ACADEMIC PRESS
Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Biomedical Informatics 35 (2002) 123–139
Journal of Biomedical Informatics
www.academicpress.com

Evidence-based careflow management systems: the case of post-stroke rehabilitation

S. Panzarasa,[a] S. Maddè,[b] S. Quaglini,[b] C. Pistarini,[c] and M. Stefanelli[b,*]

[a] Consorzio di Bioingegneria e Informatica Medica, Pavia, Italy
[b] Laboratoria di Informatica Medica, Dipartimento di Informatica e Sistemistica, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy
[c] IRCCS "S. Maugeri," Pavia, Italy

Received 27 May 2002

Abstract

The activities of a care providers' team need to be coordinated within a process properly designed on the basis of available best practice medical knowledge. It requires a rethinking of the management of care processes within health care organizations. The current workflow technology seems to offer the most convenient solution to build such cooperative systems. However, some of its present weaknesses still require an intense research effort to find solutions allowing its exploitation in real medical practice. This paper presents an approach to design and build evidence-based careflow management systems, which can be viewed as components of a knowledge management infrastructure each health care organization should be provided with to increase its performance in delivering high quality care by efficiently exploiting the available knowledge resources. The post-stroke rehabilitation process has been taken as a challenging care problem to assess our methodology for designing and developing careflow management systems. Then a system was co-developed with a team of rehabilitation professionals who will be committed to use it in their daily work. The system's main goal is to deliver a full array of rehabilitation services provided by an interdisciplinary team. They are related to identify which patients are most likely to benefit from rehabilitation, manage a rehabilitation treatment plan, and monitor progress both during rehabilitation and after return to a community residence. A model of the rehabilitation process was derived from an international guideline and adapted to the local organization of work. It involves different organizational units, such as wards, rehabilitation units, clinical laboratories, and imaging services. Several organizational agents work within them and play one or more roles. Each role is defined by the goals' set that she/he must fulfill. Special effort has been given to the design and development of a knowledge-based system for managing exceptions, which may occur in daily medical work as any deviation from the normal flow of activities. It allows either avoiding or recovering automatically from expected exceptions. When they are not expected, organizational agents, with enough power to do that, are allowed to modify the scheduled flow of activities for an individual patient under the only constraint of justifying their decision. After an intensive testing in a research laboratory, the system is now in the process of being transferred in a real working setting with the full support of its future users.

Keywords: Knowledge management; Evidence-based medicine; Practice guidelines; Care delivery process; Careflow management systems; Exceptions management; Stroke

1. Introduction

Evidence-based medicine has been widely promoted as a way of improving clinical outcomes. It refers to the management of individual patients through individual clinical expertise integrated with the judicious use of current best evidence from clinical care research. The scientific literature represents the major source of knowledge, which should always be integrated into and complemented by local, practice-based evidence for individual and site-specific clinical decision making [1].

In current health care systems, however, scientific knowledge about best care is not applied systematically or expeditiously to clinical practice. Many years are required for new knowledge generated by randomized controlled trials to be incorporated into practice, and even then application is highly uneven [2]. The extreme

* Corresponding author. Fax: +39-0382-505-373.
E-mail address: mstefa@aim.unipv.it (M. Stefanelli).

1532-0464/02/$ - see front matter
PII: S1532-0464(02)00505-1

variability in practice in clinical domains in which there is a strong scientific evidence and a high degree of expert consensus about best practice indicates that current dissemination efforts fail to reach many clinicians and patients, and that there are insufficient tools and incentives to promote the rapid adoption of best practice. The time has come to invest in the creation of a more effective infrastructure for managing clinical knowledge to foster its application to health care delivery.

Knowledge management is the name given to the set of systematic and disciplined actions that an organization takes to obtain the greatest value from knowledge available to it. Knowledge, in this context, includes both the experience and the understanding of the people in the organization and the information and knowledge artifacts, such as electronic patient records, protocols, and guidelines, available within the organization and the outside world. Protocols and guidelines usually capture both literature-based and practice-based evidence into a textual format, which can be easily diffused but uneasily used in routine work. Thus, there is a great effort to disseminate them as machine-interpretable representations, which are more suitable for individual clinical decision support use. However, the goal of knowledge management is not only increasing the performance of individuals within the organization but of the organization as a "whole." It implies an organizational view of the problem where individuals cooperate within evidence-based care processes, each behaving according to the role the organization assigned her/him [3]. Thus, only cooperative care processes can attain the goals, in terms of efficiency, effectiveness and quality of care, the organization planned to achieve [4].

The goal of this paper is to provide an overview of methodologies and technologies that can be applied to knowledge management and to assess their actual or potential contribution to the basic processes of knowledge creation and sharing within health care organizations. The aim is to identify trends and new developments that seem to be highly innovative and to relate them to the research in the field of Medical Informatics, rather than provide a comprehensive review of already available products or systems.

Taking an organizational view of evidence-based care processes convinced us to assess the potential of Careflow Management Systems (CfMS) to support medical knowledge management in domains where guidelines have been developed and disseminated. Those guidelines provide the knowledge, which we can start from to develop an evidence-based model of the care process. Several limitations of currently available workflow technology need to be eliminated in order to successfully apply it within health care organizations. A special attention has been given to the problem of exceptions handling since its solution has been considered fundamental for the success of CfMS. We designed and implemented a system for the management of post-stroke rehabilitation to assess the potential of CfMS in real medical practice.

2. Knowledge management

Although there are many different definitions of knowledge management, we can take the following, proposed by Smith and Farquhar [5], as a representative statement of its primary goal:

> Improve organizational performance by enabling individuals to capture, share and apply collective knowledge to make optimal decisions... in real time.

By real time, they mean the time available to make a decision, that is to take an action that will affect, as desired, the patient clinical outcomes. This is essential in Health Care Organizations (HCOs) where the performance of care very often depends on many actions executed by a team of multidisciplinary professionals. Given the explosion of medical knowledge, HCOs should thus embark on the knowledge management work in search of near term performance improvement using knowledge derived from biomedical research. Moreover, they also should envisage longer-term benefits, including continuous personal and organizational learning.

The potential of the knowledge management can be properly evaluated if some basic concepts are taken into consideration. First of all, it has been pointed out that large part of knowledge is not explicit but tacit. Following Polanyi's [6] epistemological investigation, tacit knowledge is characterized by the fact that it is personal, context specific, and therefore, hard to formalize and communicate. Explicit, on the other hand, is the knowledge that is transmittable through any formal or semiformal representation.

Nonaka and Takeuchi [7] analyzed the interaction between tacit and explicit knowledge concluding that they are not totally separate but mutually complementary entities. They interact and interchange into each other in the creative activities of human beings. Their dynamic model of knowledge creation is anchored to a critical assumption that human knowledge is created and expanded through a social interaction between tacit and explicit knowledge. This process has been called knowledge conversion: it represents a social process between individuals and not confined within an individual. These ideas lead us to focus on the processes by which knowledge is transformed between its tacit and explicit forms in HCOs within cooperative care processes. Organizational learning takes place as individuals participate in these processes, since by doing so their knowledge is shared, articulated and made available to others.

Four different modes of knowledge conversion have been postulated, as shown in Fig. 1: socialization, externalization, combination, and internalization.

1. Externalization (tacit to explicit) is the process of conversion of tacit into explicit knowledge through some formal or semiformal representation language. By its nature, tacit knowledge is difficult to convert into explicit knowledge. Through conceptualization, elicitation, and ultimately articulation, typically in cooperation with others, some proportion of a person's tacit knowledge may be captured in an explicit form. Typical activities in which externalization takes place are those dealing with guideline development, which start from clinical research findings provided by scientific literature (in this case such knowledge is explicit for some researchers but tacit for most clinical practitioners), adaptation of a guideline to the local organization willing to adopt it (some tacit organizational knowledge is converted into explicit knowledge by representing organizational structure and roles to which guideline needs to be adapted), and further development of the guideline according to the experience gained in using it (results from clinical practice may suggest how to extend the guideline by either adding, modifying, or refining some guideline's recommendations).

2. Combination (explicit to explicit) is the process of recombining or reconfiguring bodies of already existing explicit knowledge that leads to the creation of a new body of explicit knowledge. There is often a need to foster knowledge combination, namely to enrich the available knowledge in some way, such as by either restructuring it, so that it is more usable or expandable, or including some new knowledge elements describing activities involved in a care process dealing with clinical problems, which were not considered from the beginning.

3. Internalization (explicit to tacit) is the process of individual learning by repetitively executing an activity applying some type of explicit knowledge (e.g., a protocol or a guideline) and absorbing achieved actions' results as new personal tacit knowledge. Moreover, individuals can also re-experience what others previously learned by reading scientific documents. However, this process is becoming very challenging because they have to deal with ever-larger amounts of knowledge sources, which describe new diagnostic or therapeutic procedures potentially effective in increasing the performance of the care processes.

