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On Predicting the Results of Applying Workflow Management in a Healthcare Context

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ABSTRACT
Even though workflow management systems are currently not being applied on a wide scale in healthcare settings, their benefits with respect to operational efficiency and reducing patient risk seem enticing. In the presented study, we show how an approach that is rooted in simulation can be useful to predict the benefits of using a workflow management system. The approach is discussed and its application is demonstrated in the setting of the pre-operative process as being executed in the Bronovo hospital. The approach is considered useful for other healthcare organizations in search for a better foundation for the application of workflow technology.

Keywords: healthcare process, workflow, simulation, Human error criticality analysis, workflow management, case study, quality measurement healthcare.

INTRODUCTION

Workflow management technology is widely applied in the financial services and in governmental settings. The fundamental idea is to separate the flow logic from application code that is used for executing a certain process (Van der Aalst & Van Hee, 2002). The advantages of using a workflow management system (WfMS) to manage a business process can be summarized as follows (Reijers, Rigter & Van der Aalst, 2003):

- *Less coordination effort*. The WfMS liberates human actors from the routine work they need for coordination; it is the WfMS that oversees which of the potentially many actors needs to be involved at a certain stage.
- *Higher quality*. The WfMS will offer actors the work packages, including the required information, in accordance to a predefined way of working to deliver the preferred quality of service, while it also allows for exception handling.
- *Higher efficiency*. The WfMS will not offer more work to actors than what is required to produce an acceptable result. Specifically, available information can be made available throughout a process and tasks will only be executed as often as necessary.
- *Higher maintainability*. Ejecting the business control flow from traditional applications and moving it towards a WfMS simplifies the adjustment of both the logistics and the content of work.

Healthcare processes too require the cooperation of many different organizational units and medical disciplines. One can also see that the timely availability of information and the coordination of work are important elements in diagnosis, treatment, and care activities. Despite these matches with what workflow has to offer, it has been noted that WfMSs are not yet broadly used in healthcare environments (Reichert & Lenz, 2007).

It is an open question what the underlying causes are of WfMSs being hardly used in healthcare. One may speculate that much of ongoing IT initiatives in healthcare relate to the introduction of electronic patient records, which favors a *data* perspective rather than a *process* perspective. Secondly, one can observe a disparity with respect to traditional workflow domains, since a healthcare setting transcends pure information processing – people rather than documents are in the loop. Applying workflow may therefore be more difficult. Thirdly, it has been argued that healthcare settings require

a level of flexibility that WfMSs systems cannot deal with (Quaglini et al., 2001; Ash, Berg, & Coiera, 2004). It has to be added here that current workflow technologies have improved considerably in this respect over the past years.

This paper explains how the advantages of using a WfMS in a medical context can be estimated up-front. The described approach demonstrates that it is possible to assess the benefits of using this type of technology to improve both the *efficiency* and *quality* of a medical process. The approach is based on the use of discrete event simulation and builds on a quantitative analysis of an as-is situation, as well as on the modeling of the to-be situation after a WfMS has been introduced. By doing so, this paper aims to contribute to the more widespread application of WfMSs in medical contexts, since it clarifies how the benefits can be made more transparent.

The structure of the paper is now as follows. In the following section, we will provide some background information, explaining the primary ingredients of our approach. In Section 3, we will describe the context in which our approach has been applied, i.e. the pre-operative assessment process within the Bronovo hospital in The Netherlands. Sections 4 and 5 respectively deal with the followed approach and the results thereof. The paper concludes with a summary and an outlook.

BACKGROUND

The approach that is followed to assess the effectiveness of a WfMS in a particular medical setting primarily involves *simulation*. While such an approach has proven to be quite feasible to assess quantitative aspects of systems, even in the healthcare domain (Jun et al., 1999), we also wish to extend it with a qualitative assessment. The latter is done by incorporating the *Human Error Criticality Analyses (HECA) methodology* in our approach. These elements will be discussed in this section.

Simulation

The main technique used in our approach for estimating the effectiveness of a WfMS is simulation (Law & Kelton, 1975). This use of simulation in the described approach entails two steps: First, the development of a process model is required, which we approached by using a formal modeling language based on Petri-nets using the Protos tool (http://www.pallas-athena.com). Protos not only provides the control structures needed to model workflows, it was also specifically designed to model business processes. Among its most important features are the facilities to make visual models of workflows, handle roles and resources, generate documentation, and verify the soundness of models.

