

# Improving Operational Support in Hospital Wards through Vocal Interfaces and Process-Awareness\*

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## Abstract

*Providing operational support to clinicians during their daily activities in hospital wards is a challenge for information technologies. In particular, solutions should provide very usable user interfaces, possibly deployed on mobile devices, and should be able to enact and monitor the execution of clinical guidelines. In this paper, we present the preliminary outcomes of the TESTMED project, a small project in which vocal and touch interfaces are being experimented as a viable solution for clinicians' interaction with the system, and a process-aware approach has been undertaken for the (semi-)automation of clinical guidelines.*

## 1 Introduction

Healthcare is one of the largest business segments in the world and it is a critical area for future growth. It is based on many professionals working in a multidisciplinary environment with complex decision-making responsibilities. In the last years, the Business Process Management (BPM) community studied how to organize clinical activities in care processes and to automate their execution [10]. A care process definition consists of a network of clinical activities (a.k.a. tasks) and their relationships. In this context, a *process-aware information system* (PAIS) defines, creates and manages the execution of care processes through the use of a software system which is able to interpret the process definition, interact with process participants (doctors,

nurses, etc.) and possibly invoke other tools and applications. A PAIS supports the automation of a care process, in whole or in part, during which information, documents and tasks are passed from one participant to another.

Nowadays, the main problem is that clinical assessment and treatment decisions are complex activities, and many complicating circumstances – often not easily predictable in advance – may arise. Currently, BPM capabilities, driven through pre-specified and automated rules sets, have addressed only some parts of the lower-level administrative processes (electronic ordering, appointment making [11], etc.) but have made little progress into the core clinical activities. Moreover, clinicians operate in a culture of personal responsibility for decisions, by making it difficult to accept automated systems as the primary decision route.

In this paper we present the initial outcomes of the TESTMED<sup>1</sup> project, whose purpose is to reduce the gap between the fully automated solutions provided by the BPM community and the clear difficulties of applying a traditional process management approach in the healthcare context. TESTMED proposes to develop a PAIS where the emphasis is not on automating the decision making, but on assisting the clinicians through the availability of recommended care pathways for particular conditions, together with the provision of relevant information (such as the impact of certain medications, contraindications, etc.) that reduce the risk arising from a decision. Care pathways are presented in the form of “best practices” (or clinical “guidelines”) and provide clinicians with appropriate knowledge to enact the medical treatments. After all, the use of high-level guidelines that capture both literature-based and practice-based evidence is becoming a reality in hospitals all around the world [16, 13, 2, 18]. The TESTMED project aims, on one side, at finding an effective way for the clinicians to exploit the guidelines, i.e., to acquire, by reading or listening, the guideline and to make effective use of it. We believe that the adoption of mobile devices with specific user interfaces (which do not distract the clinician from

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<sup>1</sup>The acronym TESTMED stands for *meTodi e tEcniche per la geSTione dei processi nella MEdicina D'urgenza* (in English, *methods and techniques for process management in emergency healthcare*).

assisting the patient) can be a valuable solution. We have investigated the integration of voice and touch interfaces with interesting results that will be shown in the following. On the other side, the TESTMED prototype is able to trace and monitor every choice originated during the guideline execution. This allows (i) to document the specific patient care management process, which may have a legal relevance in case of issues, (ii) to provide a knowledge base, consisting of all the patients' cases, on which to execute subsequent analysis in order to infer more evidence and possibly improving the guideline itself, and (iii) to provide (semi-)automated support to the actors, by providing notifications and relevant data collected during the execution, etc.

The TESTMED prototype has been jointly developed and evaluated with DEA (that is “Dipartimento di Emergenza ed Accettazione”, corresponding to the Emergency Department/Room) of Policlinico Umberto I - the main hospital in Rome (Italy). The first tests have concerned the guideline enacted for patients suffering from chest pain<sup>2</sup>, which is one of the most common reasons for the admission in the emergency room (5% of all visits) with high mortality in case of failure diagnosis and improper dismissal (2–4%)[12]. Leveraging the encouraging results of our initial tests, we plan to perform in the next months an extensive system evaluation and validation. This will require the enactment of additional guidelines, as well as the collection of both quantitative and qualitative data for assessing the real impact on clinical work practices.