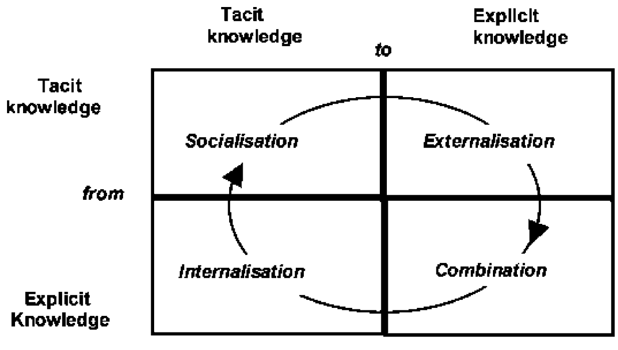

Fig. 1. The knowledge conversion processes in a knowledge creating organization according to Nonaka and Takeuchi.

4. Socialization (tacit to tacit) is the process of learning by sharing experiences that creates tacit knowledge as shared mental models and professional skills. Apprentices learn their practical and cognitive skills through socialization by observing, assisting, and imitating the behaviors of experienced practitioners. Knowledge sharing is often done without ever producing explicit knowledge and, to be most effective, should take place between people who have a common culture and can work together effectively [8]. Thus, tacit knowledge sharing is connected to ideas of teams, communities and cooperation. Typical activities in which tacit knowledge sharing can take place are those carried on during both a medical team meeting, which analyzes the effects of therapies delivered on managed patients, and a scientific society meeting, which discusses the impact of the most recent research findings on clinical practice.

Knowledge management aims to properly facilitate and stimulate the above described knowledge conversion processes. They continuously occur during daily medical work. Thus, to build effective systems to manage cooperative care processes it is essential to provide the right tools to support them as we tried to do in developing the system described in this paper.

3. The management of the post-stroke rehabilitation process

In order to allow an easier understanding of the methodology we developed to design and build a CfMS as a component of a medical knowledge management infrastructure, we took into consideration a specific care process: the post-stroke rehabilitation process. It is relevant enough from the socio-economic point of view to justify our efforts and it is complex enough to challenge our methodology.

Stroke is the commonest cause of adult disability and the third leading cause of death in most countries. It is crucial therefore, that an effective strategy for prevention and treatment of stroke is implemented. Guidelines for the management of stroke have been published to disseminate much of the research evidence that has been accumulated. Their recommendations—that stroke patients should be managed in special units called stroke units—have been confirmed and supported by an extensive and rapidly growing body of evidence. There are few circumstances in medicine where specialist care has been shown to be of greater benefit, and yet the proportion of stroke patients who receive specialist care is disappointingly low. There is a consistent evidence that functional outcome improves and case fatality reduces when stroke unit care was compared with general medical care [9–12]. One of the strengths of the specialist team approach comes from the experience it can acquire since stroke units may care a larger number of stroke patients per year than general hospitals may have. Thus, the opportunities to learn from similarities and differences are clearly better with them. Such an evidence can be explained, from the knowledge management perspective, by considering that a stroke unit represents a favorable setting to develop the knowledge conversion processes of internalization and socialization described in the previous section.

Effective care of stroke requires teams of efficient, informed health care professionals, who can work together in carefully planned patterns appropriate to the problems posed by individual patients. The following four main phases can be distinguished:

1. Initial management.
2. Early management of acute stroke in the Emergency Department (ED) and for hospitalized patients.
3. Planned management of care after acute treatment.
4. Rehabilitation and follow-up.

Every stroke care management system has the responsibility to match its resources with generally agreed upon guidelines for each of the clinical presentations of the disease and to show that its patterns of care are effective and efficient (evidence-based medicine). Whenever possible, modeling of careflow should take advantage of the efforts of international or national organizations to provide evidence-based guidelines.

This paper describes in some detail a CfMS for managing the activities in the rehabilitation phase. The careflow model of the post-stroke rehabilitation process was derived from a guideline developed by the Centre for Health Economics Research [13] and adapted to Italian rehabilitation organizations by the Stroke Prevention and Educational Awareness Diffusion (SPREAD) initiative [14]. The original guideline was also delivered by the Agency for Health Care Policy and Research (AHCPR) in the usual format including three versions: a full version, a quick reference version and a version for patient and his family. In addition there are flowcharts that facilitate careflow modeling. The goal of this guideline is to improve the effectiveness of rehabilitation in helping individuals with disabilities from stroke to achieve the best possible functional outcomes and quality of life. The guideline addresses rehabilitation needs from the time of an acute stroke through the ensuing weeks of recovery and return to a community residence.

4. A careflow management system

To describe the architecture of a CfMS it is worthwhile to use the glossary [15] defined by the Workflow Management Coalition, which is a non profit organization with the objectives of advancing the opportunities for the exploitation of workflow technology through the development of common terminology and standards. It has been recognized that all workflow management products have some common characteristics, enabling them potentially to achieve a level of interoperability through the use of common standards for various functions.

A CfMS is a system that defines, creates, and manages the execution of careflows (Cfs) through the use of software, running on one or more Cfs engines, which are able to interpret the care process definitions, interact with Cfs participants and, where required, invoke the use of ICT tools and applications. Careflow indicates the automation of a care process, in whole or in part, during which information, documents or tasks are passed from one participant to another for action, according to a process definition. This identifies the various process activities, procedural rules and associated control data used to manage the Cfs during process enactment. Many individual process instances may be operational during process enactment, each associated with a specific set of data relevant to the individual process instance. Thus, a CfMS consists of software components able to store and interpret Cfs process definitions, create and manage Cfs instances as they are executed, and control their interaction with Cfs participants and applications. Such systems also typically provide administrative and supervisory functions, for example to allow work assignment, audit and management information on the system overall or relating to individual process instances.

Since we strongly believe that HCOs need to design and implement more effective organizational support processes to make change in the delivery of care possible, CfMS technology has been taken into consideration to assess its potential to improve HCOs' performance based on an efficient and effective management of care delivery systems. The strategic goal is to define a methodology that may contribute to create knowledge-based HCOs that foster and reward quality care improvement by (1) providing to their members an infrastructure to support evidence-based practice, (2) facilitating the use of ICT, and (3) preparing them to better serve patients in a world of expanding knowledge and rapid change [16].

The core activity in developing a CfMS is represented by formulating Cfs' definitions. While clinical practice guidelines describe the activities of a medical team in a comprehensive manner for the purpose of defining best practices, Cfs focus on the organization of medical work with regard to a possible support of their execution through ICT.

Cfs are *case-based*, i.e., every piece of work is executed for a specific patient. One can think of a patient care process as a Cf *instance*. The goal of Cfs is to handle patients by executing medical tasks in a specific order. A Cf process definition specifies which tasks need to be executed and in what order. A task, which needs to be executed for a specific case, is called a *work item*. Most items are executed by a *resource*, either human or technological. A work item executed by a resource is called *activity*. To facilitate the allocation of work items, resources can be grouped into classes. The resource class based on the capabilities (i.e., functional requirements) of the HCO's members is called *organizational agents*. If the classification is based on the structure of the HCO, such a resource class is called *organizational units* (e.g., team, laboratory, clinic, department, etc.).

A CfMS may also contribute to solve the communication problem within HCOs since it is able to manage automatically a great amount of communication acts among organizational agents involved in patient care. Such view was stimulated by the *continuum view* developed by Enrico Coiera [17]: he pointed out that communication and computation tasks are related, but drawn from different parts of a task space. We strongly believe that knowledge management, in general, and CfMS, in particular, may provide an effective approach to overcome the false dichotomy between communication and computation tasks: careflow technology can be used to make communication more efficient by supporting organizational agents in sharing the needed medical and organizational knowledge.

Fig. 2 shows the basic elements of the organization ontology on which the model of a HCO can be based on. It represents an adaptation of the organization ontology developed within the TOVE project [18]. We modeled a HCO defining a set of constraints on the activities performed by organizational resources. In particular, a HCO consists of a set of organizational units (e.g., wards, laboratories, clinical units, rehabilitation units, etc.), a set of organizational agents (members of an organizational unit), a set of roles that the members play in the organization, and a set of organizational goals that they are committed to achieve.

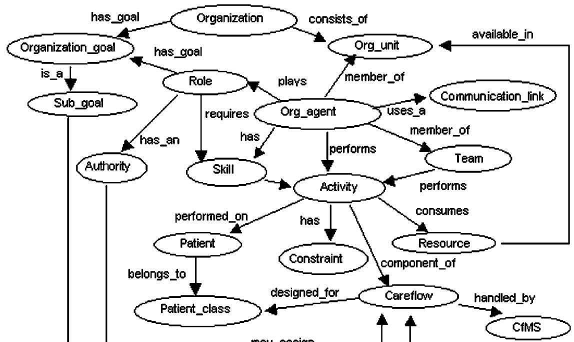

Fig. 2. The basic elements of the organization ontology of a health care organization. Ovals represent classes of entities and arrows the relationships between them.