While Protos models are excellent to unambiguously capture a process and to enable their validation with professionals, a second step was necessary to develop models that can be run by simulation software. This consisted of transforming these process models into CPNTOOLS simulation models (http://cpntools.org). There are many general purpose simulation tools, but CPNtools was selected for this project because of the advantages described by Jansen- Vullers & Netjes (2006). Additionally, it is highly important in our approach that in combination with a tool developed by Gottschalk et al. (2006) it is relatively simple to export a Protos model to CPNtools.

Human Error Criticality Analysis

The Human Error Criticality Analysis (HECA) is a tool developed by Yu (2000) to identify critical human tasks and their associated error modes, to determine the relationships between them, and to provide reliability and system safety information for system improvements (Yu, 2000). HECA was originally created for the assembly of rockets, an environment where the quality of the process has to be measured without defects due to their obvious severity. To do this, HECA looks at error modes, the possible states of error an environment can be in. The method follows 9 steps, which were all adapted for a hospital setting from (Yu, 2000). Figure 1 depicts the steps in HECA.

Step 1: Follow Standard assembling procedure. Look at the standard assembling procedure. In any context, look at the standard process to learn to know the process.

Step 2: Task analysis. Zoom in on each individual task in each process step and look for the possible errors at every step. Connect these errors to the corresponding human error mode.

Step 3: Construct Human reliability analysis (HRA) event tree. Construct a tree with every process step and all the possible errors at each process step.

Step 4: Estimate chances. Estimate the chance of each error in the HRA event tree and the chance of the error resulting in an error mode.

Step 5: Calculation of Human error probability (HEP) of human tasks. Determine the probability of human error causing different error modes with the help of the HRA event tree.

Step 6: Calculation of the reliability of a human task and total human reliability.

Step 7: Perform HECA. Determine the criticality of each human task in the process.

Step 8: Construct criticality matrix. Analyze and draw the criticality matrices.

Step 9: Summarize all critical human tasks, error modes and other information.

After these steps, HECA returns a sound evaluation of the quality of the process. HECA also gives an indication as to where the biggest improvements can be made. Process optimization, in fact, is the primary goal of HECA. To this end, there are more tools available. Still, the analysis within HECA provides a methodological

Figure 1: Steps in HECA, Yu, 2000, p. 89 (image file figure1-heca.tif)

approach to analyzing a process, independent of the solution chosen. Together with the possibility to define the error modes and risk in any desired way, it is a useful and flexible tool to be used in almost any environment.

CASE SETTING

Background

The Bronovo Hospital is a teaching hospital in The Netherlands, characterized by a high level of quality of care and a high level of service to patients. On average, the number of clinical admissions is 15,000 and there are some 200,000 outpatient consultations annually. Almost all medical specialties are present and care is delivered according to nationwide and/or international standards.

From the year 2000 onwards, a number of projects have been implemented to improve quality, especially safety and logistics. Still, it was felt that quality could be improved to a higher level by focusing on process management, recognizing that if serious complications occur, they can often be attributed to failures in the sequential steps of processes.

In 2006 an important step was taken, when it was decided to implement a fifth generation electronic patient record (EPR), Soarian™ by Siemens (Haux et al., 2003). In contrast to other EPRs, this product allows for real-time process management, which to the opinion of the Hospital Board and the Medical Staff was essential for a next step in improving quality, safety and efficiency. Essentially, SOARIAN allows the creation of a WfMS that can be specifically tailored to support the process in the most efficient manner (e.g. improved case tracking), while at the same time providing the traditional benefits of a data oriented EPR.

A particular advantage of using SOARIAN as a WFMS is that the engine can be programmed with a set of regulatory activities. For instance, it is possible to have a system of triggers and monitors whenever a case reaches certain conditions.

