Intelligent Systems for Monitoring and Prevention in Healthcare Information Systems

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Abstract. Nowadays the interoperability in Healthcare Information Systems (HIS) is a fundamental requirement. The Agency for Integration, Diffusion and Archive of Medical Information (AIDA) is an interoperability healthcare platform that ensures these demands and it is implemented in *Centro Hospitalar do Porto* (CHP), a major healthcare unit in Portugal. Therefore, the overall performance of CHP HIS depends on the success of AIDA functioning.

This paper presents monitoring and prevention systems implemented in the CHP, which aim to improve the system integrity and high availability. These systems allow the monitoring and the detection of situations conducive to failure in the AIDA main components: database, machines and intelligent agents. Through the monitoring systems, it was found that the database most critical period is between 11:00 and 12:00 and the resources are well balanced. The prevention systems detected abnormal situations that were reported to the administrators that took preventive actions, avoiding damage to AIDA workflow.

Keywords: Healthcare Information Systems; Interoperability; Availability; Monitoring Systems; Preventing Systems.

1 Introduction

In healthcare area, information systems are in fast evolution, the main goal is convert paper-based practices into computerized processes in order to ensure the healthcare delivery and improve services quality. After dematerialization, Healthcare Information Systems (HIS) can provide a better coordination between medical professionals and applications, allowing the reduction of the number and the incidence of medical errors. Furthermore it enables the reduction of healthcare costs and may provide a means to improve the hospital management [1, 2].

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Nowadays a hospital constitutes an environment with many and complex information systems. They are heterogeneous, distributed and they speak in different languages. Consequently, the impact of these systems in a hospital environment is low, once they manipulate the information in an individualized way, which does not allow a proper interaction among the different systems [1,3].

In this way, it emerges the necessity of to establish a communication link among the systems that constitutes the HIS. This lack is filled through the interoperability, which is the ability of independent systems to exchange meaningful information and initiate actions from each other, in order to operate together to mutual benefit. The main goal of interoperability in healthcare is to connect applications and data can be shared and exchanged across the healthcare environment and distributed to medical staff or patients whenever and wherever they need it [4].

The interoperability implementation in HIS must hold mechanisms that ensure the information security. More specifically mechanisms that ensure the confidentiality, the integrity and the availability of the information. This issue will be presented in the Section 2 together with the presentation of the AIDA platform, a solution to achieve interoperability in HIS. The Section 3 presents the MEWS (Modified Early Warning Score) model, which is a fault forecasting model used in the Intensive Care Units that monitors the patient vital signs and it predicts organ failures. The work presented in this paper aims to increase the AIDA availability through monitoring and prevention systems, which will be presented in the Section 4. The systems developed and presented are based on the MEWS model. In the Section 5 the results of their implementation in the AIDA (Agency for Integration, Diffusion and Archive of Medical Information) installed in the *Centro Hospitalar do Porto* (CHP) will be discussed, critical situations conducive to failure were detected and fixed. It was possible to study the workload of the AIDA main components too. Finally, in the Section 6 the conclusions and future work are exposed.

2 Interoperability in HIS

There are a variety of methodologies and architectures through which it is possible to implement interoperability between HIS. These methodologies are based on common communication architectures and standards. The multi-agent system (MAS) technology is being to stand out in the area of interoperability, including interoperability in healthcare, addressing the concerns mentioned above. The autonomy and pro-activeness features of an agent allow it to plan and perform tasks defined to accomplish the design objectives. The social abilities enable an agent to interact in MAS and cooperate or complete to fulfil its goals. The agents in a healthcare facility configure applications or utilities that collect information in the organization. Once collected, this information can be provided directly to other entities, e.g. a doctor or to a server, stored in a file or sent by e-mail to someone for it to be treated at a later date [5].

2.1 AIDA

In this context, it arises an intelligent and dynamic platform with the purpose of making the HIS interoperable: the Agency for Integration, Diffusion and Archive of Medical Information (AIDA). This platform is developed by researchers at the University of Minho and it is implemented in several large health organizations in Portugal, including the CHP. AIDA is responsible for the process of integration of different information sources. To achieve that, it uses the Service Oriented Architecture (SOA) and MAS to implement interoperability in a distributed and specific environment in accordance with standards. This platform provides intelligent electronic agents, best known as software agents that besides they have a pro-active behaviour, they provide many services such as [4, 6]:

- The communication among different sub-systems, sending and receiving information (e.g. clinical or medical reports, images, data collections, prescriptions);
- Managing and archiving the information;
- Responding to requests, with the necessary resources to carry them out correctly and timely.

