Using Models and Simulation for Predicting Efficiency as a Measure of Success of Different Telemedicine Deployments

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Abstract—**The planning and development of large-scale telemedicine system implementations throughout Europe motivates the need for cost effective ways to predict the level of their success in each new context. The efficiency of the system and that of the work process involving it influence the success of any telemedicine implementation, determining whether the existing healthcare staff will be able to manage their workload in their available time. This paper demonstrates by means of examples how we could use observations from repeated simulations of a nurse working with a telemedicine system in different contexts, which may differ in several ways, to predict the efficiency of the work process. The examples presented in the paper are based on previous experience with the use of telemedicine systems in Lothian, Scotland.**

Keywords-telemedicine; telemonitoring; efficiency; scaling up; cognitive modelling; simulation

I.   INTRODUCTION

Despite its potential advantages for patients suffering from long-term conditions, healthcare systems and the economy ([1]), the benefits of telemedicine in terms of patient care and costs have not been convincingly proven yet. Although many studies conclude that telemedicine is beneficial (e.g. [2, 3]), their evidence is often hard to generalise, as it is the result of small scale trials lead by enthusiasts [4, 5], and does not meet high evaluation standards [6, 7].

Several European countries are currently planning and developing large-scale telemedicine pilots, which will help assess whether telemedicine would work at scale. Two important examples are:

• The Renewing Health European project ([8]), which involves nine European regions in the provision of telemedicine services for large segments of the population suffering from chronic obstructive pulmonary disease (COPD), diabetes and cardiovascular disease;

• The ITTS (Implementing Transnational Telemedicine Solutions [9]) project partly funded by the EU Northern Periphery Programme, which involves partners from six Northern European countries and aims to facilitate transnational knowledge exchange for implementing telemedicine solutions at scale.

The UK is also planning a large-scale deployment of systems such as these through the Delivering Assisted Living Lifestyles at Scale (DALLAS [10]) programme. The Scottish government placed such nationwide deployment at the centre of Scotland's eHealth strategy [11].

Given the high level of risk associated with such projects, it becomes desirable to find cost-effective means to predict the success of telemedicine systems in different deployments, as this could influence the decision of investing into each deployment and help save resources. In a context characterised, on one hand, by a predicted shortage of human resources in healthcare and, on the other, by an increase in their workload due to an increase in the number of patients suffering from long term conditions ([1, 12]), the efficiency of a telemedicine system and that of the work process in which it is used are important factors for its success. We define efficiency here as how likely a healthcare professional is to care for her patients in her available time by using a work process involving the telemedicine system.

We have previously described a methodology and associated modelling approach which can be used for predicting the usability of telemedicine systems in different deployments [13]. We will only briefly summarize them in this paper, focusing only on the efficiency component of usability. Elsewhere, we have shown by means of examples how our approach would work for predicting the efficiency of the system when deployed in contexts differing in workload, user and system characteristics [14]. The differences we observed were only in terms of minutes, as actions on the system in question would take little time and rarely escalate to dramatic changes in the user's total time available. The very time intensive user work, which importantly influences the handling of her workload, lies outside of the system, within the work process. To cater for this conclusion, in this paper we exemplify how our approach can be used for predicting the efficiency of the work process involving the telemedicine system. While it may be hard for the naked eye to foresee how the user's time would vary in contexts which differ in several characteristics of her workload which may influence each other, we show how our approach can help in this respect to provide a clear indication of the time that the user would need within each context for managing her work safely. The examples contain invented facts and numbers, derived from previous experience with telemedicine systems in Lothian, Scotland ([15]). We also describe the study we commenced for validating our approach.

II. THE PROPOSED METHODOLOGY AND MODELLING APPROACH

Our methodology is a guide for reusing models, which are found to reliably determine the efficiency of a work process involving a telemedicine system into a reference deployment site, for predicting the efficiency of the same work process if the system is deployed into a potential site, using only information about the characteristics of the potential site. Its main advantage is that it reduces the need for evaluating the system and work process into each new context, thus saving resources. It also helps analyse whether the work process would be manageable in potential contexts and explore what-if scenarios involving changes to the workload, user, process or system characteristics if not. A step-by-step description of the methodology is provided in Fig 1.

