Pre-print version of: Respício A., Martinho R., Domingos D. (2017) Reliability of AAL Systems Modeled as BPMN Business Processes. In: Hammoudi S., Maciaszek L., Missikoff M., Camp O., Cordeiro J. (eds) Enterprise Information Systems. ICEIS 2016. Lecture Notes in Business Information Processing, vol 291. Springer, Cham.

Publisher version available at
https://link.springer.com/chapter/10.1007/978-3-319-62386-3_24

Reliability of AAL Systems Modeled as BPMN Business Processes

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Abstract. The use of Ambient-Assisted Living (AAL) systems has been spreading across several countries, with the ultimate purpose of improving the quality of life of patients. These systems often reflect complex architectures including several components such as sensors, gateways, Information Systems or even actuators, as well as messaging and transmitting protocols. Failures in these systems can have severe impact on a monitored patient, and most components foresee some kind of compensation countermeasures to increase reliability. Nevertheless, these measures are often self-contained to a single component and do not address the overall AAL system reliability, disregarding precedent and successor activities and interactions that exist for each time a certain value is registered or a certain alert is triggered. In this paper, we propose a new approach to calculate the overall reliability of an AAL system. We take a Business Process Management (BPM) approach to model the activities and interactions between AAL components, using the Business Process Model and Notation (BPMN) standard. By extending the BPMN standard to include reliability information, we can derive the overall reliability of a certain AAL system. To prove this approach, we also present a reliability study considering scenarios with single and pairwise reliability variations of AAL system components. With this approach, healthcare managers can benefit from important overall reliability information of an AAL system, and better allocate the appropriate resources (including hardware or health care professionals) to improve responsiveness of care to patients.

Keywords: Ambient-Assisted Living, Reliability, Business Processes, BPMN.

1 Introduction

The major purpose of Ambient-Assisted Living (AAL) systems is to improve the quality of life and care responsiveness for patients at risk while staying at their homes and performing their normal daily routines [10]. AAL provides them with an overall surveilled environment, allowing the delivery of care where and when needed, and also supporting caregivers, families and care organizations.

Applications of AAL not only provide continuous health monitoring through, for instance, vital signs recording for medical history analyses, but also play a major role in detecting emergency situations. In turn, caregivers and/or other health professionals can better organize their care business processes by receiving alerts and actuating when needed, and with the appropriate resources. Some AAL applications can even replace (self) care activities, such as auto injecting insulin when blood sugar values increase at a certain rate.

Although many times associated with support in assisting elderly people (see for instance H2020 calls of European Commission), AAL systems can also be used in patients suffering from chronic diseases such as diabetes, asthma and heart attacks. Therefore, the impact of a less reliable system can range from a false alarm transmitted to a certain caregiver and/or emergency unit service, to serious patient injury due to wrong, delayed or even non-delivered care.

Current research works and industry products related with AAL and overall to Internet of Things (IoT) applied to healthcare already provide redundancy checks and alerts to prevent greater impacts to patients using them (see, for instance, [20] and [24]). Nevertheless, these efforts to increase reliability are usually self-contained to some components of an AAL system, i.e., reliability is commonly evaluated for each component, regardless of its position in a certain sequence of activities to trigger some action (alert, register or even actuate).

In this work, we present our new and consolidated approach to calculate the overall reliability of an AAL system, by using a Business Process Management (BPM) approach and the Business Process Model and Notation (BPMN) [18] standard de facto for modelling AAL business processes. We consider each component of an AAL system as part of a business process containing essentially sensors, actuators and gateways, which interact through a sequence of activities, decision nodes and messages in order to produce alerts, to register values in a centralized (healthcare) Information System, or even to trigger actuators to provide immediate care. Since these interactions are usually subjected to several conditions, we model them as BPMN process models, in order to calculate their combined reliability. This way, we can derive the overall AAL system reliability, such as in the following example: a measure is taken by a heart rate sensor, transmitted through a network, evaluated through an Information System, and the appropriate alerts are triggered to prevent potentially fatal consequences for the patient.

We extend [14] and apply our approach to perform three analyses: 1) overall AAL system reliability calculus based on most common reliability values for its individual components; 2) overall AAL system reliability against single-component reliability variation, and 2) overall AAL system reliability against pairwise component reliability variation.

This paper is organized as follows: section 2 presents background on AAL and a typical AAL system scenario modelled with BPMN. In section 3 we refer to related work on reliability applied to most common components of an AAL system, and in section 4 we explain how we include reliability information in an AAL BPMN process model, in order to calculate its overall reliability and how we apply the Stochastic Workflow Reduction (SWR) algorithm to compute the reliability of combined BPMN process elements. Section 5 presents the three application scenarios for the calculus of the overall reliability for a typical AAL system. Finally, section 6 concludes the paper and presents future work.

2 Background

This section presents a typical AAL process model (see for instance the proposals of [2] and [6]).

The AAL BPMN process model, as illustrated in Fig. 1, uses a collaboration diagram with four pools, one for each participant or AAL component ([23], [21], [16] and [10]).