2.2 Information Security

Once AIDA stores and manipulates human related information, it is crucial to ensure its protection. The information security is based on three attributes that should be on the AIDA characteristics [7–9]:

- **Confidentiality**: provided by mechanisms that prevent unauthorized persons access and publicized private information;
- **Integrity**: this is the property that ensures that the information retains all the original features established by the owner even after handling, in other words the information should be inviolable, incorrupt and consistent;
- **Availability**: provided by mechanisms to access the required information in time by those who are authorized. In addition, it should have mechanisms for fault prevention and tolerance, so that the system be able to continue operating despite the failure of any component.

2.3 AIDA Availability

The AIDA should have a high level of availability and a proper functioning twenty-four hours a day. A short stop period or the system slowness may bring serious consequences for the services quality delivered. The AIDA platform has already implemented fault tolerance mechanisms such as: the Oracle Real Application Clusters (RAC) system, which improves the availability and the scalability of AIDA database; and a data guard solution, which consists in a replica of the original database, situated in a different place. This database is accessed when the original database is unavailable. In spite of all advantages, the fault tolerance tools do not allow the focus on the faults themselves, but only on the faults effects, trying to minimize them. Thus, it is necessary to perform a proactive monitoring on AIDA platform, taking actions before the fault occurs [10].

The AIDA availability is directly connected to its main components workflow. These main components are: its database, its agents and the machines wherein the agents perform their tasks. AIDA is a platform that ensures the interoperability in a healthcare environment and consequently, it strongly improves the quality of the healthcare services delivered to the patients. In spite of the high level of maturity of the AIDA platform, it has some flaws that influence this quality. The high availability is a strong demand in this platform and without a proper functioning of one of AIDA main components, its availability is compromised. In this context, the monitoring and prevention systems presented in this paper include these three components and they aim increase the AIDA high availability.

3 MEWS

In medicine there is already a model for the prediction, in advance, of serious health problems. This model is called Modified Early Warning Score (MEWS) and it is used in several healthcare units in the world. Particularly in the CHP, this model has been applied in the Intensive Care Unit [11].

MEWS assumes that a serious problem of health is often preceded by physiological deterioration. The use of MEWS implies a strict monitoring of the patient's vital signs. Then, using the decision table (Table 1), the scores are calculated to determine the level of risk of each patient, trying to understand when a serious problem will occur. The monitoring of patient's vital signs should be continuous and all values must be archived so that it becomes possible to understand the behaviour of the vital signs over the time [12, 13].

Table 1. MEWS Scores (adapted) [12].

MEWS Score	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Temperature (^oC)		< 35.0	35.1-36.0	36.1-38.0	38.1-38.5	> 38.6	
Heart rate (min^{-1})		< 40	41-50	51-100	101-110	111-130	> 131
Systolic BP ($mmHg$)	< 70	71-80	81 - 100	101 - 199		> 200	
Respiratory rate (min^{-1})		< 8		8-14	15-20	21-29	> 30
Blood oxygen (%)	< 85	85-89	90-93	> 94			
Urine output ($ml/kg/h$)	Nil	< 0.5					
Neurological		New confusion		Alert	Reacting to voice	Reacting to pain	Unresponsive

In order to classify the health state of the patient, the seven scores are extracted from Table 1 and then they are summed, obtaining the total score. The patient's state is characterized according to the following guidelines [12, 13]:

– When one of the parameters has the score two, the patient should be observed frequently;
– If the patient's total score is four or if there is an increase of two values of the total score, the patient requires urgent medical attention;
– If the total score is more than four, the patient is at risk of life.

This model is endowed with several advantages such as: enabling to set priorities for the interventions to be carried out; knowing better the physiological tendencies of the patient's organism through the monitoring process; assisting in making medical decisions, once it uses a quantitative criteria; predicting situations that the patient need internment in the Intensive Care Unit [11–13].