The rest of the paper is organized as follows. Section 2 describes the general approach used for dealing with the enactment of guidelines and shows some screenshots of the system. Section 3 focuses on the architecture and gives technical details of the software components used within the TESTMED prototype. Section 4 provides details of the preliminary evaluation with users and some performance tests. Section 5 discusses relevant works, and Section 6 concludes the paper.

## 2 The General Approach

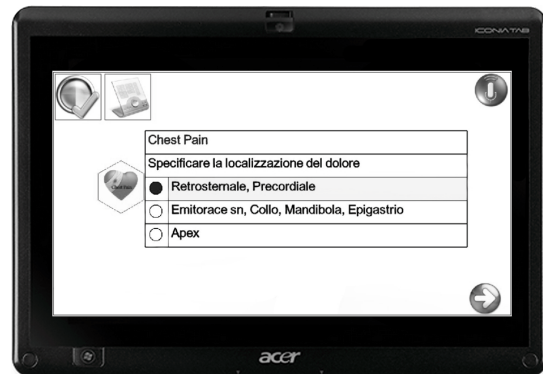
The core of the TESTMED prototype consists of two main components. A *user interface*, specifically designed to be executed on mobile devices (such as tablets), is used for supporting clinicians in the enactment of the clinical activities required by a specific guideline. The interaction between the clinician and the user interface is twofold - tactile and vocal - and is thought to be as less invasive as possible. A *back-end engine* manages the routing of clinical activities and relevant data between clinicians. The engine is based on a service-based approach: each software component which interacts with the engine is considered as an external service

<sup>2</sup>Chest pain is defined as a pain that ranges from the base of the nose and navel and between the neck and the twelfth vertebra and that has no clearly identifiable traumatic cause.

Chest Pain Score	Score
<b>Location</b>	
Substernal, precordial	+3
Left hemitorax, neck, jaw, epigastrium	+2
Apical	-1
<b>Character</b>	
Crushing, pressing, squeezing	+3
Heaviness, tightness	+2
Sticking, stabbing, pinprick, catching	-1
<b>Radiation</b>	
Either arm, shoulder, back, neck, jaw	+1
<b>Associated symptoms</b>	
Dyspnoea, nausea, diaphoresis	+2

Score < 4: Low probability of angina pectoris  
Score ≥ 4: Medium-high probability of angina pectoris

Figure 1. Chest pain score [5]



(a) Screenshot of an intermediary page of the questionnaire

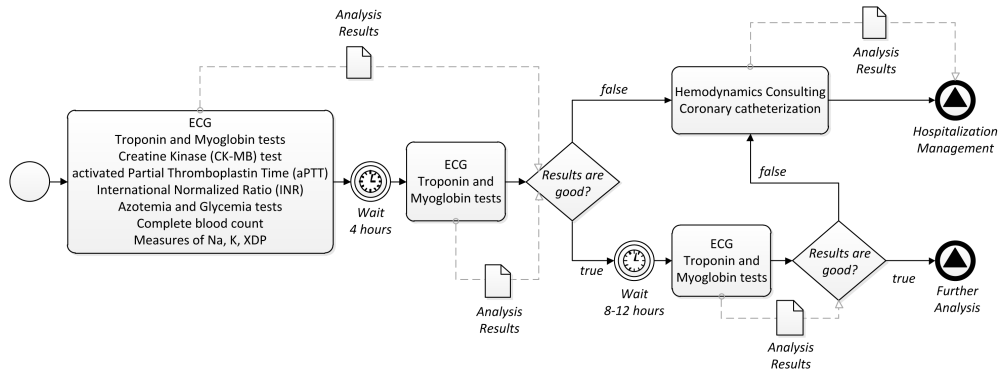


(b) Notification of a lab analysis result

Figure 2. The vocal/touch user interface

to be invoked when needed. Section 3 gives more details on the architecture of the prototype and technical details of components involved.

