10-2013

Analytical Methods for Planning and Scheduling Daily Work in Inpatient Care Settings: Opportunities for Research and Practice

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Abstract: This article identifies current challenges in the planning and execution of daily work in inpatient care settings. Inadequate planning of the processes and resources associated with inpatient care services may negatively affect their effectiveness. It may also lead to burnout of healthcare workers when the resulting work plan is unknowingly infeasible or does not incorporate the necessary human factors considerations. This paper provides with an overview of current research on inpatient care workflow planning, as well as with directions for researchers and practitioners to advance this problem using a combination of human factors engineering and analytical methods.

INTRODUCTION

Hospital efforts to shorten lengths of stay, and a higher percentage of elderly and sicker patients, have caused inpatient care workloads to increase. Nevertheless, hospital staffing levels have, at best, remained the same (Green, 2008). For example, a nurse's workload is impacted by patient acuity, staffing levels, indirect care tasks and patient turnover (Lopez et al., 2010). Thus, fixed nursing ratios may work well on a given day but have undesired outcomes on others, depending on the patient mix (Upenieks et al., 2007; Yankovic & Green, 2011), particularly if the same methods are used to get the work done in different circumstances (Cain & Haque, 2008). Furthermore, the increase in patient acuity and the increasing demand for patient safety and quality activities evidence the need for effective work planning and prioritizing strategies (Patterson et al., 2011). Inadequate planning of the processes and resources associated with inpatient care services may negatively affect their effectiveness and the corresponding patient outcomes. It may also lead to the burnout of healthcare workers.

The national push to improve the efficiency of healthcare systems makes this trend likely to continue. Therefore, there is a need to help healthcare providers identify effective strategies to provide quality care with the resources available. Because inpatient care work at all levels (from patient care assistants to residents) involves some form of context-dependent decision-making, work planning strategies should support applicable instances of decision-making.

Analytical methods to support decisions have been widely applied in healthcare. However, most of this area of study focuses on medium and long-term decisions (e.g., weekly staff scheduling and resource allocation, respectively), while short-term decisions are seldom addressed. Operational (short-term) decision-making instances in healthcare depend on many changing variables such as patient mix, provider characteristics and available resources. Healthcare workers are often faced with the challenge of planning and adjusting their work patterns to meet actual patient demands when strategic and medium-term have been made and implemented. The success of a given strategy depends, then, on the expertise of healthcare workers to address those uncertain demands with the available resources, the most important being time. Nevertheless, even the most experienced healthcare worker can be subject to burnout and fatigue when such uncertainties are not carefully incorporated into their strategies and the resulting work plan turns out to be infeasible.

Not incorporating human factors considerations into the provider's work plan can also contribute to burnout. Efforts are needed to understand inpatient care work and investigate strategies to support the provision of high quality care while protecting the well-being of healthcare workers. Although human factors engineering research in healthcare systems is not an entirely new concept, the use of analytical models to systematically incorporate these principles into routine inpatient care decisions is a potentially innovative approach. The use of systematic decision-making, and the ever-increasing availability of technology and healthcare information systems, can provide a platform to support healthcare providers in making routine work-planning decisions, so that they can have more time to focus on clinical decisions that require critical thinking.

INPATIENT CARE WORK ANALYSIS RESEARCH

In manufacturing, the workflow of a product is defined as the sequence of steps that need to be carried out to accomplish such product (Damelio, 2011). In inpatient care settings, there is not a single definition of workflow (Unertl et al., 2010), so this paper will use a direct adaptation of the manufacturing definition. Inpatient care workflow is the set of services (and the corresponding activities) that need to be provided to each patient to achieve an end-goal: a satisfied patient with an improved health condition. Because of the complex nature of healthcare systems, the corresponding workflow is also complex (Clancy & Delaney, 2005; Vardaman et al., 2012) and requires the coordinated participation of many providers.

