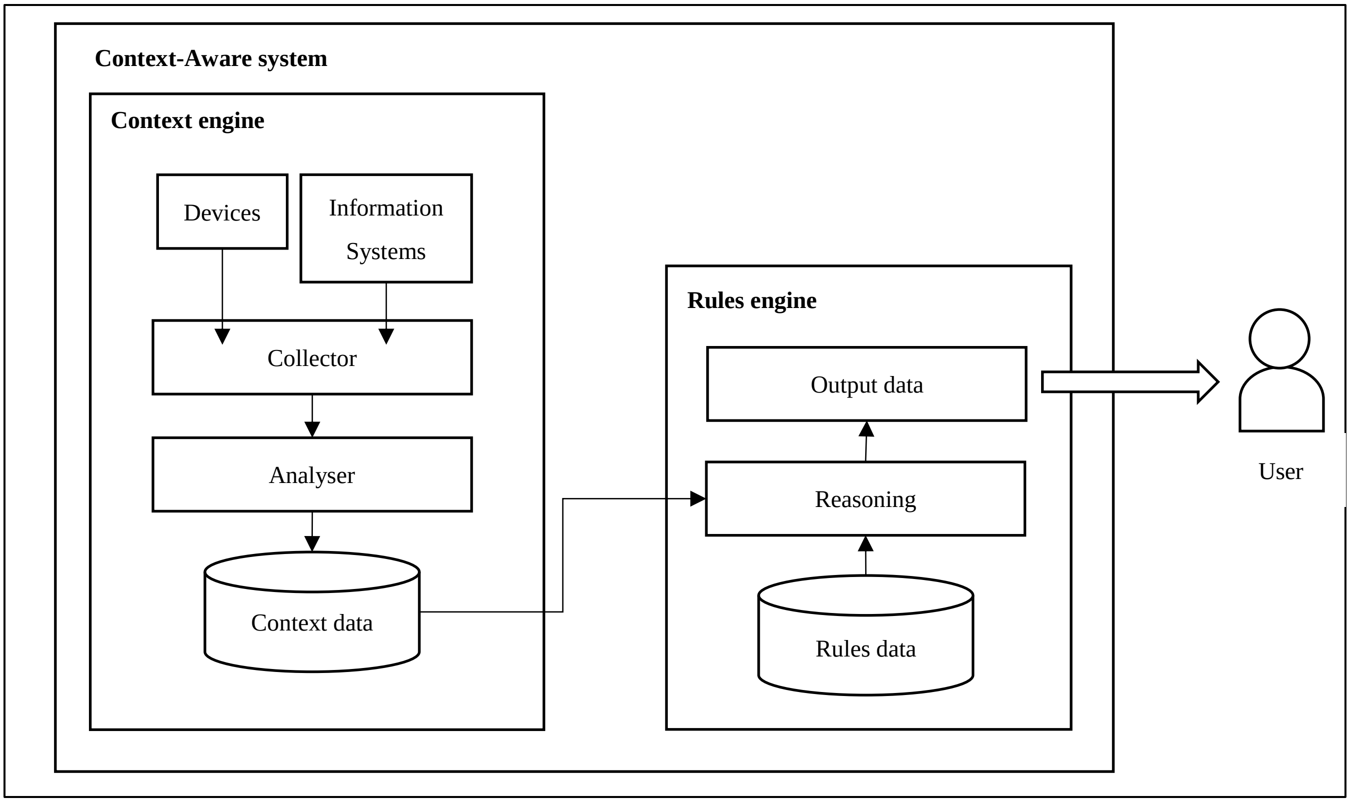

Figure 1. Illustration of context-aware systems' basic architecture.

- Spatial awareness: 'what kind of operation is taking place in a ward', 'level of activity', 'status of operation and people present in the room';
- Temporal awareness: 'past activities', 'present and future activities' that is significant for a person.