Although our methodology can be used with any type of modelling approach, depending on the level of perceived risk of the problem at hand, we have chosen to represent a work process by means of a user and system model which are run in parallel. The user model is a cognitive model inspired by the Icarus cognitive architecture ([16, 17, 18, 19, 20]), which receives as inputs a description of a user's profile in terms of goals, knowledge, skills as related to her work, and the time the user spends for performing actions on or outside of the system. We have chosen cognitive modelling due to the cognitive nature of nurses' medical work ([21], [22]). The system model is a basic labelled transition system, which receives as inputs what the system presents to the user or stores internally at one time, how this changes as an effect to user actions on it, and the time it takes to make such changes (waiting time). The 'run of the model' means the parallel run of the user and system model, simulating a user using the system and doing any actions external to it. It takes as inputs a new workload and other characteristics of the work environment, which can be either constants (the same on every simulation run e.g. the number of patients to be monitored) or numbers drawn from probability distributions (e.g. for the values of readings). A high enough number of runs helps to obtain the expected distribution of the time spent by the user in achieving her goals (doing her work) in one deployment site. By changing the characteristics of the workload and/or the inputs to the models (e.g. to reflect changes in user skills, way of doing things or system design) we can model potential deployments, which can differ in several ways, sometimes interacting with each other, to the reference one. By running another high enough number of runs, we can obtain predictions of the efficiency of each potential context, unobvious to the naked eye, and useful for the analysis of whether work would be manageable there, as we will exemplify below.

III. EXAMPLES

Let us consider the case of a hypertension monitoring work process performed by nurses with the help of an online telemonitoring system, in which the nurses follow the steps from below (derived from previous experience [15]):
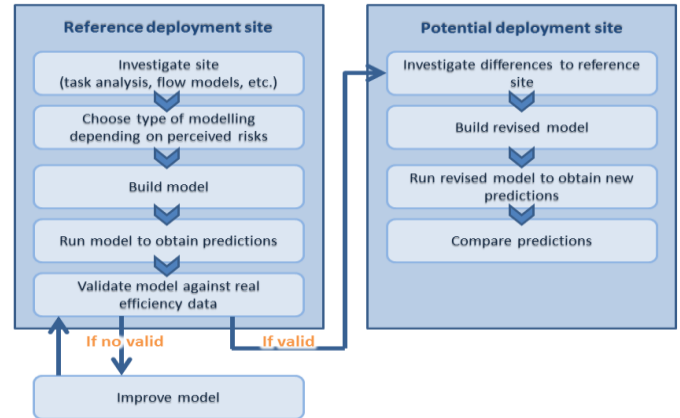

Figure 1. The methodology.

From the table of patients from the system's homepage, the nurse selects one who is flagged up (as having the last systolic-diastolic pairs as exacerbations) by choosing an appropriate action from a pop-up box, which takes her to the patient's details page. Here, she can see the patient's demographics, contact details, and last two days of systolic-diastolic pairs of readings. If the readings are concerning, the nurse clicks on a button to go into the patient's extended (seven day) details. Next, she needs to go into the electronic health record, on a separate system, to check the patient's medical history. If the patient's condition seems to be worsening, the nurse may decide to call her to check on her state, gain any additional information and give her advice. For doing this, she needs to go back to the patient's details page and retrieve her phone number. Following this call, if the nurse concludes that the patient needs an appointment with her GP（General Practitioner), she will retrieve the GP's phone number from the same page and call the GP, also passing on the medical information gained. Even if the patient did not require a call or an appointment, the nurse will next enter her conclusion as a note in a form provided on the patient's details page. Following this step or if the patient's condition noticed from the extended details page and history was not worsening, the nurse returns to the homepage. As there are no options in the system to acknowledge who has been checked, she writes the patient's name down before selecting the next flagged up patient in the list, scrolling down to retrieve her first if necessary. The nurse finishes her work when all of the flagged up patients have been checked.

Let us consider for a **first scenario** a medical practice which has recruited 20 patients for being monitored by using the telemonitoring system, and where a nurse's time allocated for the monitoring work is 2 hours (many practices in the UK allocate a fixed amount of time from a nurse's shift for telemonitoring work). Let us suppose that, according to our analysis of the context, we found that the patients' reading criticality is characterized by a mean of 30% and standard deviation of 10%. While for keystroke-level actions we use the time from the Keystroke-Level Model (KLM [23, 24]), we define the following times for actions performed outside of the system:

• Calling up patients: the nurse will dial the number in a time characterized by a mean of 8 seconds and standard deviation of 1 second. She will hold on the phone for 10 seconds. Patients pick up the phone in a time characterized by a mean of 7 seconds and standard deviation of 1 second, so the nurse will not miss any patients in this context.

