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Towards Medical Device Maintenance Workflow Monitoring

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***Abstract*—**Concerning the inpatient care the present situation is characterized by intense charges of medical technology into the clinical daily routine and an ever stronger integration of special techniques into the clinical workflow. Medical technology is by now an integral part of health care according to consisting general accepted standards. Purchase and operation thereby represent an important economic position and both are subject of everyday optimisation attempts. For this purpose by now exists a huge number of tools which conduce more likely to a complexness of the problem by a comprehensive implementation. In this paper the advantages of an integrative information-workflow on the life-cycle-management in the region of medical technology are shown.

***Keywords*—**Medical equipment maintenance, maintenance workflow, medical equipment management, optimisation of workflow.

I. Introduction

THIS article deals with the present situation of service management as well as facility management of medical technology and demonstrates a new integrative approach to optimise consisting workflows. The concept arose against the backdrop of foreseeable social and technical developments. As a result of social change acting, hospitals and medical technology (equipment and services) providers have to rise to new challenges at the healthcare market. Exemplary to mention are:

- a change in the demographic structure towards an older society [1],
- a hair-trigger financial situation of hospitals which is determined through a severe regimented service rebate and a perspicuous slowdown in investment [2],
- high expectations within the society regarding the quality offer of health care,
- the problem of the acquisition of specialised professionals, in the regarded case especially in the region of medical technology services [3],
- the consisting obligations of an incessant quality assurance and also the documentation of services rendered [4].

This requires the necessity to the optimisation of existing resources as well as the strategic scheduling to ensure continuous hospital operations. Object of the efforts are on the one hand the primary workflow concerning the patient care and on the other hand the simultaneous supporting workflows, too (so-called support workflows). Such a support should be provided by the medical technology operational business services. As the medical technology branch in a hospital is characterised by a high proportional investment volume as well as by considerable expenses concerning the operations (service, test instructions, etc.) of hardware, optimizations seem to be promising. Furthermore, decisions on re-investment need valid life-cycle information on the installed medical technology. Aims for an optimisation may consist in a minimization of the down time in order to create optimally the system availability, respectively to improve the data quality and the project outlay for the economic reporting and the medical technology controlling. Both attempts in each case aim at an improvement of the resource management.

Up to now, the management of a medical technology, both services and equipment, is characterised by considerable temporal and personnel expenditures concerning communication, coordination and documentation of workflows. Normally, the in-house technician of a hospital makes use of different media (e. g. telephone, fax, e-mail). The documentation is carried out either in a paper-based documentation in the form of a machine log or on the other hand by using appropriate software possibilities which are normally indeed limited to an absolute stock (inventory/ accounting) management. As a result of the low integration degree of medical technology under software oriented aspects, available commercial solutions are characterised by a multitude of manual entries. In addition they don't support the mobile character of daily work of the medical technician in a hospital. In this way a lot of information is not documented contemporary. In fact maintenance visits are recorded frequently after their completion in the documentation system/ facility management. In addition to the delayed documentation, the error-prone manual documentation is also important.

Nowadays, only some costly devices fulfil the technical precondition for online monitoring. In such cases, the service is outsourced to specialised medical technology providers. Products like the "Guardian Program™" with the service option "TubeGuard" from Siemens Medical Solutions/ Erlangen [5] which supervises the state of the X-ray tube in a performance-

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capable computer tomography (CT) or the Dräger Remote Service e. g. over an "Infinity Gateway™" of the company Dräger medical/ Lübeck [6] for the supervision of biomonitoring equipment are good examples. These solutions use manufacturer-specific protocols and supervise only certain devices (or families of devices).

The AIMES project, "Advanced Infrastructures for Medical Equipment and Services", is an intent to cope with the above described drawbacks and to evolve towards automated approaches to optimise maintenance service workflows in the health care domain. The project's aim is to outline communication models concerning monitoring of medical technology in consideration of the optimisation of medical workflows in hospitals. In this paper, a first analysis and results towards this goal are described.

II. Description of Medical Equipment Maintenance Workflow

The analysis of workflows for medical equipment maintenance can be done on the basis of analysing the actors, the working steps and the triggering events for maintenance interventions.