We focused our attention in this paper on a Rehabilitation Hospital, as an instance of a HCO. It represents an organization delivering a full array of rehabilitation services provided by an interdisciplinary team. It can be modeled as a HCO having a number of goals related to identifying who are most likely to benefit from rehabilitation, managing a rehabilitation treatment plan, and monitoring progress both during rehabilitation and after return to a community residence. Organizational units include wards, rehabilitation units (e.g., physical therapy unit, psycho therapy unit, speech therapy unit, etc.), clinical laboratories, and imaging services. Organizational agents may play one or more roles. Each role is defined by the goals' set that agents belonging to it must fulfil. Enough authority is given to them to achieve her/his goals. An organizational agent performs activities in the organization and uses resources (such as materials, labor, biomedical instruments, or health care information system's services). The constraint set limits organizational agents' activities. Finally, an organizational agent has skills requirements and a set of communication links defining the modes through which she/he communicates with other agents in the organization.

5. Definition of the stroke rehabilitation process

This section describes the Cfs definition we formulated, according to the ontology of HCOs shown in Fig. 2, for the Rehabilitation Hospital involved as first test site of the CfMS design methodology we developed. Given the purpose of this paper, many technical details will be omitted and the emphasis will be placed more on the representation issues of the fundamental entities involved in the rehabilitation process model.

Stroke rehabilitation frequently involves the services of several rehabilitation disciplines. The skills required depend on the nature of the patient's deficits. Medical specialties that are commonly involved include physical medicine and rehabilitation (physiatry), neurology, geriatrics, internal medicine, psychiatry, and family practice. Consulting physicians from other specialties (for example, cardiology, hematology, etc.), are called on as needed. Therapists include persons specialized in occupational therapy, physical therapy, psychology and neuropsychology, and speech-language pathology. Fig. 3 shows the hierarchy of roles played by the organizational agents directly involved in the rehabilitation process. They operate within either clinical wards or

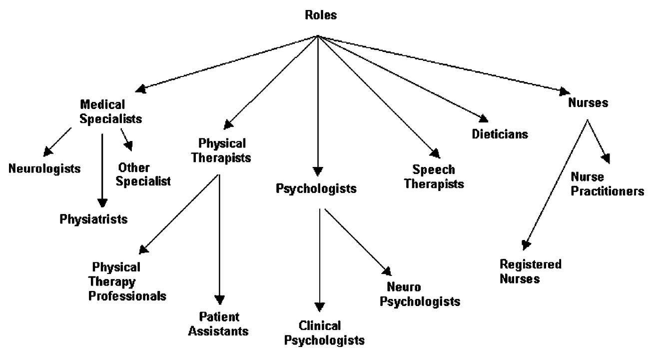

Fig. 3. Taxonomy of roles played by organizational agents involved into the post-stroke rehabilitation process within a rehabilitation hospital.

rehabilitation units, but they may also be involved in several multidisciplinary activities, mainly whenever some collective decisions have to be made (e.g., identification of rehabilitation needs, assessment of deficits' recovery).

The activities are executed according to the rehabilitation process model shown in Fig. 4. It describes the overall process that is recursively decomposed into sub-processes down to the lowest level representing activities flow. Sibling sub-processes/activities belonging to the same parent process/sub-process form a directed graph that defines the execution dependencies among them. These dependencies, including sequence, parallel, conditional and synchronization, are expressed graphically as follows. An arc pointing from a process/sub-process/activity (predecessor) to another model element (successor) denotes that the latter is to be executed immediately after the former terminates. Outgoing arcs from a process/sub-process/activity to more than one successor denote parallel execution branches of all the successors after the predecessor is completed (called split). Transition predicates may be associated with these splits. Only those arcs where transition predicate evaluates to true are executed. If the transition predicates of a split are in mutual exclusion, the split is called OR-split (representing a decision), otherwise it is called an AND-split (representing parallel execution). Incoming arcs towards a process/sub-process/activity from more than one predecessor are called join. An AND-join

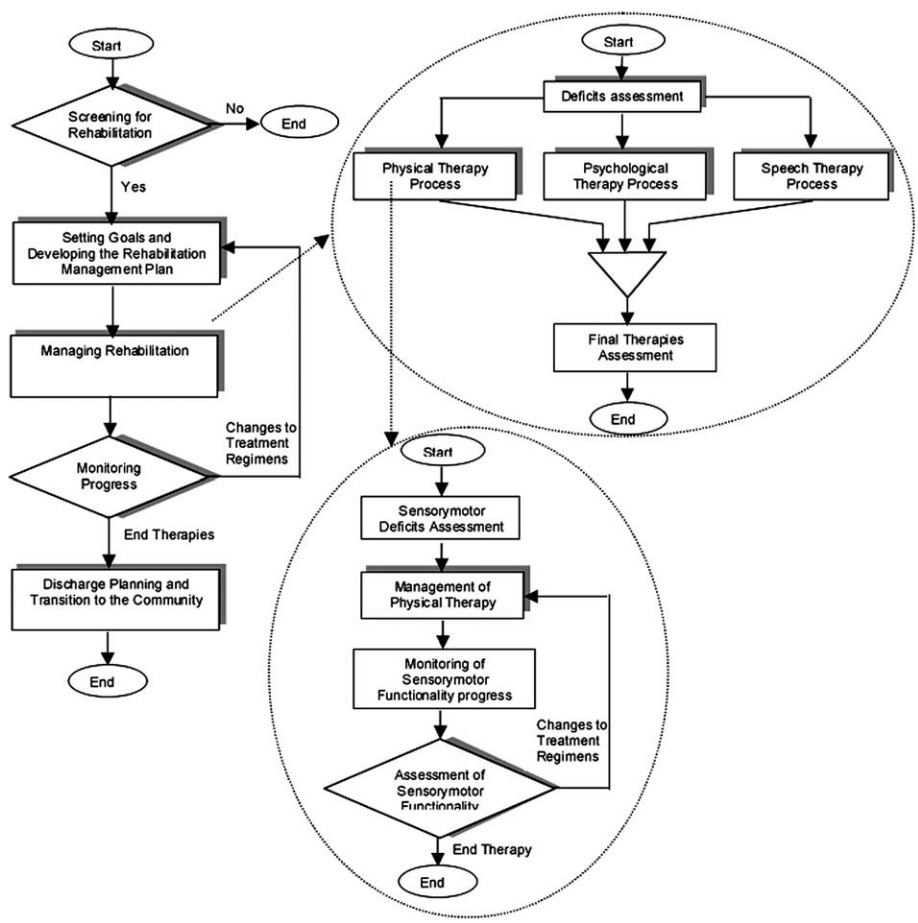

Fig. 4. The careflow model of the post-stroke rehabilitation process. Rectangles represent processes/activities, diamonds represent OR-split processes/activities, triangles represent the AND-join elements, arrows represent dependencies among them. Shadowed rectangles and diamonds indicate which processes/sub-processes have been recursively decomposed down to the lowest level representing activities flow. The diagram at the left part displays the top most view of the care process while the diagrams at the right part show how two processes are described at a lower level.

synchronization activates a sub-process/activity when all its predecessors finish. An OR-join activates a sub-process/activity when any predecessor finishes (i.e., no synchronization is involved).

For sake of simplicity, Fig. 4 shows only the set of topmost sub-processes involved in the rehabilitation process and a more detailed view for only two of these. The overall process has been modeled using ORACLE Workflow in accordance with the WfMC standards [19]. A complete description of the process model is available at http://www.labmedinfo.org/research/cfms/rehab.html. Moreover, Table 1 shows the list of attributes/facets included in the frames representing each activity: their meaning will be clarified when the main functions of the post-stroke rehabilitation management system will be described (see Section 7).

The first sub-process deals with the ***Screening for Rehabilitation***. All stroke survivors need caring and support, but only some need formal rehabilitation. People who recover completely from their strokes will not need rehabilitation, and others will be too incapacitated to benefit from rehabilitation. Between these extremes are people with varying degrees of disability. For these individuals, the goal is to identify the best possible match between their needs and the capabilities of available rehabilitation facilities. A screening examination for rehabilitation has to be performed as soon as the patient's medical and neurological conditions permit their assessment. Such an examination uses information recorded in the medical record, but also needs a direct examination of the patient and the use of well-standardized disability and mental status assessment tests.

Several threshold criteria for admission to a Rehabilitation Hospital have to be taken into account. Admission to an interdisciplinary program is limited to patients who have more than one type of disability and who therefore need the services of two or more rehabilitation disciplines; patients with a single disability can benefit from individual services, but do not need an interdisciplinary program.