• Speaking with the patients will take the nurse a time characterized by a mean of 8 minutes and standard deviation of 2 minutes.

• Calling up and speaking with the GP will take the nurse a time characterized by a mean of 3 minutes and standard deviation of 30 seconds. Please note that here we have not broken down the steps of performing the call as for patient calls from above, as we consider that the GPs will always pick up and that there is efficient communication set up between the nurse and the GP.

• Writing down names takes the nurse a time defined by a mean of 5 seconds and standard deviation of half a second.

• Checking the electronic health record (which is a separate system, and so we are not considering it within the system model) takes a time defined by a mean of 3 minutes and standard deviation of 20 seconds.

Also, let us consider that an analysis of the practice's statistical data on who has been called and how often, we found that out of the patients whose medical history the nurse checks, those who need a call are characterized by a mean of 50% and standard deviation of 10%. Also, out of the patients whom the nurse has called, we find that those who need an appointment with their GP are characterized by a mean of 30% and standard deviation of 10%. This data is used to simulate a nurse's decision of when to call the patient and GP.

We implemented the above scenario by using our modelling approach, and performed 200 runs to obtain a prediction of the distribution of the time it takes for the nurse to monitor all of the patients who are flagged up. A representation of the results is provided in Fig. 2.

The figure predicts that the nurse will always manage her work within the 2 hours (7200 seconds) allocated for it- in ideal conditions, where there are no interruptions, the latest time she will always finish is 7000 seconds- 3 minutes earlier than the deadline. Moreover, she would very rarely need the time between the last 20 and the last 3 minutes (only once in 100 work sessions would she need more than 6000 seconds- 1h 40min) and she would rarely need the time between the last 37 and the last 20 minutes (only 2.5 times in 100 work sessions would she need between 5000 seconds- 1h 23min, and 6000 seconds- 1h 40min). This analysis, together with an analysis of cost and of the nurses' workload for other duties, could aid in the reconsideration of the time allocated to them for the monitoring work. The two hour time allocation already offered to them is predicted to be the safest option, as the nurse would always manage all of the patients in this time. Nevertheless, if cost is more of a concern and/or the nurse's time is critically needed for other duties, offering each nurse 1h 45min, or even 1h 30min would be better options, and still safe enough, as in very rare cases would the nurse have to exceed them.
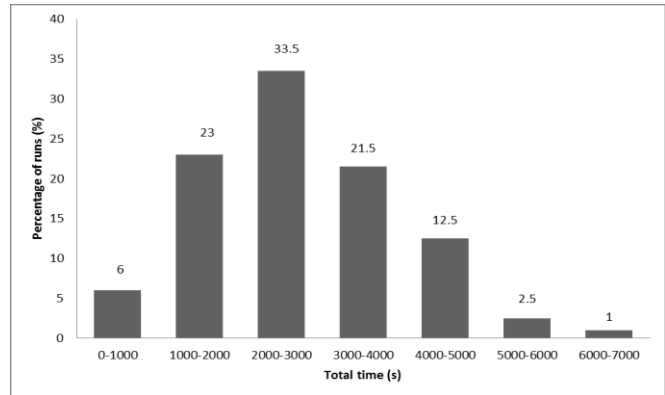

Figure 2. First scenario.

We suppose that the efficiency results in the first scenario correspond with experience there. Let us next consider that there are plans to deploy the system into two potential sites, in both of which a nurse will deal with double the number of patients than in our reference site (40), and which, it turns out, differ in various other ways. We would be interested to estimate how much time nurses should have allocated for the monitoring work in each of the sites.

The first potential deployment site (**second scenario**) has decided to recruit double the number of patients than the reference site, but these patients are less sick- the criticality of their readings has a mean of 20% and standard deviation of 5%, and the nurses are more likely to refer called up patients to their GPs- out of the patients who have been called up, those who are to be set up an appointment are characterised by a mean of 50% and standard deviation of 10%.