Another interesting characteristic of healthcare systems is that the work associated with patient workflow tends not to be linearly sequential or repetitive, as in manufacturing, particularly when it is viewed from the point of view of a single provider (e.g., a nurse) over a short period such as a single shift. There are many activities that a nurse needs to perform on each patient in a shift to achieve the ultimate goal (i.e., satisfied patient). Furthermore, such ultimate goal may not be accomplished within a single shift. This research is concerned with helping inpatient care providers organize their work in a single shift to ensure the provision of timely, high quality care while considering their own well-being. It is worth clarifying that this type of analysis should complementary to a systems-oriented workflow design. Once the inpatient care workflow (patient-centered) has been studied and (re)designed using a systems oriented approach, work analysis should be done to help healthcare workers plan and execute their assigned work in a manner that is consistent with such workflow. Traditional work analysis techniques from manufacturing are often not directly applicable and need to be adapted to be useful in healthcare settings.

Because nurses are the providers that most interact with patients in a hospital, most of the studies reviewed so far have been related to nursing work.

Nursing-based literature often uses qualitative research methods to understand and describe inpatient care work. These types of studies mostly focus on analyzing: tasks and sequences (Lundgren & Segesten, 2001; Potter et al., 2004), indirect care interventions (McCloskey et al., 1996), interruptions (Hopkinson & Jennings, 2013; Tucker & Spear, 2006), medication administration activities (Jennings et al., 2011; Keohane et al., 2008), and the impact of the implementation of health information technology on workflow (Niazkhani & Aarts, 2009). Some research articles focus on the analysis of nurses' cognitive work (e.g., Wolf et al., 2006).

Some elements are common to these types of studies. Data is commonly collected from direct (field) observation and from surveys to nurses. The most common analysis methods include coding or categorizing notes obtained from observation and interviews into an existing or proposed classification system. Proportions in each category are commonly used as a measure of relevance of the corresponding category. Most studies illustrate their results using a narrative description of the work studied, while some of them propose some categorization for activities or situations of interest (e.g., categories of nursing activities, failures or interruptions). Graphical or visual representations of nursing work are scarce.

Human factors engineering (traditional work analysis) techniques have also been extensively used to categorize provider work (Battisto et al., 2009), to investigate how the time of providers is distributed (Capuano et al., 2004; Desjardins et al., 2008; Hendrich et al., 2008; Keohane et al., 2008), and to analyze the nature and distribution of interruptions (Rivera-Rodriguez & Karsh, 2010). Identification of waste, in the form of unnecessary work, motion and transport, is often an important component in human factors-based studies. For example, Capuano et al. (2004) used work sampling techniques to identify unnecessary work and implemented a series strategic and medium term solutions related to system (re)design, task (re)design and task allocation, among others. Desjardins et al., (2008) used a time-and-motion study to investigate the time spent by nurses on non-nursing activities and proposed a set of work reorganization strategies to reduce such activities. Wolf et al. (2006) and Potter et al. (2004) used link analysis and a cognitive pathway to map the physical and cognitive movements associated with tasks performed by a nurse and a patient care technician during their shift. This study can be very useful in evaluating the cognitive load of healthcare providers through a workday. Most of these studies provide strategies or recommendations to improve nursing work by eliminating waste. However, these strategies are mostly static and may become obsolete when contextual variables change (e.g., new team-members, changes in patient population).

As in any process, there are many opportunities for improving nursing work. Interesting remarks and conclusions found in the literature motivate a focus on streamlining its planning and execution. For example, Cornell et al. (2010, 2011) argues that nursing work lacks a structure that allows for the completion of care tasks actually needed by patients. Pan et al. (2009) found that the actual timing of medication administration activities in clinical settings is usually suboptimal. Jennings et al. (2011) highlight that nurses can have good and bad days, depending on the needs of their assigned patients. These conclusions support the need to identify strategies for nurses, and other decision makers, to efficiently and effectively plan and execute predictable activities, such as medication administration, to ensure the timeliness and completion of such activities.

Workload on a given day is also affected by unpredictable activities, often referred to as interruptions in the medical literature (Tucker & Spear, 2006; Hall et al., 2010; Kowinsky et al., 2012). Unpredictable tasks range from common patients' calls (e.g. to ask for help to go to the restroom or to ask a question) to emergencies due to unforeseen health deterioration. Tucker & Spear (2006) found that interruptions due to faulty systems, which need to be re-engineered through process improvement initiatives, represent about 5% of interruptions; while the majority of interruptions (about 95%) originate from medical work, and should be solved by designing the work to be robust to these interruptions. Cain & Haque (2008) also highlights the need for designing work so that it accommodates variations due to interruptions while complying with high quality standards. Clancy & Delaney (2005) and Magrabi et al. (2011) suggest the use of computational models to understand interruptions and investigate their aggregate effects on medical work and outcomes.