The Body Area Network (BAN) sensor devices are used for monitoring vital signs, i.e., heart and body activity in this example (based on [20]). The heart activity is assessed through the heart rate, the blood oxygen, and the blood pressure, by using a heart rate monitor, a pulse oxymeter and a sphygmomanometer, respectively. The system monitors the body activity by using an accelerometer. While this process only uses sensors, BANs can also include actuators. For instance BAN devices can, on a diabetic patient, auto inject insulin through a pump, while monitoring the insulin level [11].

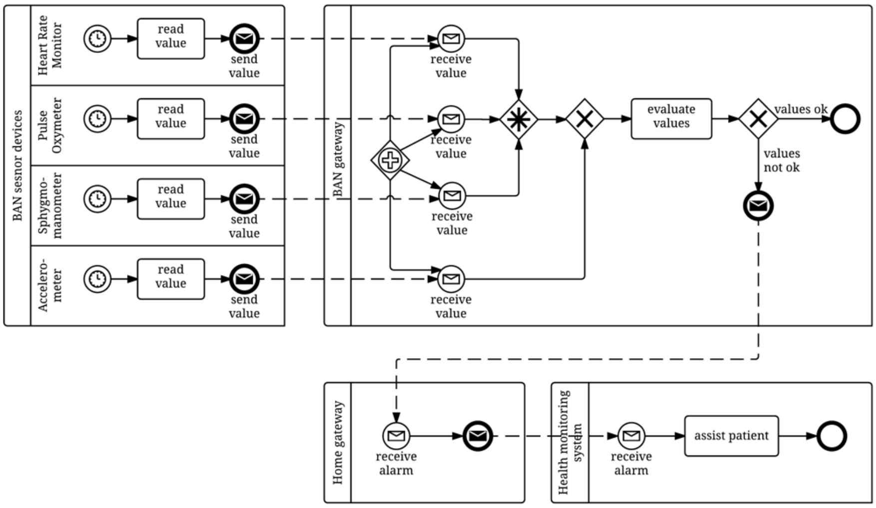


Fig. 1: AAL BPMN process model

As defined in this process, sensors read values from the patient from time to time by using a timer and send them to the BAN gateway. The interaction between sensors and the BAN gateway can also be implemented through the request-request paradigm, where the BAN gateway starts the interaction asking for the values. Depending on sensor computational capabilities, they can also filter the data they transmit, sending only values that are considered relevant. However, for this reliability study, these differences are not significant.

The BAN gateway, another participant of the process, is responsible for the communication inside that BAN and to the home gateway. Besides it receives the values from sensors, it also validates, aggregates and analyses these values. The reception of sensor values is modelled with a BPMN Event-Based Exclusive Gateway. The information about heart rate should be provided by at least two out of three devices, and this behaviour is modelled with a BPMN Complex Gateway. After evaluating sensor values, the BAN gateway sends an alarm to the health monitoring system (HMS) to assist the patient, in case any emergent situation is detected. The communication between the BAN gateway and the HMS is performed through the home gateway.

Smart phones or wireless routers can be used as home gateways. They communicate with the BAN gateway through wireless technologies (Bluetooth or WiFi, for instance) and provide the connectivity to the internet. From the point of view of the process model we could omit the Home gateway pool, as it does not define any business logic. However, this way, the participants of the process are coherent with the components of a generic AAL architecture and it simplifies the reliability study as the process includes all the components and connections.

Finally, with the health monitoring system, caregivers and physicians monitor patients remotely.

3 Related Work

The *reliability of a system at time t*, denoted by $R(t)$, can be defined as the probability of the system to be up continuously in time interval $[0; t]$ [13]. This metric is adequate for systems operating continuously, where a single momentary failure can have a high or even critical impact.

McNaull et al. discuss the quality issues of each component of an AAL system. BAN devices (sensors and actuators) reliability depends on their quality and manufacturer [15]. According to the same authors, the mean-time between failures (MTBF) metric can be used to assess it. In addition, sensors data quality (accuracy) also interferes with reliability as anomalous values can be discarded, for instance, in BAN gateways. Quality of data depends on sensor calibration as well as on the correct use and application of sensors. For instance, other heat sources can affect temperature sensors.

In [20] a use case where the health of patients is monitored considering heart and body activities is presented. The system uses a heart rate monitor, a pulse oxymeter, and a sphygmomanometer to monitor the heart activity. The body activity of patients is monitored with an accelerometer on knees and a motion detector in the room. Taking into account the required reliability of the system, the authors determine the minimal combinations of sensors the system needs. However they only use the information about the reliability of each device.

BAN gateways can be used to increase the reliability of the system. They may evaluate sensor data and detect anomalous and inconsistent values, considering the expected ones, which may have been established during the testing period of the AAL system [15]. In case of anomaly, erroneous sensor values are discarded and BAN gateways can request for new sensor values. If the problem persists, the BAN gateway can alert the health monitoring system. Another way to increase system reliability is by defining a fault tolerant behaviour for the BAN gateway.

Body sensors and actuators communicate with each other and with the BAN gateway using mostly wireless technologies, such as IEEE802.15.4 /ZigBee [8]. The latest international standard for wireless BAN (WBAN) is the IEEE802.15.6 [9]. Home and BAN gateways also communicate through wireless technologies (Bluetooth or WiFi, for instance).