A context-aware system, as shown in Figure 1, comprises two main modules:

- Context engine: This module interfaces with other information systems and devices to collect raw data. These are then fed to an analyzer to classify raw data and generate context data.
- Rules engine: This module acts as filter between the data and the user. By applying a set of pre-defined conditions that define what, when, and to who the information must be presented. Such rules can be defined manual or automatically.

The adoption of context-aware systems based on these definitions is growing in a variety of domains, such as smart homes, airports, travel/entertainment/shopping, museum, and offices, as mentioned in [20].

IV. Discussion and Conclusions

Health IT usability, and adoption in daily practice is closely related to the systems' semantic and technological interoperability. This requires the systems to provide a comprehensive platform for process support. On the other hand, to provide this platform, structured knowledge that is not currently available in the Electronic Health Record (EHR) systems in use in most Norwegian hospitals would be required.

V. Future Work

Technological interoperability can be achieved by describing clinical guidelines using standardized languages. The context-aware methodology described Section III can support both the knowledge and technological interoperability required.

A context-aware system can collect data not only from the EHR, but also from the other IT implemented at the hospital. Such data can then be made available in different patient settings, and processed according to rules, to generate new knowledge. A context-aware system can also learn from the user interaction with the system to automatically improve his/her experience. In this manner, a context-aware system is able to provide process support by analyzing process related data of two categories: (1) "what is done"; (2) "how it is done".

The progression of a patient in a clinical process is determined by the completion of the tasks that compose the same process. However, EHR systems are not always updated on the tasks' completion as different individuals evidence different work patterns. If technology is able to separate the process related data as described above, then it becomes possible to achieve adaptive workflows.

 ISBN: 978-1-61208-618-7

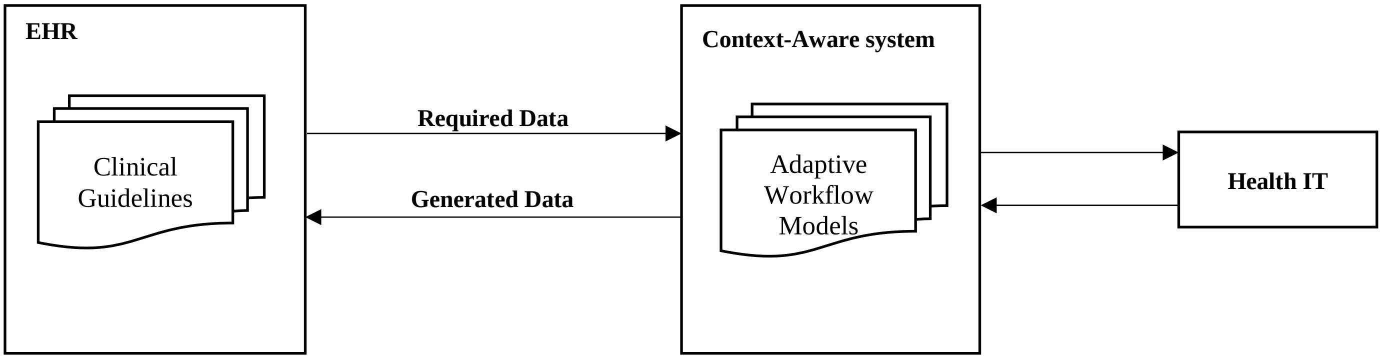

Figure 2. Illustration of the proposed context-aware based health IT system architecture.

"What is done" can be described by translating clinical guidelines using a standardize language like OpenEHR archetypes.

"How it is done" can be achieved by using machine-learning techniques, fed with context data, to adjust the clinical guideline to the individual user work pattern. The semantic interoperability is achieve through the definition of the data required to support workflow on the individual level to bring both concepts together using OpenEHR archetypes. An illustration of the system architecture is presented in Figure 2.

Context-awareness allows health IT to provide process support by managing the complexity inherent to clinical processes while supplying the technology with the process standards required to ensure usability.

ACKNOWLEDGMENTS

The authors would like to thank the regional health authority Helse-Nord for funding the research project HST 1304-16.

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 ISBN: 978-1-61208-618-7