If a patient is admitted to the program, the second sub-process, i.e., ***Setting Goals and Developing the Rehabilitation Management Plan***, starts. A summary of the patient's medical record and information collected during the screening examination has to be available at the time of admission to any rehabilitation program, so that changes in the patient's condition can be identified and questions about medical management can be resolved promptly. A thorough baseline rehabilitation evaluation needs to be completed within three working days from admission to an intense rehabilitation program. The initial history and physical examination by a physician and a nurse should be done within 24 h or during the first visit. These timelines, reflecting expert opinion, attempt to establish a reasonable balance between feasibility and the need for a prompt treatment. Rehabilitation goals should be realistic in terms of current levels of disability and potential for recovery, and should be mutually agreed to by the patient, family, and rehabilitation professionals. It is important that rehabilitation goals are recorded in the medical record in explicit and measurable terms so that they can serve as yardsticks against which to measure the patient's progress during rehabilitation.

Then, the Managing Rehabilitation sub-process is activated. It requires measures to prevent recurrent stroke and complications; treatments for comorbidities; and rehabilitation interventions with their sequence, intensity, frequency, and expected duration. A schematic diagram of the main components of the rehabilitation management plan is shown in the upper right part of Fig. 4, while the bottom-right part of the same figure describes the activities involved in the Physical Therapy sub-process. The use of standardized instruments facilitates reliable documentation of functional disabilities. This helps to increase the consistency of treatment decisions, facilitates communication among therapists, and provides a reliable basis for monitoring progress. A broad-based disability scale needs to be used with all patients. The choice of specific impairment measures will depend on the deficits of the individual patient.

The main components of a rehabilitation management are the following:

1. It addresses both rehabilitation needs and medical problems, such as complications of stroke or comorbidities. The plan includes: treatment goals, interventions planned to achieve the goals, and the frequency, duration, sequencing, and intensity of interventions.
2. It defines the remedial treatments provided by the rehabilitation setting for sensorimotor deficits and cognitive/perceptual problems.

The patient's progress, i.e., the sub-process called ***Monitoring Rehabilitation***, is required to be assessed regularly during rehabilitation and the results are used to adjust the treatment plan. During an intense rehabilitation program, evaluations should be performed at least weekly in an inpatient rehabilitation facility. A subset of the standardized measures administered at baseline assessment has to be chosen: they target those impairments and disabilities that have been the focus of treatments during the preceding period. Absence of progress between two evaluations should lead to a change in regimen, transfer, or discharge (unless specific circumstances have interfered with rehabilitation).

Discharge from a rehabilitation program or transfer to a different type of program, i.e., the sub-process called ***Discharge Planning and Transition to the Community***, has to be considered when reasonable treatment goals have been achieved or when no measurable progress is found on two successive evaluations. Discharge planning should begin on the day of admission and should

Table 1
Frame representing the activity *Rehabilitation Visit* through its attributes. Every attribute is represented through facets inherited from the class of entities it is Member_Of

UNIT: ***Rehabilitation Visit***
CREATED by: ***Silvia on. 4/02/2002***
MEMBER Of: ***Visits***
MODIFIED by: ***Silvia on. 13/05/2002***
MEMBERS: ***none***

ID.CODE
Comment: Cf activity identification code
InheritedFrom: CfMS
AdmissableValues: alpha-numeric.type
CardinalityMin: 1
CardinalityMax: 1
Values: *r1*

SUCCESSOR.OF
Comment: activity whose is a successor
InheritedFrom: Acitivities
AdmissableValues: One.of (Activities)
CardinalityMin: 1
CardinalityMax: 1
Values: ***Screening for Rehabilitation***

MAX. CONTRACTING.TIME
Comment: max time to assign a task
InheritedFrom: Activities
AdmissableValues: numeric.type
CardinalityMin: 1
CardinalityMax: 1
Values: ***10***

SUBCONTRACTOR. AGENT
Comment: id code of the organizational agent committed to execute the activity
InheritedFrom: Acitivities
AdmissableValues: One. of(Id.Organ.Agents.Code)
CardinalityMin: 1
CardinalityMax: 1
Values: ***physician 1***

MAX.EXECUTION.TIME
Comment: max time to execute the activity
InheritedFrom: Activities
AdmissableValues: numeric.type
CardinalityMin: 1
CardinalityMax: 1
Metrical.Unit: min
Values: ***30***

EXECUTION.END.TIME
Comment: time instant the organizational agent completed the activity execution
InheritedFrom: Activities
AdmissableValues: date.type
Cardinality Min: 1
CardinalityMax: 1
Values: ***05/08/2002 11:12:48***

BIOMEDICAL.INSTRUMENTATION
Comment: biomedical instrumentations needed for activity execution
InheritedFrom: Resources
AdmissableValues: Belong.To(Resources)
CardinalityMin: 0

RUNNING.CODE
Comment: activity identification code within an instance of the Cf
InheritedFrom: CfMS
AdmissableValues: alpha-numeric.type
CardinalityMin: 1
CardinalityMax: 1
Values: ***2r1E_STROKE2002-05-08_18:28:27.0***

CONTRACTOR.AGENT
Comment: Cf agent responsible for distributing the activity
InheritedFrom: Organ.Agents
AdmissableValues: One.of(Organ.Agents)
CardinalityMin: 1
CardinalityMax: 1
Values: ***physician0***

SUBCONTRACTOR.ROLES
Comment: roles allowed to execute the activity
InheritedFrom: Roles
AdmissableValues: One. of(Roles)
CardinalityMin: 1
CardinalityMax: 3
Values: ***Physicians***

EXECUTION. CONSTRAINT
Comment: evidence strength justifying the task execution
InheritedFrom: Activities
AdmissableValues: One.of(high, medium, low)
CardinalityMin: 1
CardinalityMax: 1
Values: ***high***

EXECUTION. START.TIME
Comment: time instant the organizational agent accepted the activity execution
InheritedFrom: Activities
Admissable.values: date.type
CardinalityMin: 1
CardinalityMax: 1
Values: ***05/08/2002 10:58:12***

ORGANIZATIONAL.UNIT
Comment: organizational unit where the organizational agent executes the activity
InheritedFrom: Organ.Units
AdmissableValues: One.Of(Org_Units)
CardinalityMin: 1
CardinalityMax: 1
Values: ***visiting-room-3***

EXECUTION. STATE
Comment: execution state of the activity
InheritedFrom: Activities
AdmissableValues: One.Of(tobeexecuted,under.execution, executed, exception)
CardinalityMin: 1

Table 1 (*continued*)

CardinalityMax: 5 **Values:** ***none***	**CardinalityMax:** 1 **Values:** ***executed***
USER.FORM **Comment:** form to be filled with patient data during activity execution **InheritedFrom:** CfMS **AdmissableValues:** One. Of(pl/sql. procedures) **CardinalityMin:** 1 **CardinalityMax:** 1 **Values:** ***physician.rehab_visit***	**EXCEPTION.TYPES** **Comment:** exception that may occur during the activity execution **InheritedFrom:** Exceptions **AdmissableValues:** Belong.To.(Exceptions) **CardinalityMin:** 0 **CardinalityMax:** 4 **Values:** ***none***
PATIENT.ID **Comment:** identification code of the patient on whom the activity is executed **InheritedFrom:** Patient **AdmissableValues:** One.Of(Patients) **CardinalityMin:** 1 **CardinalityMax:** 1 **Values:** ***pt0023***	**COST** **Comment:** cost of activity **InheritedFrom:** Activities **AdmissableValues:** numeric.type **CardinalityMin:** 1 **CardinalityMax:** 1 **Metrical.Unit:** **Values:** ***50***

be a systematic, multidisciplinary process, coordinated by only one organizational agent. Decisions should reflect a consensus among the patient, family/caregivers, and rehabilitation staff. Routine follow up care after discharge should give high priority to prevent recurrent stroke and complications, decrease cardiovascular risk, and thus prevent falls or other injuries.

The overall rehabilitation process has been described above in a simplified form with the aim of stressing its high complexity. We believe that such a complex care process can be carried on efficiently and effectively only by providing the involved health care professionals with a suitable CfMS allowing them to share and use patients' information and medical knowledge. A model of the care process has to be considered as an essential piece of that knowledge: it should evolve under the pressure of exploiting as soon as possible new research findings and the experience accumulated by delivering care to patients according to a well-defined process of care. This represents a clear example of the knowledge externalization process (described in Section 2), that is the conversion of knowledge from tacit into explicit, which is essential to dynamically update the knowledge needed to increase the HCOs performance.