Computational and mathematical models are extensively used to understand problems, as well as to identify and evaluate solutions in similar situations in which decisions need to be made to accomplish a goal under limited resources. The discipline that focuses on using analytical methods to analyze complex systems is known as *Operations Research* (OR). In what follows, a brief description of OR in healthcare will be provided, and opportunities and challenges in its application to inpatient care provider work design will be discussed.

ANALYTICAL METHODS IN HEALTHCARE

Analytical methods, such as systems simulation and optimization models, have been used in healthcare delivery and medicine to support complex decisions (Pierskalla, 2010). This literature has increased over the years and continues to increase at a fast pace (Brailsford & Vissers, 2011). Applications include decisions in the management of operating rooms, such as the assignment of time to surgical cases, construction of surgical schedule, and patient scheduling (Guerriero & Guido, 2011) as well as identifying performance measures and incorporating uncertainty into the problem formulation (Cardoen& Beliën, 2010). Applications have traditionally focused on strategic and medium-term decisions, such as resource planning and utilization, quality management, finance, policy and regulation, workforce management, and risk management or forecasting (Brailsford & Vissers, 2011; Rais & Viana, 2010), as well as on operational decisions, such as performance monitoring, managing appointment systems, modeling patient flow and determining staffing levels.

A common application is the use of optimization techniques to support staff scheduling and rostering. In these optimization problems, the aim is to find the best schedule possible taking into consideration patient demand, required staffing levels, staff availability and, sometimes, worker preferences (Ernst et al., 2004; Hulshof et al., 2012). Models have been developed for decisions as broad as determining the number of personnel needed in a period of interest, and as detailed as determining the shifts to which each specific staff member should be assigned in a period of interest (e.g., a week). Yet, important decisions are made at the operational level, within a single shift, for which the application of OR-based decision-support models is limited.

Most of the decisions made within a shift are clinical and depend on the expertise of healthcare professionals. However, some decisions that appear to be routine (such as in which room to locate a patient or the best way to sequence patients in the next round) may have a direct impact on care quality and patient safety. Some studies have addressed these kinds of decisions. For example, Saghafian et al. (2011) used analytic and simulation models to design and evaluate emergency department triaging strategies to increase patient safety and operational efficiency under different conditions. Wang et al. (2013) proposed analytical formulas to model the processes that take place within a patient room during a patient visit to an emergency department. The model provides healthcare decision-makers with quantitative tools to investigate the impact of process changes on length of stay. Kortbeek et al. (2012) identified efficient flexible nurse staffing policies using float nurses that depend on workload prediction based on expected hourly census. Yankovic & Green (2011) used queuing models to evaluate nurse-to-patient ratios in terms of understaffing and overstaffing in different (possible) scenarios.

An important reason why these types of models are not more widely used in inpatient care work planning may the difficulty in identifying and quantifying parameters that represent the associated processes and outcomes. Thus, these applications need to incorporate extensive reviews of relevant medical literature, use human factors principles at some level, and involve active collaboration between healthcare decision-makers and OR professionals to understand the processes, develop the corresponding models, quantify parameters, and evaluate the derived strategies.

INPATIENT CARE WORK MODELING AND ANALYSIS: RESEARCH OPPORTUNITIES AND CHALLENGES

This paper explores the potential use of analytical methods to support the planning and execution work in inpatient care systems. The vision is to develop systematic methods to understand and support decisions made by front-line healthcare workers throughout their workday that may impact patient outcomes. To that end, it is important to seek answers to the following high level questions:

What are the types of decisions that healthcare workers make throughout their workday? Can (some of) these decisions be modeled and made systematic using analytical methods? What analytical methods are most appropriate for each specific type of decision? What information is needed to ensure that such decision support models are useful to decision-makers?

A major challenge in the use of analytical methods to support care services consists of defining and measuring system features that can be used to formulate practical models. For such models to be practical, it is necessary that the corresponding parameters can be estimated using information commonly available in hospitals.