Reliability of wireless networks depends on interferences of other devices; obstruction of the signal due to lifts or wall, and attenuation, i.e., the strength of the signal reduces during transmission.

Baig et al. [1] compare wireless transmitted data with manual recorded data and hospital collected data. They use a total of approximately 2500 transmissions of 30 hospitalized patients and they conclude that, in wireless transmitted data, losses vary from 20% (blood glucose) to 80% (blood pressure and heart rate). They also conclude that data losses were mainly due to distance and data transmission delays were due to poor signals, signal drops, connection loss and/or poor location.

Despite the evaluation of the reliability of each AAL component is crucial, it is not sufficient to study the overall system. This way, in the following, we present related work about computing reliability for composite tasks and/or even for the overall process.

Indeed, while reliability has been a major concern for networking, critical and real-time applications, as well as middleware ([20], [24]); the increasing use of workflow, specifically, in more critical systems, justifies the works on workflow reliability.

In the context of workflow modelling, Cardoso [3] defines task reliability as the probability that the components operate on users demand, following a discrete-time model. In this context, the failure rate of a task can be described by the ratio number of unsuccessful executions/ scheduled executions. The task reliability, denoted by $R(A)$, is the opposite of the failure rate, that is:

$$R(A) = 1 - failureRate(A).$$

In the same work, Cardoso proposes a predictive Quality of Service (QoS) model for workflows and web services that, based on atomic task QoS attributes, is able to estimate the QoS for workflows, considering the following dimensions: time, cost, reliability, and fidelity. To compute QoS for the overall workflow, the author developed the Stochastic Workflow Reduction algorithm, which applies a set of reduction rules to iteratively reduce construction workflow blocks until only one activity remains. The QoS metrics of the remaining activity corresponds to the QoS metrics of the process. Cardoso defines reduction rules for the following construction blocks: sequential, parallel, conditional, loop, fault tolerant, and network systems [3]. He applies his proposal to the METEOR workflow management system [12]. To estimate the reliability of web services compositions, [5] generalizes the Cardoso proposal, covering all the generic workflow patterns of [25].

Within the WS-BPEL context, in [17], the authors compute the reliability of WS-BPEL processes taking into account most of the workflow patterns that WS-BPEL can express, while the method of [7] also incorporates advanced composition features such as fault, compensation, termination and event handling.

Using Unified Modeling Language (UML) models, Rodrigues et al. annotate system component interactions with their failure probabilities [23]. They convert them into a formal executable specification, based on a probabilistic process algebra description language, which are executed on PRISM. This way, they can, for instance, identify the components that have the highest impact on the reliability system.

By focusing their work on BPMN, Respício and Domingos [22] calculate the reliability of BPMN business processes by using the Stochastic Workflow Reduction method of Cardoso ([3]; [4]). To meet this goal, they extend BPMN with reliability information and identify the BPMN process blocks for which they can apply one of the reduction rules.

The work we describe in this paper applies and extends the proposals of [22] to evaluate the reliability of AAL processes.

4 Reliability Information in BPMN Processes

To include reliability information in BPMN business processes we use the extension, whose XML Schema we present in Listing 1. The definition of this extension is based on the work proposed in [22].

The extension has two elements. The first element, named `ReliabilityInformation`, has two attributes: the `requiredReliability` which defines the minimum accepted reliability value for the process or flow node, and the `calculatedReliability` which is the reliability of atomic activities and events (initialised with a pre-determined value) or the reliability for decomposable activities (sub-processes) and processes computed using the SWR method [3].

The second element is the `Probability`. The probability value is used with conditional `SequenceFlow` elements within conditional process or loop process blocks and defines the probability of the process execution path of taking them.