First, an actor is the person involved in the maintenance service. The main kinds of actors are the following:

- Clinical staff, medical qualified personnel (e. g. doctors, nurses, medical technical assistants, laboratory personnel, etc.). They are the users of the equipment.
- In-house (maintenance) technicians in charge of medical equipment and other employees of in-house maintenance areas (e. g. building services)
- Technicians from external maintenance service providers (medical technology manufacturer, service provider, etc.)

Second, a working step is any task required for maintenance purposes. Some of them can be the following:

- **Alarm generation** (fault detection), i.e. the action that fires the maintenance procedure because the occurrence of a possible misbehaviour has been detected.
- **Fault diagnosis**, i.e. the identification, isolation and location of the fault and possible causes. All the actors could be involved in this task.
- **Service intervention**: this is cut normally into the so-called first line service which is often ensued by captive medical technician and if necessary by the following service of an external service technician (medical technology manufacturers, other service providers or the like).
- **Documentation**: services rendered and expenditures (time, spare parts, etc.) will be documented in conclusion and future tasks will be specified (e.g. a short-term inspection of the result of maintenance).

And third, a trigger event is a condition that fires some of the working steps of the maintenance workflow. The main triggers are the following:

- scheduled service intervention: via an a priori agreed appointment (e. g. for a scheduled maintenance, safety-related inspection or medical engineering inspection),
- spontaneous service intervention: through the occurrence of a device error.

The single components (actors, events and working steps) interact in the course of the service workflow according to the particular device classes in different manner. Thereby, different device classes (Magnetic Resonance Imaging (MRI) vs. syringe pump) make very different demands on a service management. Several criteria can be used to classify medical equipment, as for example:

- Location:
  - stationary medical technology (e.g. MRI)
  - mobile medical technology (e.g. syringe pump)
- Cost:
  - high investment volume (e.g. MRI)
  - low investment volume (e.g. syringe pump)
- Amount:
  - high quantity (e. g. syringe pumps)
  - low quantity (e.g. MRI)
- Diagnosis capabilities:
  - Small: devices without diagnosis capabilities and non repairable equipment.
  - Medium: devices with the ability for auto-diagnosis
  - Large: devices without prerequisites for auto-diagnosis

As a function of the device class there are different approaches with regard to the operational costs and the technologic effort concerning the service management maintenance.

III. Methodology for Supporting Workflow Monitoring

Current advances in medical devices allow us to think in a scenario in which all medical equipments involved in a hospital will be connected to a communication infrastructure. The maintenance operations related to all this devices can then be approached in an automated way taking advantage of the current hospital information applications, as for example, planning tools, data bases of human resources (technicians), etc. Thus, instead of dealing with a burden workflow execution based on manual interaction, the maintenance workflow can be controlled with a computer program.

Monitoring workflow applications have been already deployed in many enterprises related to manufacturing process. But maintenance of medical equipments has some particularities that require a special infrastructure.

At this point, it is important to distinguish between device monitoring and device maintenance workflow monitoring. On the one hand, device monitoring consists on the design of appropriate strategies for fault detection and diagnosis of a device (or a class of devices), while device maintenance workflow monitoring is related to track the real-time status of flow progress in a maintenance plan. Table 1 shows the main differences between both approaches.

Thus, while monitoring a device, a failure means that the device does not work; while monitoring a maintenance workflow, a failure means that some maintenance task should be finished, but it is not. This situation will incur in a delay on

the maintenance workflow and thus in the device availability. Similarly, a preventive event, while monitoring a device, means this device is subject to some maintenance tasks according to manufacturer's recommendations (consumable replacement for example); while a preventive issue in workflow monitoring is related to periodical or scheduled revision (for example when adjusting maintenance plans for new equipment or when use cases have been altered) so the overall maintenance process can be improved and optimized. Finally, prediction events are related to anticipative actions. In the case of device monitoring several techniques can be used to predict a trend on the equipment status (as for example, "low battery level") that will probably lead to a device failure. Data mining tools are used for this purpose when historical registers are available. Similarly, data mining tools can also be used to analyze workflow execution and recognize similar and past situations in which some deadlines where not accomplished. Based on that information, the maintenance responsibilities can review its maintenance workflow or resources assigned to it, to avoid bottlenecks and to improve the equipment usage.