4 Monitoring and Preventing Systems

This section presents the monitoring and prevention systems developed for the database, machines and agents of AIDA. Once all of them are based on MEWS, it was created three score tables, one for each AIDA main component. To develop prevention system, it is indispensable to realize a monitoring process. A high knowledge about the system is demanded in order to select the performance indicators properly. These indicators should be based on the system workload and other parameters that are important to prevent faults [14].

4.1 Database

Through the performance views, a tool provided by Oracle to collect information about database state, it was possible to collect the AIDA database performance indicators, in addition Unix scripts were responsible to collect information about the processor and memory of database server. In this way, the twelve performance indicators selected to accomplish the monitoring and prevention faults were [15]:

– **Processor utilization**: high values may seriously compromise the database workflow;
– **Memory utilization**: it is also a fundamental key to a database proper functioning;
– **DB time**: this is the time elapsing between the instant of placing of the query by the user to the reception of all results, this time should be the lowest possible;
– **Number of transactions**: It is the sum of the number of commits and the number of rollbacks effectuated by users;
– **Number of operations**: one transaction consists in a set of operations, depending on the query it can have more or less operations per transaction;
– **Calls ratio**: it is the ratio between recursive calls and total calls (sum of recursive calls and user calls). A recursive call occurs when a user request needs one query SQL that needs another SQL query. Ideally, this ratio should be lower as possible;

– **Number of current sessions**: a high number of sessions opened may cause an excessive use of memory;
– **Size of redo file**: the amount (KBytes) of redo files;
– **Buffer cache ratio**: the percentage of data that is in memory cache, if this ratio decreases, this may indicate memory problems;
– **Amount of I/O requests**: a high value of this parameter may indicate memory problems and frequent access to the disc;
– **Amount of redo space requests**: it indicates if there is enough space to write in the buffer;
– **Volume of network traffic**: it is the network that interconnects all the components of the database. If this value is very high, the database becomes slower and it compromises the users requests.

In the Table 2 it is presented the score table for AIDA database. The scores attribution is made through percentiles, inspired in the 95^{th} percentile method used for billing in Internet Service Providers and websites [16]. In the Table 2, all performance indicators have the same limits to establish the score to each one.

Table 2. Score table for the AIDA database based on the performance indicators selected.

Score	**0**	**1**	**2**	**3**
Values	$\leq p80$	$]p80, p85]$	$]p85, p95]$	$> p95$

Once this score table is based on percentiles, it was necessary collect a reasonable amount of data related to each performance indicator during a period of time. It is important to refer that there is a specific percentile for each score of each performance indicator for each hour of the day. The system developed is upgradeable, new percentiles are calculated at the end of the day based on new measurements.

After a discussion among the system administrators and Information Systems (IS) specialists, it was decided that the total score is calculated 15 in 15 minutes using the averages of all performance indicators collected during this period. In this way false positive situations are avoided and the effectiveness of this prevention system is increased. Similarly to the MEWS, if the total score is more than four, it is a critical situation that compromises the database availability. This situation is conducive to fault occurrence, so the system developed send an email to system administrators warning the database state in order to they take preventive actions, avoiding damage in the HIS. For less serious situations (total score less than 5 or an increase of 2 values), visual warnings appear in the monitoring dashboards developed with the objective to monitor the activity of the database, machines and agents.

4.2 Machines

With the purpose of to know the AIDA machines behaviour and then to prevent possible faults, three performance indicators were selected, all of them related to their workload (free percentage of processor, memory and disk space). These parameters were collected through Windows Management Instrumentation (WMI) technology, which enables a simple exchange of information through a powerful set of tools based on standards. With a simple query-based language named Windows Query Language (WQL), this technology allows the user to obtain a wide range of information about the hardware and software of a specific machine. Obviously the user must know the required credentials.

In the case of the machines, initially there was an attempt to create a score table based on percentiles as the Table 2 previously presented, but it did not succeed. The application sent several warnings false positives per day. The computer performance limits for a good operation is an issue that varies a lot. Those limits depend of the objectives that the system administrators want for a specific machine. So, the score table was created with default fixed limits based on the administrators experience, their knowledge about the system and opinions from IS specialists. Through a management page, the administrators can change these limits for each parameter either generally or specifically for one machine, anytime. The default score table for all machines, based on MEWS, it is presented in the Table 3.

Table 3. Score table for the AIDA machines.