In order to better explain the TESTMED approach, we present the case study of Chest Pain, used in the project as the testbed of the approach. Typically, a patient suffering from chest pain is checked by a resident on duty in the emergency room and, on the basis of general impressions, patient history, risk factors and *chest pain score* it is decided whether or not to admit the patient for clinical observation.



**Figure 3. The care pathway for a score greater than 4**

The chest pain score allows to assess the clinical characteristics of acute chest pain, by calculating a semi-quantitative score. The score is used to improve the diagnostic and prognostic accuracy, in order to safely classify patients into low and high-risk subsets for cardiac events. Figure 1 depicts the original scores adopted in the DEA. The score is derived by evaluating a set of four clinical characteristics: (i) the *localization* of the pain; (ii) the *character* of the pain; (iii) the *radiation* of the pain and the (iv) *associated symptoms*. A partial score is associated to every characteristic, and the sum of these values produces a final score that predicts the angina probability. A chest pain score lower than 4 identifies a low-risk probability of coronary disease, whereas a score greater or equal than 4 can be classified as an intermediate-high probability of coronary risk. Different values of the rate correspond to different clinical treatments to be followed by the patient.

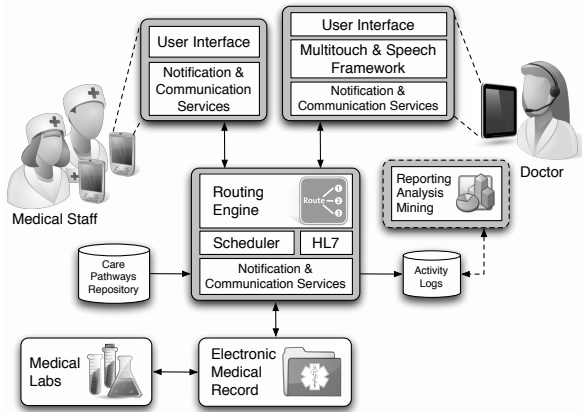
Now, let us see how the TESTMED prototype really works. When a patient suffering from chest pain asks for a visit, the doctor on duty in the emergency room fills a questionnaire useful for determining the chest pain score related to the patient. The survey is presented in a textual form through the user interface of the prototype (see Figure 2(a)). The interaction can be tactile or vocal. The doctor wears a headset with a microphone linked to the tablet; s/he can listen to the questions related to the questionnaire and reply by choosing one of the proposed answers. Each possible answer is coupled with a specific characteristic and provides an associated rate. After the survey completion, the system proposes - in the form of a care pathway - a therapy composed by a set of medical treatments and analysis prescribed to the patient. For example, if the chest pain score for a patient is greater than 4, the suggested care pathway is similar to the one shown in Figure 3. Here the care process is modeled through the *Business Process Modeling Notation* (BPMN); the reader should note that BPMN is not the language used to represent care pathways to clinicians, but only to graphically represent the path to the reader of the paper. The activities depicted in Figure 3 concern, first

of all, the enactment of some general analysis for the patient (e.g., ECG, complete blood count, etc.). After 4 hours from the first set of analysis, it is required to repeat some medical tests, like ECG and Troponin and Myoglobin tests. When the results of the analysis are ready, it is required to decide whether to hospitalize the patient or not. If the analysis outcomes present some values considered dangerous by the doctor, the care process suggests to make further tests (in our case, an hemodynamics consulting and a coronary catheterization) and, based on the results obtained, to activate a further procedure concerning the hospitalization of the patient. If the analysis outcomes are considered good by the doctor, the same medical tests (ECG and Troponin and Myoglobin tests) are repeated after further 8-12 hours. If the outcomes are again good, the process suggests to proceed with new analysis prescribed by the doctor; on the contrary, bad results mean to make an hemodynamics consulting, a coronary catheterization and to activate the procedure concerning the hospitalization of the patient.