Thus, a monitoring process consists on the following steps: 1) acquire the data required for monitoring; 2) data processing to obtain monitoring parameters; 3) condition monitoring, i.e. evaluation of parameters of condition and determination of their status with respect to their nominal operation conditions; 4) perform a reactive action in case of failure; and 5) perform a proactive action to improve the maintenance workflow. In addition to that, the start up of the monitoring process should be also considered. The overall picture can be seen in Fig. 1.

A. Data Acquisition

The required data to track maintenance workflows is related to actors, events and steps, as stated above. Thus, data acquisition is related to obtain these data, as for example,

- a device status information,
- a spare part has arrived,
- an in-house technician is absent or ill.

This data should be acquired directly from the medical equipment and the hospital information services. Thus, the key issue here is to build an appropriate interface to connect medical equipment and hospital information services in a common infrastructure that enables the maintenance workflow monitoring.

B. Data Processing

This step consists on processing the acquired data so that the appropriate maintenance events can be generated. That is, data acquisition is related to raw data sent by different applications/ interfaces. This data should then be interpreted as maintenance events to be handled in the maintenance infrastructure. For example,

TABLE I
DEVICE MONITORING VS. DEVICE MAINTENANCE WORKFLOW MONITORING

	Device Monitoring		Device Maintenance Workflow Monitoring	
	Event	Action	Event	Action
Failure	The equipment does not work	Repair the equipment	The deadline has expired with no success on the maintenance task	Change the deadline/ scale the problem
Preventive	The equipment will be revised periodically	The equipment is revised periodically	The maintenance workflow is revised periodically	Change workflow parameters relating to statistics on equipment use and downtimes
Predictive	The equipment will fail (it has decreased the quality in its output)	Anticipate equipment maintenance operation	The deadlines will not be satisfied because of an overload in the maintenance service	Re-schedule maintenance workflow

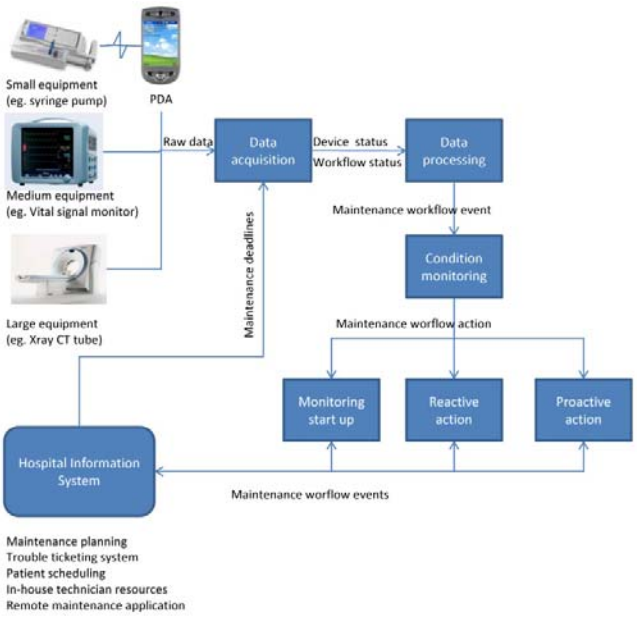

Fig. 1 Steps on medical equipment maintenance workflow monitoring

- from a device code a failure maintenance event is generated, and thus a maintenance workflow instance should be initiated,
- from a spare part arrival, a maintenance task should be either continued or started,
- from the information about the sick leave the maintenance escalation event should be activated and the maintenance task reassigned to another technician.

C. Condition Monitoring

Conditioning monitoring is related to determine the current

status of a maintenance workflow instance. Three condition states can be detected:

- Start, when a workflow maintenance instance should be initiated due to a device failure or a device preventive maintenance operation (scheduled maintenance).
- Failure, if a delay is incurred.
- Predictive, when, for example, an overload due to an increase on maintenance operations can be detected and a possible delay on non-priority maintenance tasks can be predicted.