6. The management of exceptions

A critical challenge for any CfMSs is its ability to respond effectively when *exceptions* occur. An exception can be defined as any deviation from an *ideal* care delivery process that uses available resources to achieve the desired clinical goals in an optimal way. Exceptions can arise from changes in resources availability, task requirements or task priority, and anomalous, but expected even if rare, effects of delivered care. They can also include incorrectly or lately performed tasks, resource contentions between two or more distinct activities, unanticipated opportunities to substitute or eliminate tasks, conflicts between actions taken in different activities and so on. Exceptions can be frequent and extremely disruptive. They often are not detected until some activity actually becomes late. At this point they are typically handled as *fires* and are kicked up to higher management layers for resolution since they can cause cascading exceptions shoving aside the normal flow of work. Exceptions often are not handled following standardized preferred processes so they can be addressed inconsistently and with uneven effectiveness. If not detected and handled effectively, exceptions can thus result in severe impact on the efficiency and effectiveness of the care process.

Cf management technology is currently ill suited to deal with exceptions. It typically makes many implicit assumptions in defining a more or less idealized normal process: violations of any one of them can lead to exceptions. Cf models can, of course, include conditional branches to deal with expected exceptions. Inclusion of exception handling branches, however, can greatly complicate the process model and obscure its normal behavior, making it difficult to define, understand, and modify. Current Cf modeling methodologies and tools do not support the definition of exception handling procedures separately from the normal process.

Expertise in resolving exceptions represents an important type of tacit knowledge, which is accumulated during daily care delivery. It is so important in order to achieve the expected performance of the overall care process to justify any effort to convert, as soon as possible, that knowledge from tacit into explicit knowledge and to combine it with the already available one. Then, an evidence-based care process, represented by the normal Cf, can be continuously improved by learning from exceptions, which occurred in daily work. They can reveal either elements of knowledge requiring further investigations or weaknesses in the management of the care process. Tools for prescribing exception handling strategies can also reduce or eliminate the discretion of Cf participants in precisely identifying the cases most likely to profit from individual attention and experience.

Some very interesting knowledge-based approaches have been recently proposed to solve the problem of managing exceptions [20–22]. We adapted that developed by [21,22]: it can be summarized as schematically shown in Fig. 5. A normal Cf model is checked at design time, annotating activities with exception types, which describe the expected ways they can fail. They can become more numerous by analyzing the behavior of people involved in the process and analyzing the large amount of data automatically collected by the CfMS. This effort required us to develop a continuously growing taxonomy of exception types, a subset of which is shown in Fig. 6. The normal Cf model was then augmented during the formulation of the Cf model with *sentinels* that check for anticipatory/actual manifestations of those exceptions, i.e., Cf faults. When the care process is enacted, these sentinels flag any Cf fault they encounter and notify it to the CfMS. It can then use the knowledge base of exception types associated to Cf activities to activate an exception handler to avoid/resolve the problem, allowing the process to continue (*automatic resolution*). Since it is not possible to guarantee the success of any automatic exception handling mechanism due to the incompleteness of available knowledge, the involvement of organizational agents is critical for resolving those exceptions that cannot be dealt with by the CfMS. In these cases the CfMS notifies its failure and

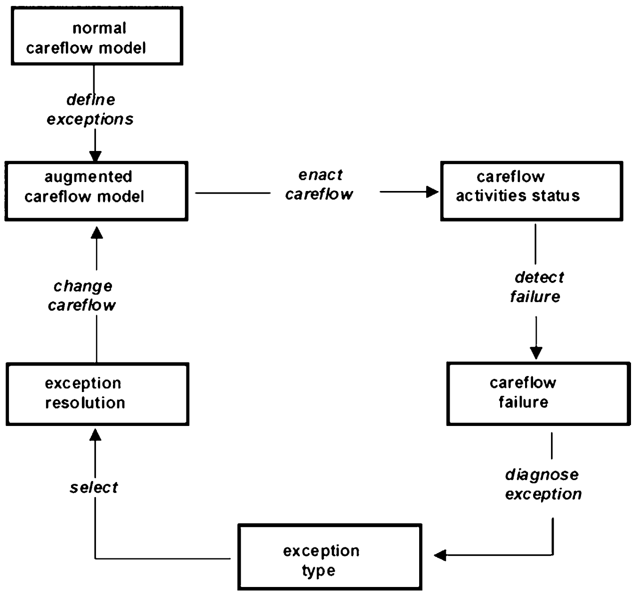

Fig. 5. Process of augmenting a normal careflow model through the definition of exception types in order to manage them.

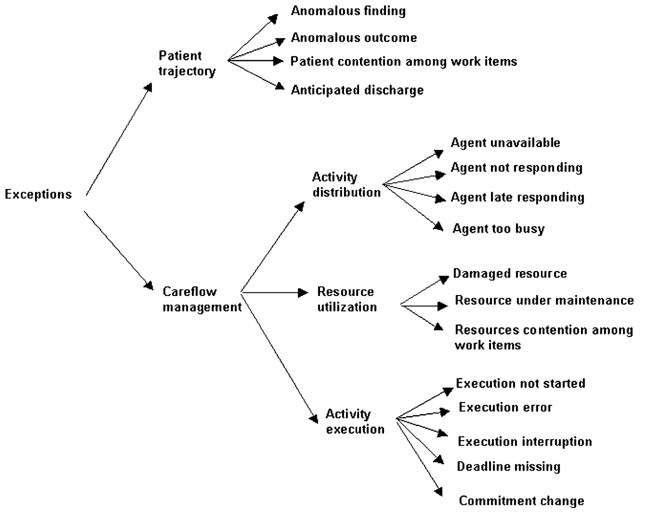

Fig. 6. Taxonomy of exception types.

provides functions allowing those agents to change properly the involved instance/instances of the Cf (*manual resolution*).

Several exception types and exception handlers have been defined to manage them. We mainly focused our efforts on representing exceptions management knowledge related with possible Cf faults caused by two classes of exceptions: the first one is related with the actual ***Patient trajectory*** within the HCO (either the time course of the patient clinical status or the sequence of work items involving her/him), and the second one with the ***Careflow management*** process. This latter class of exceptions has been subdivided into three sub-classes representing exceptions dealing with ***Activity distribution*** (distribution of work items to human agents), ***Resource utilization*** (utilization of needed HCO infrastructures, biomedical instrumentation, material, etc., to execute activities), and ***Activity execution*** (problems that may occur during the execution of an activity).

Every exception type is represented by a frame that gives its definition, what situations it is known to be particularly critical to generate it, and how it can be handled. The frame representing, for example, the ***Deadline missing*** exception is shown in Table 2. It includes pointers to anticipation/detection processes that specify how to anticipate/detect Cf faults, which may be caused by that exception type. These descriptions, once incorporated into the augmented Cf model, play the role of sentinels that check for manifestations of impending or actual exceptions. The sentinel for detecting a deadline missing, for example, operates by monitoring the execution time looking for missed deadlines, and the sentinel for anticipating this exception, by contrast, looks for situations where agents are too busy since a set of high-priority tasks is expected or at hand.

The next step is to define how to react when a fault is detected during the enactment of the Cf process. A key

Table 2
Frame representing the exception type ***Deadline missing***

Exception
Deadline missing
For process
Activity. execution_monitor: it is activated to check the execution of activities
Definition
The activity has not been executed on time
Criticality
Problems deriving from the delay in the execution on either the patient condition or the execution of the subsequent activities
Anticipation
Sentinel. reach_deadline: it monitors the reaching of deadline advising the organizational agent
Detection
Sentinel. detec_deadline: it looks for missed deadlines comparing the current time with the expected deadline. Deadline for all activities in execution is contained in *field.table.pr_deadline* of *table.execution_activities*
Avoidance
Through the user interface agents have the possibility to postpone the activity deadline
Resolution
Handler.deadline_missing is activated

challenge here is that the manifestations can often result from a wide variety of possible underlying causes. Many different exceptions (e.g., delay in task execution, delay in task distribution, damage of a resource, unavailability of a resource, etc.), typically manifest themselves, for example, as missed deadlines. Just as in therapy planning, abducing an appropriate intervention requires diagnosing the underlying cause of the presenting manifestations. Our approach for diagnosing exception causes is based on the well known *heuristic classification method* [23]. This approach works by traversing the exception taxonomy. Every exception includes defining characteristics that need to be true in order to make that diagnosis potentially applicable to the current situation. When an exception is detected, the relevant part of the exception types taxonomy is traversed top–down like a decision tree, iteratively refining the specificity of the diagnoses by eliminating exception types whose defining characteristics are not satisfied. Distinguishing among candidate diagnoses will often require additional information about the current exception and its context, just as medical diagnosis often involves performing additional tests. Heuristic classification represents a *shallow model* [24] of diagnostic reasoning because it is based on explicit knowledge converted from tacit knowledge accumulated in patients' care management. Reasoning from first principles seems to be very difficult when human and software agents are coordinated by a CfMS. However, we are planning to use later on other AI methods (belief networks, case-based reasoning, etc.), as soon as enough experience has been accumulated by monitoring real behaviors of Cf agents in real working environments. This will allow more dynamic and effective conversion of tacit into explicit knowledge to manage exceptions more effectively.