Understanding Healthcare Providers' Work

Once a patient-centered workflow has been established through a systems oriented approach (Cain & Haque, 2008), inpatient care processes should be studied from the point of view of a provider that has been assigned a set of patients to care for during a period of interest (a shift). Their objective is to provide the necessary care to those patients with the highest quality standards possible while incorporating relevant human factors considerations, such as minimizing walking time and reducing cognitive load throughout the day. The assigned patients have some specific service requirements according to key individual characteristics. The provider needs to decide when to carry out the activities associated to those services, taking into consideration the medical requirements of such services, the needs of the other patients assigned and the resources available.

Although planning helps to ensure that care plans are consistent with the appropriate guidelines, resources are used efficiently, and patients' needs are addressed, such benefits will not be observed if the plan is not successfully implemented (Magnan & Maklebust, 2009). Because of the high variability of patient care needs from day to day, effective work planning and its implementation remain a challenge. Traditional work design methods alone are not sufficient to characterize healthcare providers' work or to design and evaluate work planning strategies.

The first challenge in this area is to identify appropriate techniques to characterize and study inpatient care work, and that support proactive decision-making. In this research, the focus is on the decision of organizing the workday at the beginning of a shift, and modifying such plan for the remainder of the shift when unpredictable tasks disrupt its execution. In what follows, a preliminary approach to understand the problem based on optimization techniques (Taha, 2003) is illustrated.

Example Analytical Approach: *The Rounding Problem*

Healthcare providers often organize their workflow in terms of rounds. Rounds are prevalent throughout the many healthcare professions (e.g., residents' rounds, nurses' medication administration rounds, patient care assistants' fall prevention rounds) because they facilitate remembering and sequencing tasks that need to be carried out in the short term. Understanding the processes and decisions involved in planning rounds, and identifying robust strategies to plan and execute such rounds, will potentially impact most healthcare-related professions, and potentially other service provider industries. Furthermore, studying the problem of rounds will provide with insights into other problems that affect front line providers, for instance: the location of patients within a care unit, the location of specialized equipment, and the provisioning of supplies to provide a specific service. Therefore understanding the rounding problem constitutes in itself a research opportunity.

A round can be defined as a set of activities to be carried out consecutively and without interruption, within a predetermined period of time. The first decision is to design a rounds-based schedule that allows for the timely completion of all activities required by the assigned patients throughout a shift. Preliminary interactions with actual healthcare workers showed that some of them plan their rounds using time slots defined by their start time. These start times usually correspond to each hour of the shift, and their duration is estimated to be the full hour. Activities are then assigned to each time slot (often using a printed schedule template) according to explicit patient needs. Following concepts from the literature on service planning and scheduling (Pinedo, 2005), the round planning decision could be represented using an optimization model that:

- assigns each predictable activity to a specific round, taking into consideration the timing requirements of the activities and the timing of the round;
- makes sure that activities assigned to a single round can be carried out within the time period of the round (often not enforced in practice); and
- provides with sufficient time to address unpredictable activities without significantly disrupting the timely performance of predictable ones.

The model could be mathematically expressed as follows:

Parameters:

N number of predictable activities that need to be carried out in the shift
p_j duration of activity $j = 1, 2, \ldots, N$
r_j earliest start time of activity $j = 1, 2, \ldots, N$
d_j latest termination time of activity $j = 1, 2, \ldots, N$
T number of time slots available in a shift
α_t effectively available time within each time slot $t = 1, 2, \ldots, T$
w_{jt} profit of assigning activity j = 1, 2, ..., N to time slot $t = 1, 2, \ldots, T$

Decision variable:

$$\mathrm{x_{jt}} = \begin{cases} 1, & \text{if activity } \mathrm{j} = 1,2,\ldots,\mathrm{N} \text{ is assigned to time slot } \mathrm{t} = 1,2,\ldots,\mathrm{T} \\ 0, & \text{otherwise} \end{cases}$$