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns="http://.../relybpmn"
xmlns:bpmn=http://www.omg.org/spec/BPMN/20100524/MODEL
targetNamespace="http://.../relybpmn">
  <xsd:import namespace="http://www.omg.org/spec/BPMN/20100524/MODEL"
   schemaLocation="BPMN20.xsd"/>
  <xsd:group name="relyBPMN">
    <xsd:sequence>
     <xsd:element name="ReliabilityInformation"
                  type="tReliabilityInformation"
                  minOccurs="0" maxOccurs="1"/>
     <xsd:element name="Probability"
                  type="tProbability"
                  minOccurs="0"
                  maxOccurs="1"/>
    </xsd:sequence>
  </xsd:group>
  <xsd:complexType name="tReliabilityInformation" abstract="false">
    <xsd:attribute name="requiredReliability" type="xsd:decimal"/>
    <xsd:attribute name="calculatedReliability" type="xsd:decimal"/>
  </xsd:complexType>
  <xsd:complexType name="tProbability" abstract="false">
    <xsd:attribute name="value" type="xsd:decimal"/>
  </xsd:complexType>
</xsd:schema>
```

Listing 1. BPMN extension for reliability - XML Schema

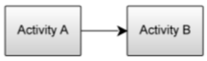
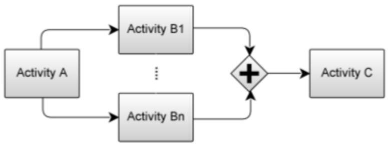
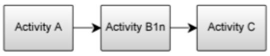
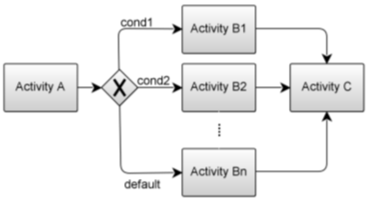
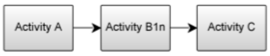
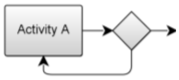
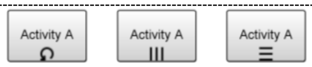
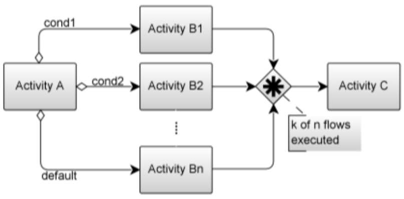
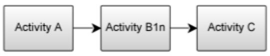
The reliability of processes is calculated with the SWR method [3] (it is similar for decomposable activities). This method applies a set of reduction rules to the process, iteratively, until only one activity remains. The reliability of the remaining activity corresponds to the reliability of the process.

Table 1 presents the application of the six reduction rules of Cardoso to BPMN, identifying the BPMN process blocks for which the reduction rules can be used [22].

As the AAL BPMN process subject of our study also has events (see Fig. 1), we use the same reduction rules for process blocks composed by events or activities, in an undifferentiated way.

In addition, when using reduction rules with collaboration diagrams, they are applied to the overall diagram by omitting pools and lanes. However, to overcome the limitations of the block structured approach of Cardoso, where one starting point and one ending point are needed, we transform the collaboration diagram by adding two new gateways. To have a unique starting point, we add an Exclusive Event-Based Gateway without any incoming sequence flows and with one outgoing sequence flow to each start event of the collaboration diagram. Similarly, to have a unique end point, we add an Inclusive or Merge Gateway with an incoming sequence flow from each end event and without any outgoing sequence flows [19].

Table 1. Reliability of the Reduced Block [22]

<table>
<tr><th>Initial Block</th><th>Reduced Block</th><th>Reliability of the Reduced Block</th></tr>
<tr><td>Sequential

</td><td>
</td><td>$R(AB) = R(A) * R(B)$</td></tr>
<tr><td>Parallel

</td><td>
</td><td>$R(B1n) = \prod_{1 \leq i \leq n} R(Bi)$</td></tr>
<tr><td>Conditional

</td><td>
</td><td>$R(B1n) = \sum_{1 \leq i \leq n} p_i R(Bi)$</td></tr>
<tr><td>Loop

</td><td>
</td><td>$R(A') = \frac{(1 - p)\, R(A)}{1 - pR(A)}$</td></tr>
<tr><td>
</td><td>
</td><td>$R(A') = R(A)^k$</td></tr>
<tr><td>Fault Tolerant

</td><td>
</td><td>$R(B1n) = \sum_{I_1=0,1} \cdots \sum_{I_2=0,1}(\phi(\sum_{i=1}^{n} I_i - k) * \prod_{i=1}^{n} 1 - I_i + (2I_i - 1)R(Bi))$</td></tr>
<tr><td>Network

</td><td>
</td><td>$R(A') = R(P1)$</td></tr>
</table>

5 Reliability Study

This section presents a case study focusing on the reliability evaluation of the AAL process presented in section 2.

Initially, process designers set up the minimum accepted values for the reliability of activities and sub-processes (`requiredReliability`). The BPMN process model is then enriched, through the relyBPMN extension, considering these values as well as pre-estimated values of the attributes `calculatedReliability` (initialized with pre-estimated values for atomic activities and events) and `Probability`. Then, the SWR algorithm iteratively computes the `calculatedReliability` for sub-processes, reaching the reliability value for the overall process (the collaboration diagram).

In the following, we describe the application of this method to assess the reliability of the collaboration diagram displayed in Fig. 1, considering different scenarios and variation of reliability of different AAL system components.

The experiment started by establishing a base case scenario and computing the corresponding reliability. After, a sensitivity analysis on the process reliability was made. The objective of this analysis was to evaluate the impact on the reliability of the overall process resulting from variations of the reliability of separate elements. This analysis was made in two phases. Firstly, we made vary the reliability of separate elements individually. Secondly, the reliability values of a pair of elements were varied in a discrete mode and for each pair of values the process reliability was computed.