For a number of reasons, the pre-operative assessment process (PAP) was chosen as the first process to apply the process management system to. First, 60% of all hospital admissions concern patients that are being operated on. Secondly, it has been suggested that up to 50% of pre- and post-operative complications might have been prevented if the pre-operative preparation had been optimal. Thirdly, the Inspectorate of Health Care in the Netherlands had recently issued a report disclosing that the quality of the pre-operative assessment process in the Netherlands was poor. Main drawbacks were the lack of transparency of the process, the lack of adequate communication between the different people involved in the process, the lack of one director of the process and the lack of transparent documentation. With an operational WfMS using the EPR, we expected the following benefits:

- Significant improvement of completeness of the information pre-operatively
- Adequate informed consent in all patients
- Clear roles for all involved in the process
- Transparency during the process for all involved
- Better preparation for the operations (adequate medication, antibiotics, blood transfusions)
- Shorter processing time

Eventually, these benefits were expected to result in fewer complications and better logistics.

The Pre-Operative Assessment Process (Paper Based Form)

The "old" pre-operative assessment process (PAP) was based on paper forms and unfolded as follows: When a surgeon and a patient agree on an operation, a so-called pre-operative form (POF) is filled out on a paper form. The form consists of a section for the surgeon to indicate the type of operation, expected duration of the procedure, pre-operative antibiotics to prevent a wound infection, major comorbidity, specific extra measures (materials, post-operative ICU admission etc.), and anticipated problems during or after the operation. Another section is a questionnaire for the patient to fill out, concerning medical history, allergies, and intoxications. After the POF is completed, the surgeon's secretary gives the patient a provisional date of operation and checks all the necessary specific measures. Next, the patient goes to the Pre-operative Department. Here, a nurse checks the questionnaire section of the POF and completes it with contact information and takes vital information such as blood pressure, heart rate, temperature, and nutritional condition. Afterwards, the patient consults the anesthesiologist who checks all the available information and judges the pre- and post-operative risk. According to this risk, extra tests may be invoked, such as blood tests, X-rays, ECG and other function tests for heart and lungs, and additional information may be requested from other treating specialists. Also, the anesthesiologist may order blood units to transfuse during the operation. Finally, when all necessary information is present, the anesthesiologist may approve the operation and will then determine the pre-operative anesthesiology regime, to be discussed with the patient. The surgeon and his secretary are informed on this decision via a copy of the completely filled out anesthesiology section on the POF, which is sent by hospital-mail.

Finally, when the patient is admitted to the hospital for the operation, the nurse on the ward finds all information on a copy of the POF, including any specific orders to be performed pre-operatively. The information on the POF is also used by the anesthesiology nurse and the anesthesiologist during the operation itself. Annually, some 6,500 patients are being operated on after having been enrolled in this paper-based workflow.

Some of the weaknesses of this process are derived from the use of paper forms (see table 1 to table 3), for instance: paper forms can get lost, reading can be difficult at times, it is not possible to verify their completeness, there are delays with hospital mail, the tracking of cases is complex.

The PAP with WFMS

The PAP based on the WFMS was adapted from the current paper process, therefore both end up being following the same paths (except for some exceptions). With this fact in mind, the WMFS can be explained by focusing on the differences. For instance, the step where one needs to use the hospital mail is removed, there is no need to make copies of forms, and check-ups on test results as required by the anesthesiologist happen much sooner, as well as many other differences noted in tables 1 to 3.

Figure 2: PROTOS modeling (Figure2-Protos.tif).

KPI's

Using interviews with personnel at the hospital and following guidance from (Verbeek et al., 2000; Yu, 2000; Park & Jung, 1996) we were able to define a set of evaluation criteria in terms of key performance indicators (KPIs). These were used to measure the performance of the PAP and would be monitored during the process simulations of the PAP. The set consists of two parts: *quantitative KPIs* such as waiting time, approval time and approval time till due date, and a *qualitative KPI*, i.e. the HECA measurement.

The HECA quality measurement was slightly adjusted from its originally intended use. Every type of error mode (i.e. wrong antibiotics, wrong dose of antibiotics etc.) was given a score on a one to five scale to show the risk the event exposed to the patient. With this method we were able to present the quality of the process in a quantitative way, enabling comparison and reuse of the method. The basic assumption behind the use of the HECA measurement is: *when the quality of the process is high, the risk to the patient is reduced and when the quality of the process is low, the risk to the patient increases.*

Data Gathering

At the time this research was carried out, there were few measurements available on the PAP's performance. In order to fully understand this process as well as to discover changes to be brought about by the WfMS, a set of research activities, guided by research from Van der Aalst (2004), were executed:

Interviews*,* at least one member of each role in the process was interviewed: nurses, secretaries, anesthesiologists and surgeons, personnel from the IT department, as well as a consultant from Siemens. With the information provided in the interviews, we were able to model the existing, paper-based PAP as well as the anticipated, WfMS-based processes. In total, ten interviews were conducted.