Once a fault has been detected and diagnosed, the CfMS is ready to invoke an exception handler associated with that exception. A frame, as that shown in Table 3, describes every exception handler. It includes a definition, the condition for its activation and the pointer to the exception resolution process. This can be built using the same formalism and enacted by the same engine used for modeling and enacting the normal Cf model. The process for resolving the missing deadline exception, for example, is schematically shown in Fig. 7. At first a notification is sent to the executor agent asking

Table 3
Frame representing the exception handler ***Handler.deadline_missing***

Handler
Handler.deadline_missing for exception deadline missing
Definition
A solution is found contacting the executor of the activity. If the contact fails then an alternative solution is found
Prediction
Missed deadline
Action
At first a notification is sent to the executor asking her/his justification about the missed deadline. Then she/he can decide either executing the activity immediately, committing the activity to another agent or aborting the execution. If the executor ignores the notification then the activity is considered failed and the CfMS decides between deferment and re-execution, directly assigning the activity to another agent
Recording
Table.task_information: it records information about the time spent for execution
Table.pendinq_tasks: if the activity execution fails it records information about the activity

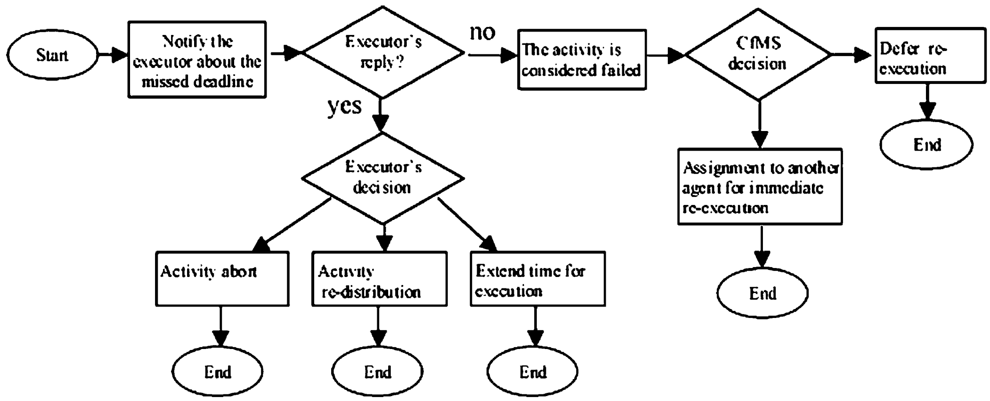

Fig. 7. Diagrammatic representation of the process for managing the exception type ***Deadline missing*** through the exception handler called ***Handler.deadline_missing.***

her/his justification about the missed deadline. Then she/he can decide either executing the activity immediately, committing the activity to another agent or aborting its execution. If the executor ignores the notification then the activity assignment is considered failed and the CfMS decides either deferring the activity or assigning it to another agent.

A very critical task for a CfMS is the distribution of work items to organizational agents. It may have problems dealing with unavailability of people as a result of vacation or illness, overloading, context-dependent suitability, and delegation. In these cases an exception arises requiring the activation of an exception handler. In order to reduce as much as possible to manage work distribution tasks as exceptions, we put a great attention on building a more comprehensive mechanism for work allocation based on various parameters that define a suitable allocation metrics. Literature on work distribution is typically driven by considerations related to authorizations and permissions. However, Cfs are operational processes where there is a highly dynamic trade-off between quality and performance. For example, an approaching deadline and an overloaded agent may be the trigger to offer a work item to somebody else through a negotiation process. The acceptable solutions are explicitly defined by constraining the admissible values of the work item's features, e.g. new execution time, cost, expertise of the new executor of the work, etc.

We followed a very promising approach suggested by [25] to solve the work distribution problem. Two basic mechanisms have been identified for work distribution in the CfMS: push and pull mechanisms. The former one operates by pushing a work item to a single agent belonging to the role defined as the qualified one to execute that work. The selection of the specific agent depends on criteria explicitly defined by the manager of the whole Cf. The pull mechanism is adopted when an agent is allowed or requested to pull work items from a view of a common pool of work items. For example, physicians can be asked to pull patients from the list of recently admitted ones to the Rehabilitation Hospital to perform the first assessment visit. In case of an unjustified delay in doing that, an exception arises.

The push mechanism is a special case of the pull mechanism in that only one agent is requested to execute a given work item. This strategy is very efficient if the organizational model is reliable enough to avoid suffering from the drawback that an item is pushed to a worker unavailable for some reason. On the other hand, with a pull mechanism, multiple agents are offered to do this work item and chances are higher that one of them will be available to perform it. The use of both mechanisms gives more flexibility provided that suitable criteria are defined to establish which is the default one for each work item distribution.

The work allocation mechanism allows a dynamic balancing of quality and performance considerations. It is based on four parameters: suitability, urgency, conformance and availability. Suitability is the qualification of a human resource (physician, nurses, etc.,) to execute a task. Each activity has a time-dependent urgency that considers approaching deadlines and patients' health conditions; tasks with higher urgency have to be done in shorter time. Conformance is a measure of constraints violation. In work distribution some constraints have not to be violated, their violation causes penalties, and conformance is a measure of these penalties. Two examples of constraints are: health professionals already too busy in the execution of some activities should not be taken into consideration in the distribution of a new work item, as well as professionals who are neither accepting any new activity nor executing accepted activities do not have to be considered. Availability takes into account the time spent in a day by each organizational agent executing the activities of the CfMS, workload, planned absences, etc., During tasks distribution, these parameters are considered for all the agents within a role to find the most suitable ones to which the activity's execution can be proposed.

Exceptions may occur in spite of the flexibility of the work allocation mechanism we developed. As shown in Fig. 6, some exception types have been represented in the class Activity distribution. Table 4 shows how a specific exception, Agent not responding, has been represented and Table 5 describes which mechanism can

Table 4
Frame representing the exception type ***Agent not responding***

Exception
Agent not responding
For process
Activity.distribution: this process is activated every time a work-item has to be assigned to an agent for execution
Definition
An agent to whom the work-item has been proposed is not responding
Criticality
The execution of the activity slows down with possible consequences on the execution of the subsequent activities
Anticipation
Sentinel.agents_status: it checks the agents' occupational status monitoring *table.occupied_agents* that records information about the activities the different agents are doing or committed to do
Detection
Sentinel.timer_distribution: it detects the missed deadline for distribution. It compares the current date with the deadline. Deadline is obtained adding the time allowed for completing the distribution activity read in *table. task_desciption* to the distribution starting time
Avoidance
Activity.who: it finds the most suitable agents to whom the execution of the work-item can be proposed. Many factors like availability, suitability, violation of constraints, work_item urgency are considered
Resolution
Handler.agent_not_responding is activated

Table 5
Frame representing the exception handler ***Handler.agent_not_responding***

Handler
Handler.agent_not_responding for exception agent not responding
Definition
Looking at the circumstances the handler can solve the problem automatically or requests an agent with enough authority to solve it
Precondition
Nobody is responding to the request of executing an activity
Action
Find other agents to whom the execution of the activity can be proposed. If there is no potential executor then the Cf responsible agent is advised of the situation and decides what to do, otherwise the work-item execution is proposed to another agent
Recording
Table.task_data: it records information about the time spent for distribution process

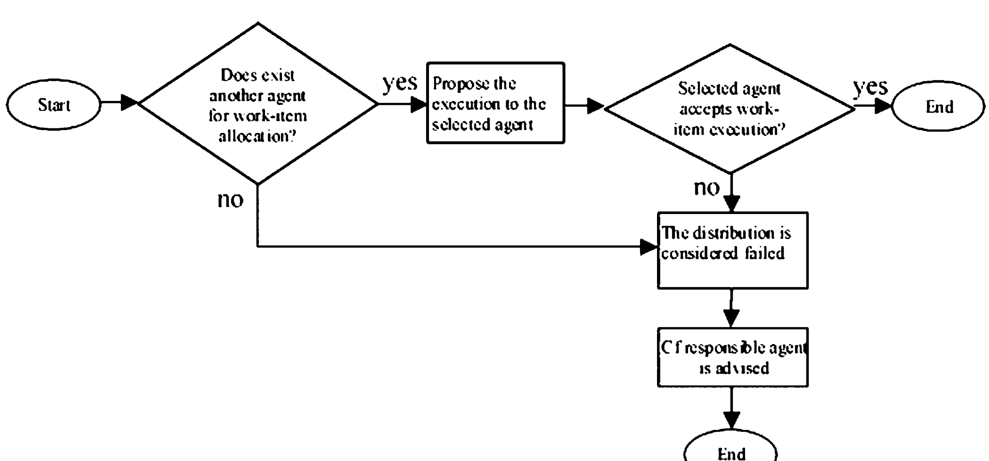

Fig. 8. Diagrammatic representation of the process for managing the exception type ***Agent not responding*** through the exception handler called ***Handler.agent_not_responding.***

resolve the problem. The process of managing such that exception is diagrammatically displayed in Fig. 8. It fully exploits the flexibility given to the CfMS to change the flow of activities in those cases that require it.