5.1 Evaluation of the Overall AAL System Reliability in the Base Case Scenario

In [20], Parente et al. propose reliability values for the type of sensors used in our use case, namely the Heart Rate Monitor (HRM), the Pulse Oxymeter (POxy), the Shygmomanometer (Shygm), and the Accelerometer (Acc), which are used to initialise the atribute `calculatedReliability` of the tasks “read value”.

Based on the measures of [1], we establish the reliability value associated to the transmission from sensors to the BAN gateway, which is used to initialise the `calculatedReliability` of the “receive value” tasks. For setting the reliability value for the transmission from the BAN gateway to the HMS, through the home gateway, we consider both connections together to simplify the study. This reliability value is used to initialise the `calculatedReliability` of the task “receive alarm” of the HMS.

The base case scenario, as illustrated in Table 2, considers the values proposed in [20] for the reliability of sensors; the value 0.992 for the reliability of transmission from sensors to the BAN gateway; and the value 0.99 for the reliability of transmission from the BAN gateway to the HMS.

The `calculatedReliability` attribute was set to 1.0 for the remaining activities and events, such as the process start, the evaluation of the received values in the BAN gateway, and the “assist patient” activity. In addition, the `requiredReliability` value for all process activities and events was set to 0.6, as this was assumed to be the minimum acceptable reliability.

The reduction rule for the fault-tolerant gateway considers four feasible combinations of receiving two out of three signal devices: (HRM, POxy, Shygm), (HRM, POxy), (HRM, Shygm), and (POxy, Shygm).

Table 2. Reliability values for activities and transmissions for the base case scenario

BAN devices (sensors)	Raw Reliability		
	Sensor	Sensors to Gateway	BAN Gateway to HMS
HRM	0.8	0.992	0.99
POxy	0.7	0.992	0.99
Shygm	0.6	0.992	0.99
Acc	0.9	0.992	0.99
Overall reliability	0.6901		

For the base case scenario, the reliability of the process takes the value 0.6901. This value is above the required reliability value, meaning the base case is feasible for implementation in a real life system.

5.2 Impact of Individual Reliability Component Variation *Versus* Overall AAL System Reliability

The study continued by making variations on different reliability values and assessing the resulting reliability of the global AAL system modelled as a BPMN process. We separately altered the reliability of the following elements: 1) each sensor, 2) the transmission from sensors to the BAN gateway, and 3) the transmission from the BAN gateway to the HMS through the home gateway.

Fig. 2 displays the results of this study. Chart (a) displays the results of the variation of the Accelerometer reliability in three scenarios. The base case scenario corresponds to fix all the other values of the original base case (Table 2) and making the reliability of the accelerometer vary in the interval [0.6; 1], using steps of 0.01. The worst case scenario differs by setting the reliability values of the remaining sensors to 0.6 (the minimum allowed value), while for the best case the reliability of the other sensors was set to 0.99 (considering an optimistic value).

Chart (b) shows the effects on the process reliability due to variation of the HRM reliability considering the same scenarios. As receiving (or not) information from the other sensors in the fault tolerant gateway has the same impact, this chart would be the same for the sensors POxy and Shygm. Chart (c) displays the impact of varying the reliability of transmission from the sensors to the BAN gateway, for similar scenarios – worst case (all the sensors' reliability set to the minimum 0.6), base case (all values set to the base) and best case (all the sensors' reliability set to 0.99). Finally, chart (d) discloses the dependence of process reliability from the reliability of the transmission from the BAN gateway to the HMS, using the previous scenarios.

The results reveal that the reliability of the process is mostly sensitive to reliability variations of the transmission from the sensors to the BAN gateway (chart (c)), then to variations of the accelerometer reliability (chart (a)), to variations of transmission from the BAN gateway to the HMS (chart (d)), and, finally, to the reliability of a single sensor (HRM, Pulse Oxy, Shygm) (chart (b)). The analysis of scenarios for the different charts allows concluding that the process reliability is more sensitive to variations of the value under analysis in the best case scenario and less sensitive in the worst case scenario. Nevertheless, the process reliability is insensitive to reliability variations of the sensors HRM, POxy, and Shygm for the best case scenario.

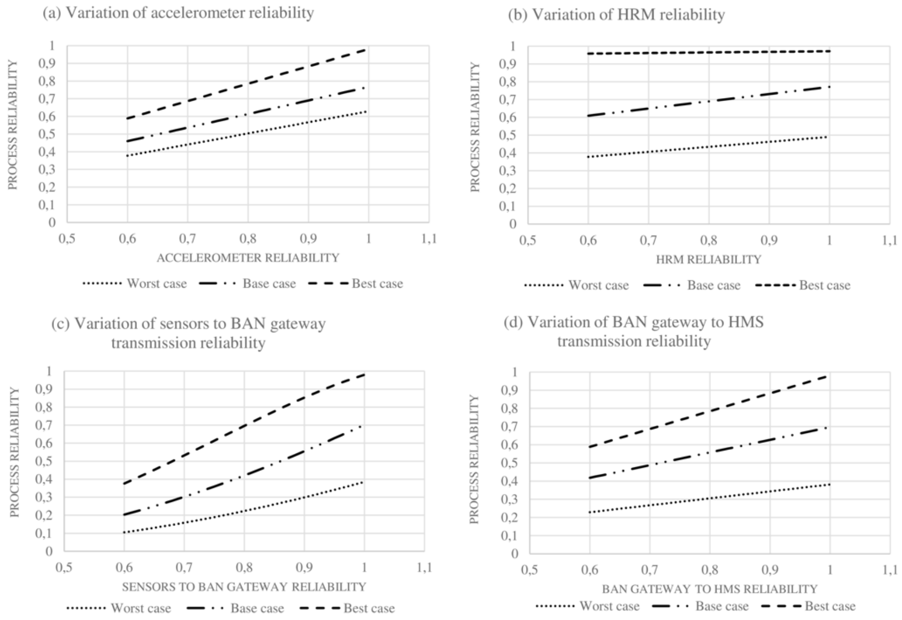