Use of existing data: using a set of pre-operative forms (representing over 140 cases), as well as internal data from each department concerning error handling (over six months worth of cases), we were able to obtain some reliable statistics on the model. For instance, existing data was used on how many patients need tests, re-tests, or are directly admitted to operations.

Observations*,* a set of measurements was undertaken in the hospital concerning the logistic aspect, i.e. queuing times and consult times. This was done during a period of more than six weeks in order to guarantee statistically reliable data. The information obtained includes: Inter arrival times, processing times of patients in consultations, distribution of patients by sex, age, medication, allergy, and type of operation

(classified by the range of operation duration).

Expert knowledge, which was used to complete missing data such as: estimations of some of the processing times, as well as probabilities of paths a patient takes in the process and the risk assessment. A survey, based on the work by Basra and Kirwan (1998) was designed for each of the roles required by the process (i.e. three surgeons, four anesthesiologists, several nurses and secretaries).

Simulate Future Set-Up - Existing Situation With Workflow

With the knowledge obtained during the data gathering, the process model of the paper-based PAP, henceforth referred to as *papermodel1,* was captured and transformed into a simulation model. Later, following the same method, a model of the newly anticipated situation was built, named *WfMSmodel1*. The external factors of the model, such as arrival of patients, operation times, amount of surgeons available, and amount of anesthesiologists available were kept similar to the *papermodel1*. This would allow a fair comparison of the simulation models in terms of their KPIs.

Simulate future set-up - Existing situation with workflow and potential improvements

One of the goals for the hospital in question was to establish if there were other possible improvements. Following guidance on process redesign (Reijers & Limam Mansar, 2005), coupled with observations of improvements to the process, two recommendations were suggested and approved by the stakeholders at the hospital.

These recommendations for improvements would also be measured using simulations, which would provide insight into how valuable they would be. Therefore, using the *WfMSModel1* as a basis, two more models were developed as variants of the future situation:

- *WfMSModel2* for ***Improvement1***: Operations are only scheduled after they have received approval from the anesthesiologist, instead of leaving it at the discretion of secretaries.
- *WfMSModel3* for ***Improvement 2***: The anesthesiologist checks for any cases awaiting approval every 3 days, instead of doing it at his or her own discretion (which varies from every day to once a week).

For the sake of illustration, part of the simulation model for the second type of improvement is shown in Figure 3. It captures the anesthesiologists working in a round robin fashion at the Bronovo.

RESULTS

Setting KPI's

The following, quantitative KPI's were used to measure the effectiveness of each simulation, as visualized in Figure 4:

- **Approval time:** Time patient waits from visit to surgeon until anesthesiologist approval;
- **Approval time with additional tests:** Same as the previous KPI, but only for those cases that require testing;
- **Waiting time until operation:** The time a patient waits from the visit to surgeon until operation;

Figure 3 CPNtools modeling the anesthesiologist behavior (file figure3-cpntools.tif)

- **Anesthesiologist approval until operation:** The time a patient waits from approval until operation;
- **Waiting time patients:** The time a patient waits queuing;
- **Number of reschedules:** The number of re-schedulings an operation had;
- **Operation hours lost:** The hours of operating room lost;
- **Operation date to due date:** The period of time before the due date the operation happened;
- **Operation date to due date with rescheduling:** Same as the previous, but only for cases that had to be rescheduled.

With respect to the qualitative KPI, the **HECA** measurement was used.

Simulation

The simulation models were quite complex and some design decisions were taken to make them behave in conformance with reality. At the end, the results of simulation of the paper based approach , per *Jansen- Vullers & Netjes (2006),* were validated with available data and verified with the expert. It was agreed that they perform similar to real life cases.

- **Behavior of Doctors:** Anesthesiologists work in a round robin fashion, one giving consults each day until a full rotation;
- **Random Events:** Events such as cancellations, lost paper forms had to be taken into consideration;
- **Case urgency:** Each case can have any of four possible types of urgencies according to the hospital practices. *Urgency1* represents cases that have a due date of 48 hours, *urgency2* is fourteen days, *urgency3* is three months and, finally, *urgency4* corresponds to 6 months.