Each condition monitoring state requires a different actuation on the maintenance workflow. First, starting a maintenance workflow instance involves the initiation of a new monitoring process. Second, a failure should be corrected as soon as possible in what it is called the reactive maintenance. And third, a predictive state requires a proactive maintenance.

D. Monitoring Start up

For each maintenance workflow running a monitoring process should be started. Since several workflows should be controlled at a time, concurrent approaches should be followed when implementing the workflow monitoring. In this line, agent technology offers, for example, the possibility of organizing the different workflow instances according to several criteria, as the in-house technician responsible of the maintenances and the kind of medical equipment, among other. An additional agent should also assume the role of coordinator, dealing with possible preventive and predictive issues (see Fig. 2).

E. Reactive Action

When a failure occurs, there is a delay in the workflow progress. For this purpose the escalation procedure involved in the workflow should be activated. As a result, the workflow would be dynamically adapted to the new circumstances. This includes the actuation on the current patient scheduling so that the delays should be informed to the medical staff.

F. Proactive Action

When some information in the system predicts that there could be a failure in the current maintenance workflow instances, several actuations are possible among them, to dedicate more resources to the current maintenance operations, to give priority to some of them, and so on.

IV. Results

In this section the current maintenance workflows being used in several hospitals that have been the matter of our study are analyzed. Then, two case studies are explained, and on the result sections the benefits of a supporting middleware for maintenance workflow monitoring are discussed.

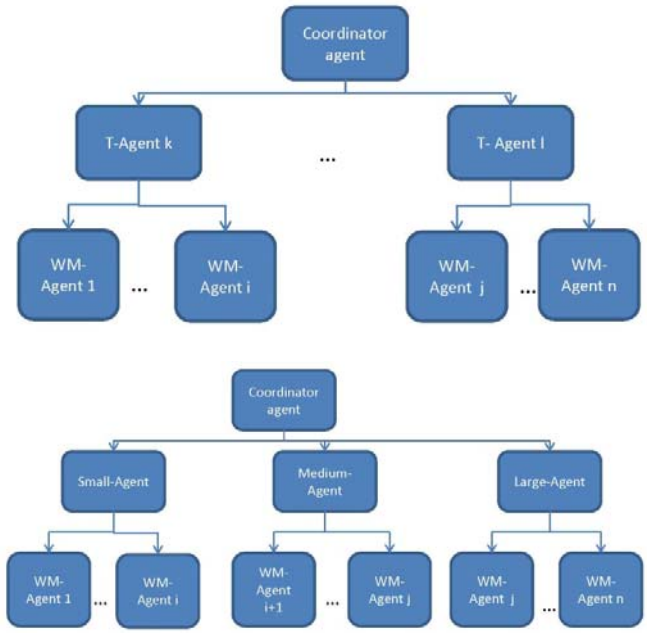

Fig. 2 Two possible workflow monitoring (WM) organizations with agents. *Top*: each workflow instance is monitored by a WM-Agent. The maintenance operations assigned to an in-house technician are coordinated by a T-Agent. *Bottom*: WM-Agents are grouped according to different maintenance workflow typologies

A. Materials and Methods

The hospital as an enterprise is characterized by the collaboration of different medical departments which are supported by in-house technical oriented corporate divisions of the hospital, manufacturers of medical devices and specialized third party companies. Within the scope of the service provision a broad range of medical technology is used. This is descended from regions like the radiologic imaging, biomonitoring, up to the laboratory diagnostics. The medical technology is characterized by special requirements specifications in each of these branches. In the scope of the project considers the analysis of:

- established workflows,
- participating actors, and
- established interfaces.

These analyses are taking place in a combination with medical technology manufacturers, manufacturers of facility management software and medical technicians.

Furthermore an initial survey of hospitals with different profile (basic/ regular level until maximum level) was carried out. The 12 hospitals involved in Germany are segmented in respect of their supply rate as follows:

- 7 hospitals with a Basic/ Regular level,
- 3 hospitals with a Specialised level,
- 2 hospitals with a Maximum level.

The number of beds of the polled hospitals lay between 125 and 2.500 and this is the expression of the different supply rates.