Fig. 2. Impact on the process overall reliability due to varying separate reliabilities: (a) variation of accelerometer reliability (upper left); (b) variation of HRM reliability (upper right); (c) variation of sensors to BAN gateway transmission reliability (lower left); (d) variation of BAN gateway to HMS transmission reliability (lower right).

The charts also allow identifying variation ranges for reliability values of the different elements that meet the required reliability for the overall process. In addition, few conditions allow to reach an overall reliability greater than 0.9 – if the transmission from the sensors to the BAN gateway has a reliability of at least 0.92.

5.3 Impact of Pairwise Component Reliability Variation *Versus* Overall AAL System reliability

The third phase of the study consisted of making pairwise variations on the reliability values of sensors and assessing the resulting reliability of the overall AAL system. We changed the reliability of the following pairs of sensors: 1) the shygmomanometer together with the accelerometer, and 2) the shygmomanometer together with the pulse oxymeter. The reliability value of the shygmomanometer sensor is associated with the fault-tolerant (parallel event-based) gateway in the AAL system BPMN process (Fig. 1), while the accelerometer is not, and both results are joint further in the parallel gateway before the "evaluate values" task. The charts in Fig. 3 show two perspectives of the variation of the overall reliability resulting from this pairwise variation. The reliability of both sensors was varied from 0 to 1 considering increments of 0.01, and for each pair of values the corresponding overall reliability was computed.

The charts give evidence to the lines of equal reliability (isolines) and the resulting bands. Each isoline divides two contiguous areas of different colours (two bands). All points in the same isoline correspond to combinations of one value for Shygm reliability with a value for the Accelerometer reliability that lead to the same reliability of the overall system. By a band we understand the area between two consecutive isolines, which includes reliability values between those values represented by the two isolines. By an isoline interval we understand the variation of reliability between two consecutive isolines. The isoline interval is equal to 0.1 and is the same over all the displayed charts. The surface is plotted using a heat-color scale, where red represents the lowest reliability band [0.0-0.1] and dark green colours the band for the highest reliability [0.9,1].

Chart (a) of Fig. 3 displays a 3D perspective of the process reliability surface in function of reliabilities of the sensors Shygm and Acc. It can be observed that an increase in the accelerometer reliability has a higher impact for high values of the Shygm reliability – the slope of the surface projection, in the plane process reliability-accelerometer reliability, increases as the Shygm reliability increases. Similarly, the impact of varying the Shygm reliability is higher for high Acc reliability values – the slope of the surface projection in the plane Shygm reliability-accelerometer reliability increases as the accelerometer reliability increases.

The highest reliability band, representing values of process reliability between 0.9 and 1, is almost inexistent, and corresponds to values of Shygm and Acc reliability very close to 1. The second highest reliability band, representing a reliability between 0.8 and 0.9, corresponds to Acc reliability values greater than 0.9 together with Shygm reliability values greater than 0.75.

The charts reveal a tendency of a behaviour following a regular pattern. The lines are continuous and monotone.

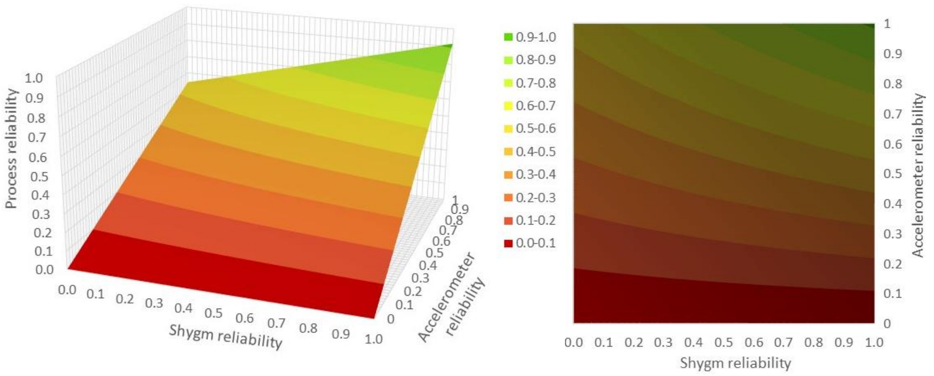


Fig. 3. Value of the process reliability resulting from the joint variation of the shygmomanometer reliability and the accelometer reliability (a) 3D view; (b) lines of equal reliability and bands

Chart (b) exhibits a projection of the process reliability surface in the plane Shygm reliability-Acc reliability.

From this chart we can also perceive that the process reliability is stable in the Shygm reliability axis meaning that this component has a small impact in the overall process reliability when compared with the Accelerometer reliability. This is revealed by the shape of the bands which are almost parallel to the XX axis. On the opposite, an increase in the Acc reliability highly impacts on the increase of the process reliability, especially for higher values of the Shygm reliability where the bands are tinier.

Process reliability values greater than the required reliability value (0.6) are only obtained for combinations where the Shygm reliability is greater than 0.6 and the Acc reliability is greater than 0.7 .

These conclusions are in line with the composition of the process, where the result of Accelerometer joints with the result of the fault-tolerant gateway block involving the Shygmomanometer (2 out of 3).