Although one would normally expect that double the patients would mean double the time spent monitoring them, our variations on the reading criticality and percentage of patients to require an appointment with the GP make our conclusion less clear. It is in such cases that our modelling approach can be of help. By reinstantiating our models with the new inputs and running another 200 simulation runs, we obtain the graph presented in Fig. 3.
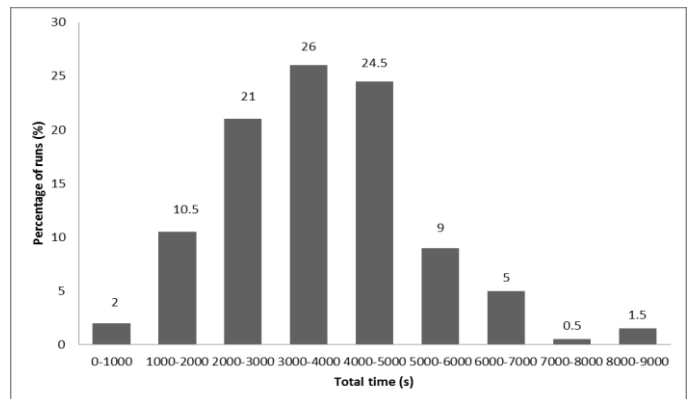

Figure 3. Second scenario.

The graph predicts that the decrease in the criticality of the patients' readings has mostly compensated the doubling of the number of patients and the increase in the percentage of called patients who need a referral, as the maximum time that the nurse would spend in this scenario is 9000 seconds (2.5 hours), only half an hour more than in the first scenario. Moreover, the nurse would need the last 17 minutes of this time extremely rarely (1.5 cases in every 100 work sessions), and the last 33 minutes very rarely (in 2 every 100 work sessions). This predicts that the safest time the nurse should have allocated is 2 and a half hours, but that 2h 15min and 2 hours would be more economical, and still safe enough, options. Our approach thus helps explore how the different inputs to the models interact to influence the total time.

The second potential site (**third scenario**) has also decided to recruit double the number of patients than the reference site, and these patients are sicker- the criticality of their readings has a mean of 40% and standard deviation of 10%. For fear that they would not be able to manage their work, the nurses here have decided on some simple questions to always ask patients whenever they call them, which would lead to less time spent during phone conversations with them- the new time is characterised by a mean of 6 minutes and standard deviation of 1 minute and 20 seconds.

Although double the patients and sicker patients would intuitively lead to more than double the time spent monitoring them as compared to the reference site, the fact that nurses speak less time on the phone with patients, where phone conversations are the most time consuming external action, will compensate some of the time, but it is difficult for the naked eye to decide how much. By reinstantiating our models and running another 200 simulation runs for this new scenario, we obtain the graph from Fig. 4.

The graph predicts that the introduction of the nurses' call protocol does not compensate greatly the time influenced by the more numerous and sicker patients, as nurses would still maximally spend more than double the time of the reference deployment site monitoring all of their patients. Nevertheless, the graph predicts that nurses would very rarely (in 3 every 100 work sessions) need more than 3h 3min (11000 sec) to handle all of the patients. Therefore, although an ideal, safest time to offer them would be 4h (over 14000 sec), 3h 30, 3h 15min and 3 hours would be more economical, and still safe enough, options.

IV. START ON VALIDATION

To validate our work, we will use our methodology and modelling approach to help predict the efficiency of a monitoring work process for a new telemonitoring system introduced in Lothian, Scotland. We are currently working on iteratively improving our modelling approach until it can be used to reliably predict the efficiency of the work process for deployment sites where the system is already being used. To do this, we are conducting observations of users monitoring patients using the system, and using data from system logs, other system documentation and the practices'
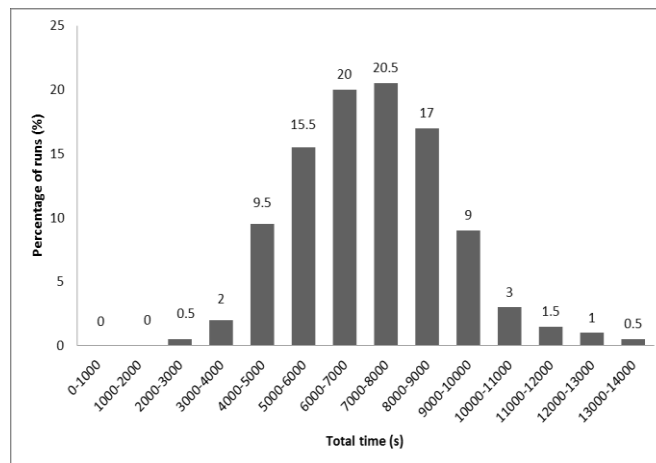