The enactment of the various medical treatments takes place in different moments of the therapy. The TESTMED prototype is able to trace the current status of the care process, by recording analysis outcomes and clinicians' decisions. Reminders and warnings notify if new information is available for some patient (for example, if an analysis is ready to be evaluated - see Figure 2(b)). In such a case, the clinician can decide to see more details about analysis results, to have the updated view of the care process status or simply to accept the notification. If there is any doubt about the goodness of the care process for a specific patient, a clinician can abort the care process in every moment.

### 3 The System Architecture

The overall system architecture is shown in Figure 4. The doctor in charge of handling an incoming patient is equipped with a tablet PC that enables the clinician to select, instantiate and carry out the specific care pathway to be followed. According to a patient-centered clinical ap-



**Figure 4. System architecture**

proach, the care pathway is selected on a per-case basis from a dedicated repository and loaded into the back-end management system to be executed. Client components deployed on the tablet device provide support for both multitouch and speech-based interaction modalities. The user interface relies on an integrated multitouch and speech recognition/generation framework, able to handle both touch and vocal inputs, and to support device-to-human interaction via text-to-speech capabilities. The interaction between client and back-end components is supported by communication and notification services. According to a service-oriented approach, all system components are abstracted as service endpoints and interact through message-based service invocations. In addition, event-based notification services provide support for asynchronous communication patterns, required to enable the routing of events produced during the execution of a care pathway. This allows the clinician to receive reminders, alerts and notifications when the status of an active process changes, new information is available, or additional actions are required. Similarly, all members of the medical staff (other clinicians, nurses, etc.) are equipped with mobile devices and are notified of the progress of the care processes and of the different activities to be executed.

Care pathways are executed and managed by back-end system components, which provide the run-time environment for interpreting, instantiating and activating a care pathway specification. The execution of clinical guidelines is supported by properly routing data, events and activities, according to a process-aware and content-based approach where activity scheduling and message dispatching are data- and event-driven. Specifically, the interaction between all involved components and services is managed by a routing engine that manages the routing of clinical activities, relevant data and generated events among the different actors, services and information systems. The routing engine relies on a scheduler component for the timely execution of activities with temporal constraints (e.g., ex-

aminations and diagnostic laboratory tests that have to be scheduled and performed within specific time intervals), and interacts with the enterprise Electronic Medical Record (EMR) system to (i) access and retrieve clinical and administrative patient data, (ii) schedule and manage examinations, lab tests, drug prescriptions, etc. according to the clinical process, and (iii) receive events and notifications about test results and examination findings to be routed and delivered to the clinicians. The interoperability with the EMR system is achieved exploiting the Health Level 7 (HL7) standard protocol<sup>3</sup> and the interpretation, processing and generation of HL7 messages is managed by a specific HL7 component. All the activities performed during a clinical process are supposed to be logged and recorded, to keep track of the events, tasks and data that contributed to the clinical and decision making process. Recorded information can be directly exploited for reporting and analysis purposes, can serve as information source for clinical trials to enhance or enable an evidence-based approach, and can provide valuable support for forensic analysis [15].

**Prototype Implementation Details.** Client components are implemented in Java and have been deployed on an ACER Iconia Tab W500 running Windows 7. Multimodal interaction support is achieved by integrating the Multitouch for Java framework (MT4j<sup>4</sup>) with the Mediavoice Speaky solution<sup>5</sup>. MT4j is exploited to build the Graphical User Interface (GUI) frames, referred to as *scenes*, and to handle (multi)touch input events, while Speaky is used to process vocal inputs via an Automatic Speech Recognition (ASR) engine and enable device-to-human interaction via a text-to-speech engine. MT4j and Speaky have been integrated so that both frameworks have a consistent internal representation of the interface status, in order to make each possible interaction event accessible by both vocal and touch commands. Care pathways are defined in an XML-encoded format. Each specification selected by the user is parsed and processed by the client application components to dynamically build the user interface (including the graphical scenes and the set of possible vocal input commands) and by the back-end routing engine to configure its internal behavior. Back-end components are Java-based as well, and have been deployed on a server machine. The routing engine relies on the Apache Camel framework<sup>6</sup> that allows to define events/messages routing rules (called *routes*), specifying from which sources to accept incoming messages and how to process and forward them to other destination components. Service-based interactions are implemented as SOAP-based Web services, while asynchronous event notifications rely on RabbitMQ<sup>7</sup> messaging capabilities. A