Score	**0**	**1**	**2**	**3**
Free processor (%)	≥ 50	$]50, 25]$	$]25, 10]$	< 10
Free memory (%)	≥ 15	$]15, 10]$	$]10, 5]$	< 5
Free disk space (%)	≥ 15	$]15, 10]$	$]10, 5]$	< 5

As in MEWS, the following situations can occur:

– If the sum of all parameters score is more than four, critical situations are detected and a warning (email) is sent to the administrators in order to they take preventive actions;
– If there is an increase of two values, it is considered that the situation is very grave, such as a situation wherein the total score is four. In these cases a warning will appear in the monitoring dashboards.

Another adaptation of this fault prevention system was considered that when one of the parameters showed in the Table 3 has the score three it is a critical situation, which triggers an email warning. It was important to implement this adaptation because any of the machines performance indicators is fundamental for a good performance. If one of these resources is overly consumed, the machine will have serious problems of accomplishing its tasks.

4.3 Agents

In the two systems of monitoring and prevention presented above, the performance indicators intervene in the process of prevention faults and in the monitoring process. In the case of agents, the prevention and monitoring systems are separated. The monitoring system collects information related to the workload of each agent so that they are analyzed in the monitoring dashboards. For the prevention of the faults, the system is based on the frequency of agent activity. In other words, it is the frequency that the agent is executed. It also can be interpreted by the interval of time that the agent takes to refresh the log file with its newest activity. To collect the values of this indicator, it is used the Directory class of .NET framework and a batch script that creates the mapped drives for the AIDA machines that execute the agents and it is where the log files are.

The agents monitoring system collects and disseminates the values of various performance indicators such as: processor and memory utilization by agent, I/O of data per second and execution time. The first three indicators are also collected through WQL queries. In this way, the system administrators can access the monitoring dashboards and to consult the agents behaviour anytime.

In the Table 4, it is presented the score table for AIDA agents based on its activity frequency (in minutes) and percentiles (inspiration in the 95^{th} percentile method again [16]). Once there is one variable in the score table, it was added the score four, becoming the system more accurate. After obtaining the results from the first tests of this prevention system, the Table 4 was adapted. The 95^{th} percentile was replaced for the 97.5^{th} percentile and consequently the other limits were modified, with also the purpose of increase the system accuracy.

Table 4. Score table for the AIDA agents based on its activity frequency.

Score	**0**	**1**	**2**	**3**	**4**
Activity frequency (min)	$\leq p85$	$]p85, p90]$	$]p90, p95]$	$]p95, p97, 5]$	$> p97, 5$

Before beginning the prediction process, it is indispensable to collect several data about agents' activity frequency during a reasonable period of time. In this way it is possible to evaluate the normal behaviour of agents and start the prevention process based on the interpretation of MEWS scores:

- If the score obtained was less than four then a visual warning will be issued on the monitoring dashboards;
- If the score was equal to four an email is sent to the system administrators in order to they take speedy action to restore the normal workflow and to prevent future damages.

New limits are constantly calculated for each agent improving the system efficacy. Besides that, this application is endowed with persistency in relation to the database state. If the database is down, all SQL statements are recorded in a file and the administrators are warned. When the database returns back to normal all registers are inserted and the limits are refreshed. During the database down time, scores do not stop of being calculated and abnormal situations are detected, however the limits are not refreshed and the limits in the score table are the last ones calculated. It is important to refer that this application does not use the same database that the AIDA uses, avoiding an overload in the AIDA database and allowing a dependency on the application operation.

5 Results

The systems presented in the Section 4 were implemented in the AIDA installed in the CHP. Besides prevention damage to AIDA workflow, detecting critical situations through the prevention systems, these systems also allowed to realize a study about the workload of the AIDA main components. This study increased the administrators' knowledge about the AIDA platform, enabling them to detect situations that need to be fixed and fragile situations that require special attention, to establish priorities for taking action and still to manage the platform in order to obtain the best balance of resources.

All the graphs presented in this section were extracted from the monitoring dashboards developed through an open source Business Intelligence (BI) tool named Pentaho Community, which revealed to be an easy handling tool, it improved the consolidation of the data and it provided a greater support for decision making [17].

5.1 Workload Results

Database

In the Table 5 is possible to verify that the AIDA database has a high utilization, an average number of sessions in the order of 681 sessions. Furthermore, it can observe that are executed on average about 214 transactions per second, resulting 742 operations per second in the database, which proves that this is a database with a very high workload.