Some additional assumptions had to be taken into account in order to have meaningful simulations:

- **Anesthesiologists required Tests:** Results vary on their availability but are always on time to schedule an operation before due date;
- **Duration of operations:** All take as long as planned;

Figure 4: Visual representation of quantitative KPIs for the PAP (figure4-qkpi.tif.)

- **Success of operations:** Operations are considered to be completed correctly;
- **Handling of urgent cases:** A case becomes urgent when there are two days or less before the due date;

To assure statistically significant data, the simulations were set up as follows:

- **Number of runs:** Each experiment consisted of 10 sub-simulations. For the final results of the simulation every sub result of the sub-simulations is averaged out with the rest.
- **Warm up time:** 41.6 days. The time it takes to reach a stable number of scheduled operations, the warm up eliminates the measurements of cases that are in the process at a point in time where the workload is below average because not enough time has passed by (e.g. The operation agenda has not reached a stable number).
- **Simulation time:** In order to get reliable numbers of samples each simulation was executed for a long enough period of time under stable conditions. For this case the time span chosen is of two years

Experiments

First and second experiment, corresponding to papermodel1& WfMSModel1. The objective of the simulation for *papermodel1* was to obtain measurements that could be set as a baseline, which then would be compared with results from *WfMSModel1* in order to measure the theoretical gains with the WfMS. While the p*apermodel1* and *WfMSModel1* are somewhat similar in that both have the same goal, they do differ. These differences are mainly notable in three ways: '*form handling*', ' *handover handling'* and '*case tracking'*. The differences are depicted in tables 1-3.

Table 1 comparison of form handling between Papermodel1 and WFMSModel1

	Papermodel1	*WfMSModel1*
Creation of forms	Handwritten by patients and doctors	Typed by patients and doctors
Management of information	Information located in the same form, sometimes out of place	Information accessible from any computer in the hospital, particular piece of data must always be on the same place.
Lost forms	Paper forms could be lost	Digital forms are saved in a server with backups, do not get lost
Completeness	There is no way to verify completeness	WfMS will not allow incomplete save of a form
Correctness	There is no way to verify correctness	Some bits of information could be verified with the use of pre sets
Readability	Handwriting can be difficult to impossible to read	Typed forms are consistent and easy to read

Table 2 comparison of handover handling between Papermodel1 and WfMSModel1

	Papermodel1	WfMSModel1
Correctness	The handover is manual, done by patients, doctors, secretaries, and snail mail. Works most of the time, delays are possible	Once a form has been saved, the handover is done automatically by the WfMS
Speed	The speed depends on the speed of the humans doing it. Some steps quite quick, snail mail quite long.	Once a form has been saved it is instantaneously assigned to the correct role.
Accountability	While for each step the corresponding role or person takes responsibility, it is difficult to track who exactly has it and what work they have done.	Once a case is assigned to a particular role or person they take full responsibility and it becomes easy to track the work done.

Table 3 comparison of case tracking between Papermodel1 and WfMSmodel1

	Papermodel1	*WfMSModel1*
Follow case status	Secretaries have to manually read files or calendar notes to know the status of case, sometimes even have to call other departments.	With the WFMS the roles and groups who have access to files can easily monitor the status of once case.
Alerts	To fire an alert the human first must know the case status and then inform involved parties.	Case triggering is automatic to all involved roles with clearly defined rules to follow.
Management of exceptions	Paper forms allow for an ad-hoc management of exceptions. While in some is cases this might be good, in others it could potentially make it hard to track others decreasing quality.	In principle WFMS are harder to make exceptions, however in a medical situation this will still be the case, but now it will be also hard to record or even track the exception.
Rules	Check up on test results is done by secretaries five days to operation date before taking corrective action.	With the WfMS model this rule has been changed for five days after visiting the anesthesiologist instead of 5 days before the operation date. (This rule is not WfMS dependant).
Equipment	This process is manual and depends on human memory and intervention. Some few times equipment is forgotten.	This process is now automated and it is assumed that no mistakes happen.