<sup>3</sup><http://www.hl7.org/>

<sup>4</sup><http://www.mt4j.org>

<sup>5</sup><http://www.mediavoice.it/>

<sup>6</sup><http://camel.apache.org/>

<sup>7</sup><http://www.rabbitmq.com/>

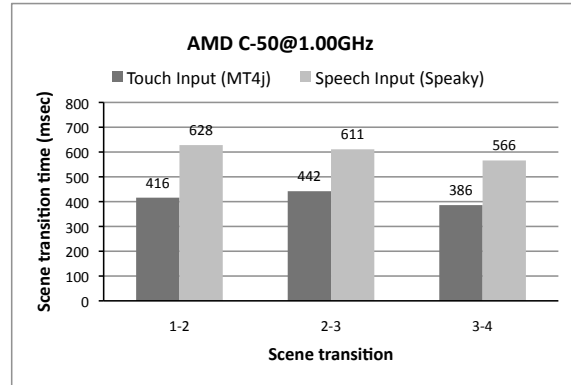
preliminary integration with the Galileo EMR<sup>8</sup> has been achieved via HL7 messages parsed and generated using the HAPI libraries<sup>9</sup>, while monitoring, analysis and reporting tools are currently under investigation.

## 4 Preliminary Evaluation

The TESTMED prototype is thought to be used in hospital wards for the enactment and the tracking of clinical activities. In this context, doctors and nurses need to collaborate in order to enact the proper medical treatments for each patient. The use of mobile devices and applications is valuable for the improvement of collaboration and coordination amongst clinicians, but there are also risks in their usage; for example, most of the care activities could be highly critical and time demanding, and the challenge concerns in developing a user interface that captures the users' attention onto the system only when it is strictly required. The development of specific interaction principles has required the use of *user-centered design* (UCD) techniques [3] during the life cycle of the TESTMED project. Such methodologies rely on a continuous involvement of users in each phase of the project, by guaranteeing that the final system may meet user expectations.

To be more specific, we produced two mockups of the system (in the months of April and September, 2011) and a working prototype in late November 2011. Each mockup/prototype has been evaluated through a wide range of usability tests (controlled experiments, thinking aloud techniques, etc.) made with real clinicians, and the outcomes have been used for an incremental improvement of the system. For example, despite users appreciated the touch interface provided in the first mockup, they asked for an interaction with the system still less invasive. To match such a request, the vocal interface (which can be used in addition to the touch interface) has been introduced in the second mockup and definitively improved in the first working prototype. Concerning the current version of the TESTMED prototype, we performed a test in the ward of DEA with 7 different users (specifically, 3 clinicians, 2 PhD student in medicine and 3 experts in Information Technology) and with the Chest Pain procedure loaded into the system. We also collected users opinions through a survey, and in general the feasibility of the twofold interaction and the idea to coordinate medical treatments through a workflow engine have been accepted and deemed usable.