Model:

$$max \sum_{t=1}^{T} w_{jt} x_{jt} \qquad (1)$$

s.t.:

$$\sum_{t=1}^{T} x_{jt} = 1 \qquad \forall j = 1, 2, \ldots N \qquad (2)$$

$$\sum_{j=1}^{N} p_j x_{jt} \le \alpha_t \qquad \forall t = 1, 2, \ldots T \qquad (3)$$

$$x_{jt} \in 0, 1 \qquad \forall j = 1, 2, \ldots, N \,;\; t = 1, 2, \ldots, T \qquad (4)$$

The proposed objective (1) was modeled as the maximization of a profit that rewards timeliness and penalizes lateness or earliness of each task, depending on the characteristics of the task. Although earliest start and latest termination times should ideally be included in the model as constraints, in practice, these times are treated as strong suggestions. Healthcare workers do their best to perform each activity as close as possible to the ideal time, as other activities allow and depending on their (implicit) priority.

The profit coefficients should then be a function of the earliest start time, latest termination time, and the time of the round to which the activity can be potentially assigned:

$$w_{jt} = f(r_j, d_j, t) \qquad \forall t = 1, 2, \ldots T \qquad (5)$$

Instead of profit coefficients, the decision-makers may prefer to evaluate the costs of lateness and earliness for each task assignment to specific rounds. Then, w_{jt} would represent the cost of each task assignment and the objective function would become a minimization problem.

Equation (2) represents each activity being assigned to one time slot, assuming that it is not allowed to break a task into two different rounds. Equation (3) ensures that the activities assigned to a time slot are completed within the effective time available in that time slot. Note that the parameter α_t was specifically defined to denote the effective time available in the time slot corresponding to a round. This parameter is intended to address unpredictable work that needs to be carried out immediately. Therefore, it should be true that α_t is less than the actual time within the time slot *t*, providing the worker with some flexibility.

As with every model, the formulation (1) - (4) is a simplified version of reality but it triggers several interesting research questions. The first natural question that arises is if the formulation (1) - (4) is the best analytical approach to model round planning decisions or if there are other modeling techniques that could better help understand and solve this problem. Active collaboration with healthcare providers is needed to revise and validate the model. It is important that the parameters of the model selected be possible to obtain or measure using information (potentially) available in the corresponding healthcare organization.

It is also important to identify the human factor considerations that are relevant to the rounding problem. Human factors variables that may affect the well-being of providers, and in-turn the effectiveness of strategies, need to be investigated and the corresponding work-planning considerations need to be identified. Relevant human factors variables may include cognitive load (e.g., related to the use of short-term memory capacity or to shift in attention focus) and fatigue (e.g., distance walked). An example of work-planning considerations would then be the desired characteristics of the activities assigned to a single round to reduce cognitive load and to minimize transportation time. Once these considerations are identified, then they should be incorporated into the work planning model and the corresponding parameters should be estimated.

In the proposed formulation, the impact of unpredictable activities on the schedule was initially modeled as an allowance on the total time of each round. The parameter α_t represents the effective time in each round, which is expected to be less than the actual time available, and equation (3) ensures that only this effective time is planned for. Therefore, each round has some flexibility to address unpredictable activities. A challenging research problem is to determine these round parameters, taking into consideration the characteristics of both predictable and unpredictable tasks as well as identified human-factors considerations. It is important to understand and quantify unpredictable tasks as well as the variability of predictable tasks to account for both in the schedule and to reduce the impact of interruptions.

Finally, an effort should be made to specify how the model can be used in practice to support decision-making and improve work. Because it is based on optimization techniques, the proposed model is in itself a decision support tool for organizing work at the beginning of the shift. Therefore, if data can be obtained or collected to estimate the proposed parameters, rounding strategies could be directly identified by implementing the model. Ideally, a model like this should interact with information in the patients' electronic medical records, so that the plan can be updated when patient needs change (e.g., a new patient is assigned to the provider). Other situation in which the plan may have to be re-evaluated is when a substantial disruption takes place and tasks have to be deferred..In such case, a model like the proposed one could be used to revise the original plan at the time of the disruption to find the best allocation of the remaining tasks (including the deferred ones) in the remaining time.

The proposed research has the potential to result in an advanced knowledge of the work organization strategies used by providers in inpatient care settings. It could provide with an innovative modeling approach for provider work that can be tailored to different healthcare settings and different service-oriented organizations. It opens a new research area within the operations planning and scheduling field by introducing a real and challenging problem: *the rounding problem*. If studied and solved using information commonly available in organizations, this problem could have a positive impact on longer term decisions such as determining staffing levels and developing policies for staff scheduling.