B. Case Studies

Based on two case studies it will be demonstrated which starting points exist concerning the optimization of service workflows and which already existing solutions have to be integrated. Two main scenarios are considered. The first one in which existing software solutions are being used (case I: the scheduled maintenance) and a scenario which obviously proves needs for an optimization (case II: the spontaneous hardware breakdown).

Case I – scheduled maintenance: This scenario regards the workflows of a scheduled service intervention for which expenditure of work, material requirements and working hours (fixed date and duration) are defined beforehand. The exemption of the medical engineering resource for the maintenance can be described well in existing (patient)-order systems and is ensued in consultation with the medical user. As the whole process isn't time-critical in the planning, the procedure can be described well with existing means of communication (telephone, fax or e-mail) and software solutions. Tools used in this scenario are based on calendar (e. g. MS Outlook or such products) and facility management software solutions (e. g. vFM from Fa. Loy & Hutz) concerning the organisation of procedures and whole documentation.

Case II – spontaneous hardware breakdown: This scenario regards the workflows during a service intervention after a spontaneous occurring breakdown (see Fig. 3). The service - process will be initiated through the detection of a hardware breakdown or through the cognition of a functional limitation by the user (usually medical personnel). The competent in-house maintenance technician will be informed by the user either by means of the central repair centre (via telephone, fax and mail) or by informal structures via direct communication. Hence, the flow of the fault report is strongly characterised by individual skills of the actors involved. After the message, usually the clarification of the error is done through an in-house service technician, which follows a first repair attempt when possible. The provider of equipment with a so-called "full maintenance contract" is informed soon directly by the in-house service technician or even by the user. As far as the company uses facility management software for the medical technology, a fault report (a so-called trouble ticket) will be arranged at this particular time.