Figure 4. Third scenario.

statistical data, which helps us both obtain inputs for our model, and gain an understanding of the true efficiency of the work process to test the results of running our model against. Once our modelling approach is found to be reliable enough, we will gather data about potential deployment contexts and use our approach to predict efficiency there. A new evaluation of the efficiency of the work process in these contexts, once the system has been deployed and users have gained some experience with it, will reveal whether our approach is successful. The system is being used for monitoring two long-term conditions, by users with different roles and experience (non-clinical call centre staff vs. clinical users- nurses, physiotherapists, GPs, more or less computer literate or used with the system), which will help us also explore how efficiency is influenced by such aspects.

V. RELATED WORK

From a methodological standpoint, although we have not found any literature describing a methodology similar to ours, the areas of performance modelling and business process change management are the closest. In the area of performance modelling, the most relevant work is that by Bailey and Snavely ([25]), as it proposes using models for the 'what-if' exploration of how, in this case, the performance of large-scale scientific programs, is affected by systems of different sizes and different jobs. Like us, they stress that such an approach helps reduce the need for more costly evaluation, and inform the choice of a system. The authors of SAP (Systems, Applications and Products in Data Processing [26, 27]) combine the two areas to propose an approach allowing the exploration of 'what-if' scenarios for business process models. The purpose of these papers is to explore changes to one deployment site, while that of our work is to compare sites differing in several aspects which may influence each other.

From a work process standpoint, time and motion is considered the most reliable method for analysing the impact that the introduction of health information systems in hospitals would have on the workflow of health professionals [28]. Recent years have seen a surge in the use

of time and motion studies in health informatics, due to some pioneering papers ([29], [30]), the development of a data acquisition tool ([31], [32], [33]) and steps towards methodological standardisation [28]. Through continuous observation of clinician work, time and motion can help deduce important aspects of the efficiency of work processes involving a health information system: the time it takes to perform each type of task, where inefficiencies may lie, the effect of interruptions, collaboration with colleagues and multitasking.

There is of course a lot of literature on using models for predicting the efficiency of a system or process in terms of execution time, most notable being the work on the GOMS (Goals, Operators, Methods, and Selection rules) family of models [34]).

Our work is not intended to compete with model-based evaluation approaches, and it is not currently evaluating the efficiency of a single work process in the same depth as the time and motion method. Its strength does not lie in the prediction of efficiency within a single context, but in being used for analysing efficiency in contexts which may differ in several ways, including scale, without the need for costly evaluation with users, and in the area of telemedicine where there is a strong motivation for such an approach.

VI. Discussion, Conclusion and Future Work

We have briefly described a methodology which can be used for predicting the efficiency of a work process involving a telemedicine system in different deployment sites, and proposed a modelling approach to be used with it. We have exemplified them in action for providing an indication of the distribution of the time needed by a nurse performing monitoring work using a telemonitoring system, and showed how these results can be used for deciding what would be a good time limit to give to nurses such that their work is safe enough. Given considerations of cost and resources, its findings can lead to a decision of whether the work in the potential site is manageable, before any resources are wasted in deploying the system in that site. Should the work be found unmanageable, we could use it to answer 'what-if' questions about the effects of potential solutions: changing the characteristics of the workload, user, process or system.

Although for contexts which differ slightly our approach might not be necessary, as the practicality of deploying the system there would be clear, there are many contexts where differences are complex and interact with each other where our approach could be useful. These contexts could be real ones where the system is planned to be deployed, or hypothetical ones- e.g. would monitoring work still be manageable if the system is to be used during an epidemic, with more and sicker patients?

We have also described the validation work that we have started for our approach. The result of the current phase will be an improved modelling approach, including changes both to its logic and the specification of the models, and a good understanding of its pros and cons. The next step is to check whether our approach will provide good efficiency predictions in potential deployment sites.

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