Extensions

In addition to human factors engineering considerations, the proposed work analysis approach can be used to create a shared understanding of other qualitative considerations of importance to patients, providers and/or the organization and to incorporate some of these into work organization decisions. In the case of nursing, for example, nursing practice philosophies (Drenkard, 2008) could be investigated and modeled. One way to accomplish this would be to incorporate constraints on the maximum number of nurses assigned to a single patient in a shift, or on the total contact time of a nurse with each one of his/her assigned patients, to ensure a true healing and human caring environment.

A modeling approach such as the proposed one should be extended to incorporate uncertainty in the duration and frequency of tasks. We proposed using a time allowance to provide with flexibility to address unpredictable tasks. There are many other ways in which uncertainty can be incorporated into the decision support model. For example, if it is possible to identify probability distributions for the model parameters, then stochastic programming (Birge & Louveaux, 1997) methods could be applicable. Also, if best and worst cases of the parameter values can be estimated, then the applicability and practicality of robust optimization (Bertsimas & Sim 2003) techniques can be explored. The robustness of solutions in the face of uncertainty, regardless of the model used to identify these solutions, can be evaluated before implementation using computer-based simulation models to identify undesirable performance under certain scenarios of interest.

In general, the proposed research has application into the implementation of (new) quality practices in healthcare organizations. The implementation of evidence-based guidelines has proved challenging in many areas of clinical practice (Stacey, 2004). In particular, quality and safety practices tend to be moved down the priority of tasks when other time sensitive situations arise (Lopez et al., 2010). For instance, in pressure ulcer prevention, although it is recommended that patients be repositioned at least every two hours, a study found that about half of the patients were not repositioned for more than 2 hours. Furthermore, about 40% of the nurses surveyed believed that the recommended standard was not being met in their units (Lyder et al., 2008).

An important reason for the lack of success in implementing new practices may be the difficulty of addressing both the existing and new responsibilities when resources are not optimally allocated. In this situation, staff are often charged with closing the gaps in the system (Henriksen et al., 2008). Thus, facilitating processes by carefully designing workflow and allocating the needed resources may positively impact the adoption of new practices. The challenge is to identify the workflows, resources and other system features that may affect system performance, as well as strategies to plan for them in an efficient manner.

Workflow analysis and design using human factors engineering provide with the necessary conditions that need to be met so that interventions are implemented efficiently. The variability in healthcare processes makes this challenge particularly interesting, and traditional static/deterministic workflow analysis and resource allocation techniques inadequate. Adaptability in the strategies is key to their success. Operations research methods have the potential to help incorporate all these conditions into key decisions in the shape of constraints and objectives, so that decisions can be adapted to the context of interest.

CONCLUSIONS

A systems approach is needed to ensure that the healthcare delivery system helps providers do the right thing while caring for patients. The research opportunity lies in combining theories from human factors engineering with analytical techniques to support operational decisions that need to be made consistently and that involve conflicting criteria such as patient needs, time constraints, resource availability and ergonomic considerations. Techniques such as optimization and computer simulation have the potential to support these kinds of decisions.

This research proposes the use of modeling techniques for understanding and organizing provider work throughout a shift. Such operational model could help identify and evaluate workflow strategies, such as timing and sequencing of rounds, that take into consideration the actual patient-mix in the period of interest. Other decisions that could be potentially supported by Operations Research (OR) methods include patient location/relocation throughout their hospital stay, and the supply, location and maintenance of the physical resources of the inpatient care work-system. The current advances in information technology and data analytics have the potential to support this effort. Electronic medical records systems (computerized charts and electronic health records) allow for more data to be available to healthcare providers at different levels of care. Nevertheless, their use in planning, implementing and evaluating direct care interventions is still on the rise.

This research has the potential to directly benefit healthcare workers by helping them systematically identify and evaluate practical strategies to efficiently provide quality care to their patients. Therefore, they will be able to focus on actual care provision and medical decision-making. In turn, patients will benefit by experiencing timely, effective, equitable, and safe care.

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