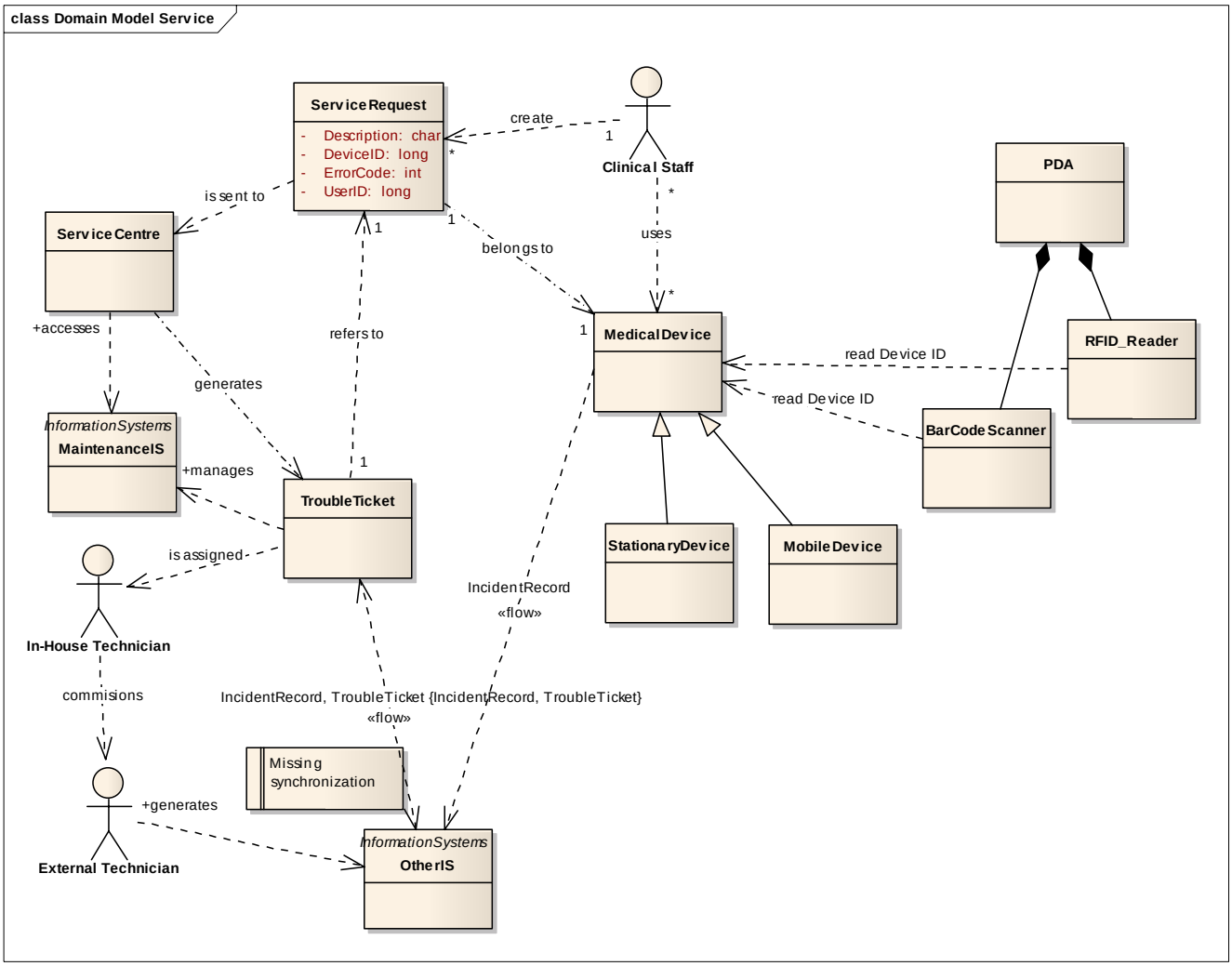

Fig. 3 Maintenance Workflow of Case II

For the following incorporation of external service providers, the instructing employee (usually a medical technician) is dependent on the communication by telephone with the corresponding call centre of the service provider. This coordinates the communication between the enquiring service technician of the hospital and the own service employee. The employee of the external company initiates a preliminary sedimentation of the fault report by phone after his notification and organizes the service initiation (fixed date, spare parts, special tools and additional personnel possibly) in dialogue with the in-house technician. Often, an iterative procedure in which several dialogues take place, span the final maintenance time.

The actual service of the external service technician will take place in the same way as scenario I with an appointed date. The maintenance visit can be implemented with appropriated spare parts depending on the success of defect explorations by the in-house medical technician and the telephonic inquiry by the employee involved of the medical technology manufacturer. In case a shortfall should be revealed, additional spare parts have to be ordered and the maintenance visit will be consequently prolonged respectively a new date that has to be arranged. The mandatory documentation is gathered at the end of the maintenance visit.

Both described cases but especially the second one can strongly vary at different times in their accomplishment despite identical persons involved. The possibility to opt between a formal and an informal communication leads possibly to redundant workflows between the medical user, the repairs receipt/ service centre, the in-house technician and the external service/ medical technology provider. The communication lines can be marked by a certain different reaction time and the priority of processing the single orders can be categorised very differently regarding the persons involved in a service workflow. Frequently there isn't a uniform scheme of decision regarding acceptable deadlines of existent maintenances. Moreover, the communication between the captive medical technician and the medical technology manufacturer (or the service provider) depends arbitrative on the respective subject-skilled and communicative qualification of the person involved. The exchange of information about a service intervention (working time, costs, spare parts, etc.) is usually carried out paper-based or in an electronically not machine-readable way (e. g. pdf-format via e-mail).

C. Results

It could be proved that many single activities don't show an automated connection and information processing in the existing service workflows. The electronic data acquisition takes place often several times as well as time-delayed and a composition of manual and electronic documentation is encountered. Currently the process quality in the region of the medical-technical service management depends arbitrative on the individual competencies of the persons involved.

The existing situation can be improved by the establishment of an integration platform (a so-called middleware) as explained above which has knowledge about a usual as well as a differing plant status and has the ability to control service-oriented workflows as well as to document them.

In the first case study, although it is already supported by software tools, the middleware proposed can improve the workflow by firing alarms if maintenance tasks take longer than scheduled, due for example, the responsible in-house technician is absent, and scales the problem appropriately. Documentation about the maintenance progress will be kept up to date, and so the process can continue even if a resource is substituted.