In order to better investigate the responsiveness of the user interface, we carried out further tests for measuring the required time needed for passing from a scene to the following one. A transition between two scenes takes place when a clinician answers to one of the questions of the survey related to the guideline loaded into the system. We re-



**Figure 5. The vocal/touch user interface responsiveness tests**

peated the same test twice by using first the touch interface and then the vocal interface. Figure 5 shows, on the x-axis, which transition is involved in the current measurement, and on the y-axis the time needed for the generation and the visualization on the screen of the new scene. Since the chest pain score involves 4 different characteristics to be analyzed, 3 scene transitions are required before the generation of the care process. We performed such tests with an ACER Iconia Tab W500 running Windows 7 and provided with 1Ghz AMD CPU and 2 GHz of RAM. On average, about 400 ms are required for the scene transitions when using the touch interface and 6-700 ms for the vocal interface. The key aspect that determines such a delay when using the vocal interface lies in the extra time needed (about 200-250 ms) for contacting the ASR engine. While a delay in speech processing was expected, it is worth noting that it does not significantly impact on system responsiveness and usability, as the overall transition time is lower than 700 ms.

## 5 Related Work

As a consequence of the introduction by the medical community of evidence-based clinical guidelines to support decision processes, many research groups have focused on computer-interpretable clinical guidelines (CIGs) and different languages have been proposed [16, 13, 2, 18], which can be classified as rule-based (e.g., Arden Syntax [7]), logic-based (e.g., PROforma [4]), network-based (e.g., EON [17]) and workflow-based (e.g., Guide [1]). All languages define a computer-interpretable representation of clinical guidelines and most of them follow a task-based paradigm where modeling primitives for representing actions, decisions and patient states are linked via scheduling and temporal constraints, often in a flowchart-like structure. Many representation models are supported by systems that allow the definition and enactment of clinical guidelines [8]. Supporting systems are based on distributed architectural

<sup>8</sup><http://www.noemalife.com/en/home/>

<sup>9</sup><http://hl7api.sourceforge.net/>

models that include a guideline modeling editor, a model repository and a run-time execution engine, as well as tools and services to access electronic medical records (EMRs). Similarly, the introduction in healthcare of workflow-based models and technologies has fostered the development of so-called Careflow Management Systems (CfMSs) [14] that aim at providing an integrated solution for supporting both administrative and medical processes. In [10] the clinical context is presented as the ideal domain for applying PAISs, usually investigated and applied in business settings. The NewGuide system [1], for example, relies on a Petri Nets based formalism for modeling guidelines and implements a distributed architecture for integrating a Guideline Management System (GIMS), an Electronic Patient Record (EPR) and a CfMS.

To date, main research activities have focused on supporting guidelines modeling and process management in static and well defined clinical contexts. Specific research activities have been carried out in the context of emergency wards and first aid environments (e.g., [6]). According to reported results about the procedures, interaction patterns and supporting systems, the main causes of delays, inefficiencies and medical errors can be ascribed to the lack of proper interaction between the medical staff and the IT systems, which are, in turn, loosely integrated in healthcare workflows, leading to duplicated or suboptimal task allocation policies. In emergency departments, which today represent the main access point for citizens to healthcare services, the medical staff operates under stress conditions in a rapidly evolving environment [9]. Our work and initial effort can be broadly positioned in this context, where the introduction of PAISs can lead to significant benefits for both patients and clinicians, allowing to identify and analyze the sources of errors, delays and complexity (which may often go undetected) in order to improve the overall performance.

## 6 Conclusions

In this paper we have presented the initial outcomes of the TESTMED project, aiming at studying and developing a system supporting clinicians during their daily activities in hospital wards, through the interplay of advanced user interfaces (i.e., mixing touch and vocal features) on mobile devices and the enactment and tracing of clinical guidelines. The system prototype has been evaluated in clinical settings through the chest pain diagnostic and treatment process. Preliminary evaluation results show a good degree of acceptance among medical staff members, and performance results confirm the feasibility and potential applicability of multimodal interfaces. Starting from our initial results, the rest of the project will be devoted to the engineering of the prototype and to an extensive validation process. By providing support for additional guidelines, our evaluation plan includes the collection of quantitative and qualitative indica-

tors that in the long run will enable a deeper understanding of how the overall clinical decision making and collaboration process is impacted.

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