Third experiment, WfMSModel2, *corresponding to improvement1*. This is a modified version of *WfMSModel1*, the main difference being that operations are only scheduled *after* the anesthesiologist has given approval for the operation. Normally, operations can be scheduled once a patient has had a consultation with the surgeon even if he or she does not have an authorization from the anesthesiologist. Usually this is not a problem, but there are a few occasions where operations have to be postponed because the anesthesiologist does not give such an authorization. This improvement's goal is meant to reduce the amount of operations being postponed, thus reducing the *operation time* by the cases affected.

Fourth experiment, WfMSModel3 corresponding to improvement2. This is also a modified version of *WfMSModel1,* but the main difference in this case is that the anesthesiologists review their pending cases for approval more frequently, i.e. every 3 days, instead of (seemingly) at random. Normally, when an anesthesiologist does not give an authorization right away, this is because he or she is waiting for test results back. Once the results for a pending case are in, sometimes they are checked right away while others could take up to a week (unless it is a case of high urgency). Clearly, this can lead to a longer *operation time* for the affected cases – an issue that this improvement attempts to address.

Evaluation

The analysis of the simulations is shown in **Table 4**, showing only differences that are significant using a 95% confidence interval. The results indicate that in terms of processing times the *WfMSmodel1* is faster than the *papermodel1*. For instance , "*Operation Time*" - which can be considered as the lead time – shows that *WfMSModel1* is better as its resulting time ranges are (279.67 to 283.6 hours) smaller when compared to the *papermodel1* (297.7 to 303.18 hours). There is a significant difference of approximately 18.85 hours between their means, a 6.69% improvement. However, the distinctness in this quantitative KPI as well as the others may be considered too small to be labeled as drastic improvements.

One possible negative aspect of the *WfMSModel1* is that patients seem to have to wait longer in queues, but this is an effect of our assumption that staff being unfamiliar with the SOARIAN user interface will need more time. Also, some of the measurements are based on estimates by experts, who would expect the use of a WfMS to be more cumbersome in places. Finally, an interesting finding is that cases with a higher urgency benefit less in processing times, which is easily explained: both processes are very efficient in handling high priority cases.

Table 4: KPI Results for Experiment 1 and 2.

	Paper-based		WfMS		Diff in	mean
	Mean	Range	Mean	Range	absolute	relative
Total Operation Hours Lost	1313.2	1,287 to 1,338	808	777 to 838	505.2	62.52%
Waiting Times Patients (minutes)	74.73	73.7 to 75.7	79.8	78.2 to 80.1	4.44	5.60%
Approval Time (hours)	73.08	72.1 to 74.0	70	69.5 to 70.5	-3.08	-4.4%
Approval Time with Tests (hours)	101.8	100.8 to 102.7	97.27	96.6 to 97.8	-4.53	-4.65%
Waiting time until Operation (hours)	300.45	297.7 to 303.1	281.6	279 to 283	-18.85	-6.69%
Operation Time to Due Date (hours)	1041.8	1,035 to 1,047	1058.5	1,049 to 1,067	16.64	1.57%
Anesthesiologist to Operation Time (hours)	248.08	245.5 to 250.5	232.2	230 to 234	-15.84	-6.82

HECA Measurement

HECA has been used as a measurement of quality. The analysis resulted in the measurement of the *PaperModel* and the *WFMSModel*. **Table 5** shows the error modes and error possibilities of the *PaperModel* and the *WFMSModel*, the increase in risk points that a specific error would have, and a comparison of error probability between *Papermodel* and *WFMSModel*. As can be seen, there are some error modes where the *WFMSModel* does not show any improvement, but most do show a significant improvement. The reduction of likelihood from implementing the *WFMS* could go up to 99% for one error mode. **Table 6** represents a comparison when adding everything up. When analyzing **Table 6** more significant improvements at all urgency levels become apparent. The biggest improvements in quality originates from replacing human tasks by machine tasks and the assumed completeness of forms, as stated in **Table** 1, **Table** 2 and **Table** 3. Also, a part of the quality improvement comes from the lower Operation time, as stated in **Table 4**. After all, reducing the time until a patient gets an operation lessens the risk for the patient. The improvements in process quality range from 24,6% to 48,6% when assuming a WfMS is in place to support the PAP. It would appear that when taking into consideration this qualitative aspect, the *WfMSmodel1* indeed shows a highly tangible benefit in comparison to *papermodel1*.