Finally, an efficient management of exceptions requires that organizational agents could be advised immediately about any exception occurrence and could interact with the CfMS to change the affected careflow instances, which may deviate or already deviated from the normal flow. Thus, the exploitation of mobile ICT is essential to provide organizational agents with personal handheld digital assistants allowing them to interact with the CfMS every time they need in their daily work.

7. The post-stroke rehabilitation management system

Marc Berg [26] carefully analyzed the coordination role played by traditional patient care information systems (i.e., electronic patient records, PACS, order-communication systems, medication systems, and so forth) in HCOs. He correctly argues that they fulfill two functions that are crucial for current medical practice: information handling and activities' coordination. Although these functions are intimately related, the coordination goal is first and foremost about the ways the organization makes its functioning possible. Information handling is related with the medical content of the work managed by the organization, that is the management of patients' trajectories. It directly deals with the professionals' cognitive task (i.e., interpreting data to derive information that triggers diagnosis, care planning and management), while the coordination task addresses the ways in which their work is regulated, distributed and supported [27]. A CfMS is able to support both tasks since it combines technologies for information and knowledge management. Thus, it makes available functions that traditional patient care information systems do not provide.

To illustrate the large variety of functions that a CfMS can make available to its user, this section will describe the prototype, which has been called R-CfMS, we developed to manage the post-stroke rehabilitation process by exploiting the Cf model and the exceptions handling mechanisms described in the previous sections. Fig. 9 shows the components of the its main user interface, which has been divided up into three sub-panes. The topmost sub-pane allows the user to access the following basic functions:

a. **Activities Management**
b. **Data Management**
c. **Communication Management**

Selecting **Activities Management** the user can interact with the work distribution system provided by the R-CfMS by either browsing the activities proposed by the system, selecting the activities she/he is pushed to execute, or browsing the activities still waiting for an agent who is allowed to pull and execute. The function **Data Management** allows the agent to use the electronic patient record management system for either browsing or analyzing available patient data. Through the function **Communication Management** the user is allowed to choose an asynchronous link to communicate with other agents involved in the rehabilitation process.

The left sub-pane of the main window changes its content according to the selected basic function. When the user invokes the activities management function, after selecting a patient through the pull-down menu at the bottom, the sub-pane shows the name of the selected patient at the top and a list of activities related with that patient in the central part of the left sub-pane. Different colors indicate the state of each activity:

1. activities that have been already executed (green),
2. activities that generated an exception during their execution (red),
3. activities that are still under execution by some agent (orange),
4. activities that are expected to be executed on the selected patient (blue).

According to the state of the selected activity, different information is shown in the central sub-pane of the main window. In the first case, it displays the clinical data acquired by the end of the activity's execution. If the activity generated an exception, potentially useful information to handle it is displayed. Fig. 10 shows, for example, the information the R-CfMS makes available in the case an activity cannot be performed by the committed agent due to the fact the patient is not available for the planned activity, ***Physical Therapy Exercises***, since she/he presents the anomalous finding ***fever***. Thus, the activity must be delayed until she/he will recover and the instance of the careflow describing her/his rehabilitation plan needs to be modified. In the case of an activity still under execution, some information dealing with its management (agent who accepted to execute the activity, technological resource used, execution deadline, etc.), is shown. However, if the user is the agent committed to execute that activity, the form to be filled during its execution pops up. Finally, if the selected activity has been scheduled according to the current instantiation of the Cf for the selected patient, some management information is given in the central sub-pane. It is also possible to select an agent who can be asked to execute that activity: she/he must belong to the role that gives her/him enough power to execute it.

A set of functions to manage the rehabilitation activities scheduled for the selected patient is made available through toolbar put on top of the left window. They are the following:

1. Switch from the activities management function to the data management one in the selected patient.

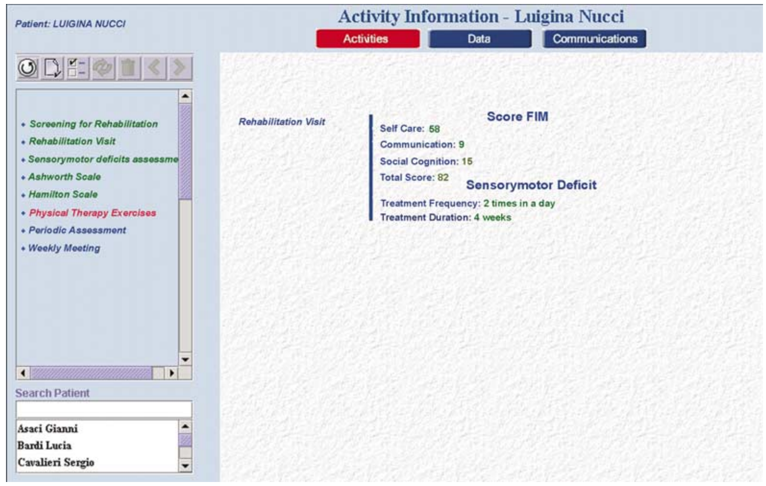

Fig. 9. Main user interface of the careflow management system. Clinical data acquired after executing the activity ***Rehabilitation Visit*** are displayed in the central sub-pane.

2. Print a report of the activities executed or expected to be executed on the selected patient.
3. Print a report of the activities executed by the agent in a given period of time on the selected patient.
4. Substitute an activity with another one.
5. Cancel an activity.
6. Add an activity, before or after a selected one.

Thus, if the user is an agent allowed to do that, she/he can easily individualize the rehabilitation process for each patient provided that any strong constraint specified in the Cf model is not violated. Moreover, any exception can be solved automatically by an exception handler, as those described in the previous section, or, in case of its failure, by an agent with the privilege to do that.

The function Data Management allows the user to browse patient data organized in sections based on medical contexts as specified in the electronic patient record structure. Moreover, she/he can perform some intelligent analysis on the data of either an individual patient or a selected population of patients.

Referring to the integration of the R-CfMS with the Health Information System (HIS) of the HCO where it will be used, two different solutions can be adopted.

1. If the HIS does not include the function of patient data management, R-CfMS can provide it. Since its user-interfaces are web-based, every user can easily access it from any workstation of the organizational units involved in the rehabilitation process.

2. If the HIS does include that function, a snapshot of the patient data already entered can be exchanged between HIS and R-CfMS through suitable XML-Schemas. Since this is the situation occurring in the

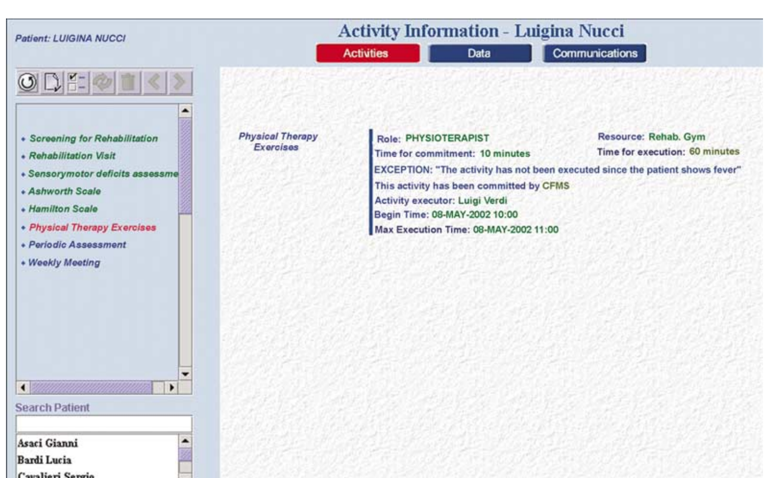

Fig. 10. Main user interface of the careflow management system. Display of the justification why the activity ***Physical Therapy Exercises*** have not been executed as expected by an organizational agent in the role of ***Physiotherapists*** due to the anomalous patient finding ***Fever***. The agent is allowed to delete the activity and plan to do it later.

Rehabilitation Hospital involved in the present study, we negotiated with the managers of the HIS how to exchange data at predefined times during the day according to the specific data set. Moreover, R-CfMS has been asked to return back to the HIS predefined syntheses of the large set of data collected in daily rehabilitation work since they have been recognized as needed for organizational administrative and monitoring purposes. Such a solution allows avoiding any double data entry and satisfies the requirement of realizing an integrated patient data management between the two operationally independent systems.