On the other hand, in the second case study, the tracking of all the timestamps involved in the maintenance workflow will assure that documentation is kept up to date, register communication events, as well as other timestamps that as a flow of information in the maintenance process goes on.

V. Related Work

There are several previous projects related to equipment maintenance, as PROTEUS [10] or DYNAMITE [11]. The former focus on medical equipment also, by mainly related to operations. Our work is more related to workflow improvements. On the other hand, DYNAMITE is mainly concerned with prediction issues, while in the present work all kind of action issues when tracking a maintenance workflow are considered: failures, preventions and predictions.

Another interesting work is [12], in which the authors propose a methodology for dynamically changing workflows in a controlled way. This work is complementary to our in the sense that the authors are explicitly dealing with what happens when workflow instances has to be changed due to escalation issues, for example.

Finally, the use of agents for workflow management in business has been a matter of study recently. In [12] the authors use agents to control the authorization operations in a given framework. In [13] a mechanism based on agents is proposed to monitor workflows in order to tackle uncertainty in the business processes.

VI. Conclusion and Future Work

The online surveillance and automated support of service workflows are important problems to be solved in the next years. Currently there are different manufacturer-specific solutions which supervise the particular manufacturer and device specific properties of selected medical technology. Thereby most different communication technologies (web-based vs. client-server-solution) become apparent at the moment. As a result of missing communication standards for the device-specific supervision there is no possibility, except of insular solutions, to select manufacturer-across device-specific data and to use these for the optimisation as well as for the control of service workflows at the moment. Consequently the demand to integrate the results of different specific monitoring solutions and to unify the service-oriented communication in the region of medical technology becomes apparent. To get an overview over the whole installed medical technology as comprehensive as possible, an enormous number of these manufacturer-specific monitoring

solutions must be operated parallel. However, this is connected with high operational expenses (administration, performance, etc.). Besides, such a patchwork infrastructure is proved to be very confusing and one has to expect inconsistency concerning the comparison of different systems. The interpretation of so-called performance data for the controlling is thus difficult. A workflow oriented management of medical equipment is as a result of employing specific solutions for single devices or device classes. The integration of manufacturer-specific data in a so-called middleware solution represents a possibility to solve this challenge.

In the long run the establishment of a standard for the device-specific maintenance-oriented communication has to be considered. Basic approaches from other industrial branches could serve as an orientation [7, 8]. Benefits of the middleware proposed can be summarized as follows:

- The reduction of process time between the recognition of an error (mainly by the medical qualified personnel or the like self-acting) and the report to the responsible service area.
- An early and automatic detection of error patterns for avoiding functional limitations and system failure.
- The collection of detailed and not distorted information for triggering and controlling the service workflows.
- Using the so-called trouble ticketing systems for supervising the temporal process in the service procedure and for controlling an escalation management.
- The reduction of down time for medical technology.
- The optimisation of compiling business reports, exporting data for the facility management as well as improving the quality of data (duplicability).

The automation of the service workflows can generate decisive advantages for the operational management and the controlling of these points.

As outlined in this paper, comprehensive works on data acquisition, data processing, equipment condition monitoring and condition evaluation have to be performed from the perspective of medical equipment maintenance workflow in order to proceed to workflow monitoring. These monitoring steps substantially differ from traditional device monitoring. In particular, interfaces with medical devices as well as with the software related to maintenance activities and resource of the hospital should be considered, and standards should be studied.

In the future it is conceivable that the equipment condition monitoring will take place either within the hospital through a suitable infrastructure or through a remote service of the particular medical technology manufacturer. Most probably it will be a mixed form out of both variants whose results will be unified in a middleware in the hospital. This involves the definition of a new service workflow of decisions for the control of different maintenance visits (reactive or proactive) as well as service calls which will be controlled and the process documentation which will be supported.

The development of an innovative monitoring setting for medical technology implies at the same time the necessity to equip the single device with obvious extended features like self-monitoring and auto-diagnosis. In addition to the implementation of other innovations this will be in future a challenge for the manufacturer of medical technology, as it similarly happens with DICOM (Digital Imaging and Communication in Medicine) based image data communication for imaging systems [9] in the last 10 years.

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