Table 5, error modes, likelihood and severity of an error for *Papermodel and WFMSModel*

	Likelihood		Increase in risk	mean	
	Paper	WFMS		absolute	relative
Wrong type of Antibiotics (AB)	0,0024	0,0006	4,86	0,0087	75
Wrong dose of AB	0,058	0,0006	3,86	0,222	99
No AB although subscribed	0,0069	0,0006	4,5	0,028	91
Extra equipment Anesthesiologist unavailable	0,0021	0,00038	3,25	0,028	91
Patient ate or drank before operation	0,00656	0,00656	4,71	0	0
Nurse forgets additional procedure	0,02	0,02	4,43	0	0
Wrong pre-operative-medicine was given	0,0265	0,000019	2,75	0,072	99
Wrong dose of pre-operative-medicine was given	0,0000006	0,0000006	3,00	0	0
No pre-operative-medicine given	0,0003	0,00006	2,50	0,0006	80
Allergic reaction during surgery	0,0103	0,00016	4,14	0,042	98
Proceed without additional surgeon equipment	0,00194	0,00038	4,33	0,0082	80
Surgeon forgets legal process	0,068	0,001	3,33	0,223	98
Patient is malnourished	0,319	0,319	4,67	0	0

Table 6: Results of different HECA quality measurements divided by type of urgency

	Paper	WfMS	Percent
Urgency1 (due deadline in 48 hours)	1.553	0.798	48,6%
Urgency2 (due deadline in 14 day)	1.398	0.838	40,0%
Urgency3 (due deadline in 3months)	2.839	1.739	38,7%
Urgency4 (due deadline in 6 months)	3.885	2.927	24,7%

To assess *WfMSModel2 and WfMSModel3, two additional experiments were carried out.*

For experiment 3 (not shown in table), the important KPI to observe is **Operation Time.** In theory, *WfMSModel2* should improve over *WfMSModel1*. However, the results show that *WfMSModel2* (280.93 hours in average with a mean of 2.08 hours for **Operation Time** with a 95% confidence interval) does not display any significant difference vs. *WfMSModel1* (281.6 hours in average a mean of 18.5 hours with a 95% confidence interval). It would appear that this suggested improvement does not bring any tangible benefits. A possible explanation for the lack of improvement is that high priority cases – those with *urgency1*and *urgency2* levels – do not receive any benefit. These have priority anyway and are attended to very quickly. Meanwhile, cases with *urgency3* or *urgency4* levels also do not show any significant improvements, probably because they are already long term operations.

Experiment 4 displays similar results as the previous one when considering **Operation Time**. The results show that *WfMSModel3* (277.61 hours in average with a mean of 3.34 hours for **Operation Time** with a 95% confidence interval) does not provide a significant difference vs. *WfMSModel1* (281.6 hours in average a mean of 18.5 hours with a 95% confidence interval). The explanation is similar as for experiment 3: cases with higher levels of priority are attended to already quickly, while long term operations do not show significant improvement (e.g. just because an approval has been given, the patient still might choose voluntarily to have the operation three weeks later. Getting the approval a few days earlier would not have made much of a difference).

DISCUSSION AND CONCLUSION

This paper has presented in considerable level of detail how simulation can be used to estimate the effects of using a WfMS to support a medical process, in this case the pre-operative process within the Bronovo hospital. By incorporating the HECA technique, it is also shown how a qualitative benefit like risk reduction can be assessed on top of logistic parameters that are concerned with operating and queuing times.

At this stage, the Bronovo hospital is pursuing the implementation of the WfMS for supporting its pre-operative process, encouraged by the results from our simulation study. Interestingly, the largest benefits of applying workflow technology in this case seem to be associated with reducing risks for patients, which is tightly connected to a WfMS' capability to make sure the correct information is available at the right time. This is perhaps a distinctively different type of performance improvement than what is seen in other domains, but a clearly important one for healthcare.

Even though simulation has been proven useful to make a tangible prediction of the effects of using a WfMS, it remains to be seen whether these will materialize. In particular, we have a limited insight at this point on the adoption of the technology in the hospital, which will be crucial for its success. We are closely following the implementation and are preparing ex-post measurements, as a means of validating our simulation approach on the one hand and establishing the benefits of using a WfMS in medical practice.

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