The same type of analysis could be reproduced for a pairwise variation of the reliability values of the Accelerometer and any other of the sensors in the fault-tolerant gateway: the Pulse Oxymeter or the Heart Rate Monitor, as their reliability contributes the same way for the process reliability.

The charts in Fig. 4 plot the process reliability surface in function of the reliability values of the sensors Shygm and pulse oxymeter (POxy). Again, a 3D perspective is given in chart (a) while chart (b) shows the projection of the process reliability surface in the plane Shygm reliability-POxy reliability. The same heat colour scale was used for plotting the process reliability values. Ten intervals for variation of the process reliability were considered. Each of these intervals corresponds to a reliability band in the chart. Contiguous bands are separated by a reliability isoline (where all points correspond to the same reliability value).

Chart (a) shows that the process reliability is more sensitive to variations of the POxy reliability for smaller values of the Shygm reliability – the slope of the surface projection, in the plane process reliability-POxy reliability, decreases as the Shygm reliability increases. The same way, the impact of varying the Shygm reliability decreases for higher values for the POxy reliability – the slope of the surface projection in the plane Shygm reliability – accelerometer reliability decreases as the POxy reliability increases.

There are no combinations of the Shygm reliability and the POxy reliability that lead to process reliability values greater than 0.9. The higher reliability band plotted corresponds to the interval [0.8, 0.9]

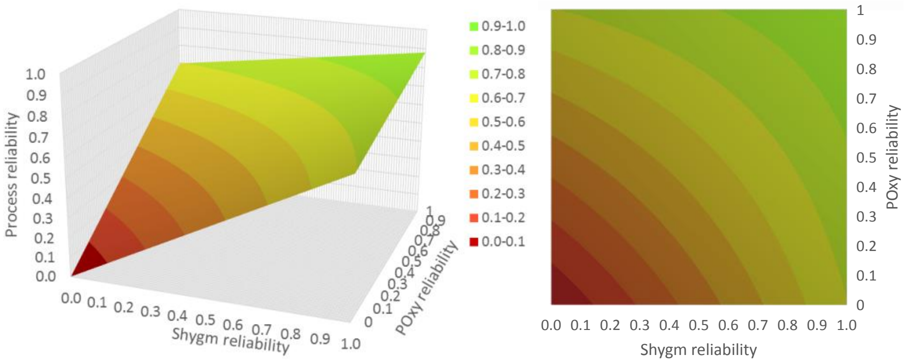


Fig. 4. Value of the process reliability resulting from the joint variation of the shygmomanometer reliability and the pulse oxymeter reliability (a) 3D view; (b) equal reliability lines and bands

The projection of the process reliability surface in the plane Shygm reliability-POxy reliability is represented in chart (b) of Fig. 3. In this case the shape of the isolines is concave downward, opposite from the isolines shape in Fig. 3-chart (b), which is slightly concave upward. The analysis of these lines confirms that the process reliability depends equally from both sensors reliability. However, the isolines and bands provide additional information on the combination of Shygm and POxy reliability values that lead to process reliability values in a given interval.

It can be observed that the process reliability is more stable in zones of higher reliability for both sensors, where the bands are larger, corresponding to a smaller surface slope.

For our case study, only process reliability values greater than 0.6 are feasible. Thus, only points in the area above the isoline of value 0.6 correspond to feasible combinations of Shygm and POxy reliabilities. These points are in the three "upper" bands of the chart.

The sensors Shygm and POxy are joint within the fault-tolerant (parallel event-based) gateway. This means that the results of this type of analysis would be the same for any pair of sensors involved in this gateway – Shygm and HRM or POxy and HRM.

6 Conclusions and Future Work

In this paper we presented a new approach to calculate the overall reliability of a certain AAL system and the way its components interact with each other. We use a BPM approach to model these interactions and to derive the combined reliability. For this, we extend the BPMN language to include reliability information for each process element and use the SWR algorithm to calculate the overall process reliability.

The study presented in section 5 exemplifies how to proceed to assess different conditions of an AAL BPMN process that involves AAL system components. This assessment can be made at design time to analyze the feasibility of the process, for instance, if a minimum level of reliability is assured. It allows to identify both individual and pairwise components which have the highest impact on process reliability and, therefore, to support the design the AAL system architecture and set the reliability requirements for its individual components.

Additionally, reliability can be computed at run time to monitor process executions hence providing an approach to identify low reliability services. In that case, for instance the sensor timers could be adjusted as well as the transmission rate increased at run time.

We are working on further developing this reliability concept within BPMN business processes, by considering not only its control-flow language elements (activities, gateways, loops, sequence and parallel flows), but also its resource and data language elements, such as resource definitions, assignments and data objects.

For this, we intend to extend a Business Process Management System (such as jBPM - www.jbpm.org), in order to include reliability information in BPMN processes, as well as runtime reliability monitoring features. These features can then help health care professionals to better allocate resources to provide the adequate care to certain monitored patients, taking into account the overall reliability of the AAL system in place.