The function **Communication Management** allows the user to use an asynchronous link to communicate either with other agents involved into the rehabilitation clinical process or with the CfMS to deal with exceptional situation. The organization model is here used to facilitate communications dealing with the management of meetings, to exchange information related to a specific patient or to contact experts for a second opinion.

To situate the R-CfMS design and development effort within the context of use, we co-produced the system with several professionals working within the Rehabilitation Hospital where it will enter in daily use. They represented the needs of agents playing different roles in the whole rehabilitation process. Our aim was to build a system whose functions fit into their work practices and relations. Hartswood et al. [28] argue for moving beyond the *design problem* through either ethno-methodology [29] or participatory design's [30] to a radical re-thinking of user-designer relations in ICT systems design and development practice [31]. Their proposal is that ICT systems design and development should be re-organized as a co-production of users and ICT professionals, breaking down between technology production and use [32]. We followed their proposal to make R-CfMS working for *these particular users*, *in this particular workplace and at this particular time*. We, as system's designers, truly tried to understand the users' work and their changing needs. In particular, the co-production effort involved the following tasks: evaluating the available careflow technology and appreciating the benefit of active workers' participation in designing and adapting the system's functions to their particular organizational setting. To this aim, we first co-designed the main system's functions and user interfaces. After reaching a consensus, we co-developed a set of role-specific functions and interfaces to support the activities in the rehabilitation process. This phase took a large part of the development time since we believe that system's usability critically depends on the users' satisfaction in their daily interaction with the system. Moreover, we agreed how to exploit mobile communication technology to allow users-system interaction whenever is needed in daily work without requiring users to sit in front of a PC.

8. Conclusions

Health care today is characterized by more to know, more to manage, more to watch, more to do, and more people involved in doing it than at any time in the past. Our current methods of organizing and delivering care are unable to meet the expectations of patients because the science and technologies involved in health care—the medical knowledge, skills, care interventions, devices, and drugs—have advanced more rapidly than our ability to deliver them safely, effectively, and efficiently.

Thus, the strategic goal today is to increase the quality of delivered care. The Institute of Medicine has defined quality as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge" [33]. Good quality means providing patients with appropriate services in a technically competent manner, with good communication, shared decision making, and cultural sensitivity.

We strongly believe that quality problems do not generally stem from a lack of knowledge, training, or effort by health professionals. Today, no one clinician can retain all the information and knowledge necessary for sound, evidence-based practice. No unaided human being can read, recall, and act effectively on the volume of clinically relevant scientific literature. Since the results of the first randomized controlled trial were published more than 50 years ago [34,35], health care practitioners have been increasingly inundated with information about what does and does not work to produce good outcomes in health care.

ICT can provide the tools for redesigning health care services. Thus, the research community in Medical Informatics should identify, adapt and implement state-of-art approaches to addressing the following challenges:

1. Use of ICT to improve access to clinical information and support clinical decision making.
2. Redesign of care processes based on best practices.
3. Knowledge and skills management.
4. Development of effective teams.
5. Coordination of care across patient conditions, services, and settings over time.
6. Incorporation of performance and outcome measurements for improvement and accountability.

This paper presents an methodological approach to design and build evidence-based careflow management systems that can achieve all the above-mentioned goals. It requires a strong collaborative effort between ICT and health care professionals. If successful, it will provide a fundamental organizational support for changing the nature of interactions among health care professional involved in care delivering processes. Then, we expect that the quality of care will improve as well as patients' satisfaction.

Without substantial changes in the ways health care is delivered, the problems resulting from the growing complexity of health care science and technologies are unlikely to abate; in fact, they will increase.

Acknowledgments

This work was supported in part by a grant from the Banca Regionale Europea, Pavia, Italy and in part by a grant from the University of Pavia.

References

[1] Sim I, Gorman P, Greenes R, Haynes RB, Kaplan B, et al. Clinical decision support systems for the practice of evidence-based medicine. Journal of the American Medical Informatics Association 2001;8(6):527–34.
[2] Balas E, Boren S. Managing clinical knowledge for health care improvement. MD Computing 1999:65–70.
[3] Stefanelli M. The socio-organizational age of artificial intelligence in medicine. Artificial Intelligence in Medicine 2001;23:25–47.
[4] Stefanelli M. Knowledge management to support performance-based medicine. Methods of Information in Medicine 2002;41:36–43.
[5] Smith RG, Farquhar A. The road ahead for knowledge management. AI Magazine 2000;(Winter):17–40.
[6] Polanyi M. Personal knowledge. London, UK: Routledge & Keagan Paul; 1958.
[7] Nonaka I, Takeuchi H. The knowledge-creating company. Oxford, UK: University Press; 1995.
[8] Davenport T, Prusak L. Working knowledge. Cambridge, MA: Harvard Business School Press; 1998.
[9] Langhorne P, Williams B, Gilchrist W, Howie K. Do stroke units save lives?. Lancet 1993;342:395–8.
[10] Stroke Unit Trialists' Collaboration. Organised inpatient (stroke unit) care for stroke. Issue 1. 2000. Cochrane Database Systematic Review.
[11] Sulch D, Perez I, Melbourn A, Karla L. Randomized control trial of integrated (managed) care pathway for stroke rehabilitation. Stroke 2001;31:1929–34.
[12] Micieli G, Cavallini A, Quaglini S. Guideline compliance improves stroke outcome—A preliminary study in 4 districts in the Italian Region of Lombardia. Stroke 2002;33:1341–7.
[13] Gresham G, Duncan P, Stason W, et al. Post-Stroke Rehabilitation. Clinical Practice Guideline. 16. 1995. AHCPR Publication no. 95-0662.
[14] SPREAD. Ictus cerebrale: linee guida italiane di prevenzione e trattamento. 2001. Milano, Catel.
[15] Workflow Management Coalition. The WfMC Glossary. In: Lawrence P, editor. Workflow Handbook. Chichester, UK: Wiley, 1997. p. 385–421.
[16] Institute of Medicine. Crossing the Quality Chasm. Washington, DC: National Academy Press, 2001.
[17] Coiera E. When communication is better than computation. Journal of American Medical Informatics Association 2000;7:277–86.
[18] Fox MS, Gruninger M. Enterprise modeling. AI Magazine 1998;(Fall):109–21.
[19] Workflow Management Coalition. Workflow Standards. In: Lawrence P, editor. Workflow Handbook. Chichester, UK: Wiley, 1997. p. 241–421.
[20] Luo Z, Sheth A, Kochut K, Miller J. Exception handling in workflow systems. Applied Intelligence 2000;13:125–47.
[21] Chiu D, Li Q, Karlapalem K. Web interface-driven cooperative exception handling in ADOME workflow management system. Information Systems 2001;26(2):93–2001.
[22] Klein M, Dellarocas C. A knowledge-based approach to handling exceptions in workflow systems. Computer Supported Cooperative Work 2000;9:399–412.
[23] Clancey W. Heuristic classification. Artificial Intelligence 1985;27:250–89.
[24] Chandrasekaran B, Mittal S. Deep versus compiled knowledge approaches to diagnostic problem solving. International Journal of Human Computer Studies 1999;52(2):357–68.
[25] Kumar A, van der Aalst WMP, Verbeek E. Dynamic work distribution in workflow management systems: how to balance quality and performance. Journal of Management Information Systems 2002;18(3):157–93.
[26] Berg M. Patient care information systems and healthcare work: a sociotechnical approach. International Journal of Medical Informatics 1999;55:87–101.
[27] Berg M. Accumulating and coordinating: occasions for information technologies in medical work. CSCW Journal 1999;8:373–401.
[28] Hartswood MJ, Procter RN, Rouchy P, Rouncefield M, Slack R, Voss A. Working IT out in medical practice: IT systems design and development as co-production. Methods of Information in Medicine 2002 (to appear).
[29] Hughes J, O'Brien J, Rodden T, Rouncefield M. Ethnography, communication and support for design. In: Luff P, Hindmarsh J, Heath C, editors Cambridge, UK: Cambridge University Press; 2000.
[30] Blomberg J, Kensing F. Special issue on participatory design. Computer Supported Cooperative Work 1998;7:3–4.
[31] Heath C, Luff P. Technology in action. Cambridge, UK: Cambridge University Press; 2000.
[32] Suchman L. Located accountabilities in technology production. In: Mackenzie D, Wajcman J, editors. The social shaping of technology. 2nd ed. Open University Press; 1999. p. 258–65.
[33] Lohr K. Medicare : a strategy for quality assurance. Washington, DC: National Academic Press; 1990.
[34] Cochrane A. Effectiveness and Efficiency, Random Reflections of Health Services. The Nuffield Provincial Hospitals, 1972.
[35] Daniels M, Bradford Hill A. Chemotherapy of pulmonary tuberculosis in young adults, an analysis of the combined results of three medical Research Council trials. British Medical Journal 1952;31:1162–8.