Acknowledgments. This work is partially supported by National Funding from FCT - Fundação para a Ciência e a Tecnologia, under the projects PTDC/EEI-ESS/5863/2014, UID/MAT/04561/2013 and UID/CEC/00408/2013. The authors thank Carlos Albuquerque and Ana Paula Claúdio for the insightful conversations.

References

1. Baig MM, GholamHosseini H, Connolly MJ, Kashfi G (2014) A wireless patient monitoring system for hospitalized older adults: Acceptability, reliability and accuracy evaluation. In: IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI). IEEE Press, pp 330-333. doi 10.1109/BHI.2014.6864370
2. Bui N, Zorzi M (2011) Health care applications: a solution based on the internet of things. In: Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (p. 131). ACM. doi: 10.1145/2093698.2093829

3. Cardoso AJS (2002) Quality of service and semantic composition of workflows (Doctoral dissertation). University of Georgia.
4. Cardoso J, Sheth A, Miller J, Arnold J, Kochut K (2004) Quality of service for workflows and web service processes. Web Semantics: Science, Services and Agents on the World Wide Web, 1(3):281-308. doi:10.1016/j.websem.2004.03.001
5. Coppolino L, Romano L, Mazzocca N, Salvi S (2007) Web Services workflow reliability estimation through reliability patterns. In: International Conference on Security and Privacy in Communications Networks and the Workshops. IEEE, pp 107-115. doi 10.1109/SECCOM.2007.4550316
6. Dar K, Taherkordi A, Baraki H, Eliassen F, Geihs K (2014) A resource oriented integration architecture for the Internet of Things: A business process perspective. Pervasive and Mobile Computing 20:145-159. Elsevier. doi:10.1016/j.pmcj.2014.11.005
7. Distefano S, Ghezzi C, Guinea S, Mirandola R (2014) Dependability assessment of web service orchestrations. IEEE Transactions on Reliability, 63(3):689-705. doi 10.1109/TR.2014.2315939
8. IEEE (2011). IEEE Standard for Local and metropolitan area networks - Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs).
9. IEEE (2012). IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks.
10. Islam SMR, Kwak D, Kabir MH, Hossain M, Kwak K (2015) The Internet of Things for Health Care: A Comprehensive Survey. IEEE Access 3:678-708. doi 10.1109/ACCESS.2015.2437951
11. Jara AJ, Zamora MA, Skarmeta AF (2011) An internet of things-based personal device for diabetes therapy management in ambient assisted living (AAL). Personal and Ubiquitous Computing 15(4):431-440. doi 10.1007/s00779-010-0353-1
12. Krishnakumar N, Sheth A (1995) Managing heterogeneous multi-system tasks to support enterprise-wide operations. Distributed and Parallel Databases 3(2):155-186. doi 10.1007/BF01277644
13. Koren I, Krishna CM (2007) Fault tolerant systems. Morgan Kaufmann, San Francisco
14. Martinho R, Domingos D, Respício A (2016) Evaluating the Reliability of Ambient-Assisted Living Business Processes. In Proceedings of the 18th International Conference on Enterprise Information Systems, Scitepress, pp 528–536, doi 10.5220/0005917005280536
15. McNaull J, Augusto JC, Mulvenna M, McCullagh P (2012) Data and information quality issues in ambient assisted living systems. Journal of Data and Information Quality (JDIQ) 4(1):4. doi 10.1145/2378016.2378020
16. Memon M, Wagner SR, Pedersen CF, Beevi FHA, Hansen FO (2014) Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes. Sensors 14(3):4312-4341. doi:10.3390/s140304312
17. Mukherjee D, Jalote P, Nanda MG (2008) Determining QoS of WS-BPEL compositions. In: Bouguettaya A, Krueger I, Margaria T (eds) International Conference on Service-Oriented Computing, LNCS, vol 5364, Springer, Heidelberg, pp. 378-393. doi 10.1007/978-3-540-89652-4_29
18. Object Management Group (2011). Business Process Model and Notation (BPMN) Version 2.0.
19. Ouyang C, Dumas M, Ter Hofstede AH, van der Aalst WM (2007) Pattern-based translation of BPMN process models to BPEL web services. International Journal of Web Services Research (JWSR) 5(1):42-62.
20. Parente G, Nugent CD, Hong X, Donnelly MP, Chen L, Vicario E (2011) Formal modeling techniques for ambient assisted living. Ageing International 36(2):192-216. doi 10.1007/s12126-010-9086-8

21. Rashidi P, Mihailidis A (2013) A survey on ambient-assisted living tools for older adults. IEEE Journal of Biomedical and Health Informatics, 17(3):579-590. doi 10.1109/JBHI.2012.2234129
22. Respício A, Domingos D (2015) Reliability of BPMN Business Processes. Procedia Computer Science 64:643-650. doi 10.1016/j.procs.2015.08.578
23. Rodrigues GN, Alves V, Silveira R, Laranjeira LA (2012) Dependability analysis in the ambient assisted living domain: An exploratory case study. Journal of Systems and Software 85(1):112-131. doi doi:10.1016/j.jss.2011.07.037
24. Siewiorek D, Swarz R (2014) Reliable Computer Systems: Design and Evaluation. Digital Press.
25. van Der Aalst WM, Ter Hofstede AH, Kiepuszewski B, Barros AP (2003) Workflow patterns. Distributed and parallel databases 14(1):5-51. doi 10.1023/A:1022883727209