The Figure 1 shows the values of four performance indicators in a specific regular day: number of sessions, processor utilization, DB time and network traffic. On this day, no abnormal situations were detected in AIDA components. The graphs are composed by two limits, the 25^{th} and 75^{th} percentiles (p25 and p75 in the Figure 1). Consequently, 50% of the data collected is in the range defined by these limits and it is expected that the next measurements occur in the same range. All four graphs in the Figure 1 present a significant peak at the end of the morning. The other performance indicators (not included in the Figure 1) also demonstrated this behaviour on this day, although not in such an obvious way. It may be concluded that, in a regular day, the period between 11:00 and 12:00 is the most critical for AIDA database.

Table 5. Average values of AIDA database performance indicators during the study period.

Performance indicators	Average values
Processor utilization (%)	18
Memory utilization (%)	98
DB time per second	6
Transactions per second	214
Operations per second	742
Calls ratio	0.14
Number of sessions	681
Redo file size (KBytes per second)	152
Buffer cache ratio	0.998
I/O requests per second	632
Redo space requests per second	0.55
Network Traffic Volume (KBytes per second)	671

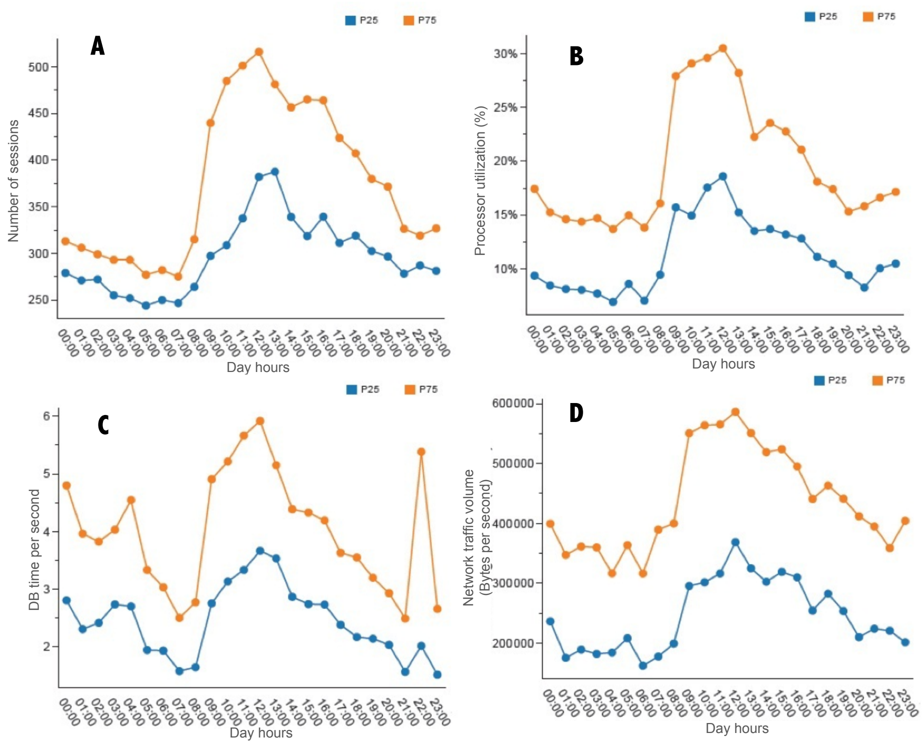

Fig. 1. Values of four performance indicators of AIDA database during a regular day. **A**: Number of sessions; **B**: Processor utilization; **C**: DB time; **D**: Network traffic.

Machines and Agents
During a month it was collected the machines performance indicators. As the Figure 2 presents, among the five machines that execute AIDA agents, the machine 08 is the one that consumes more CPU (an average of 14.09%) and the machine 01 is the one that consumes more memory RAM (an average of 42,38%). On the other hand, machine 01 is the one that consumes less CPU (an average of 5.5%) and machine 08 and machine 04 are the ones that consume less memory RAM (an average of 14.23% and 12.93%, respectively). It was also possible to confirm in the monitoring dashboards that the CPU consume was constant only varying from 5 to 10% in maximum. The consumption of memory RAM was very constant.

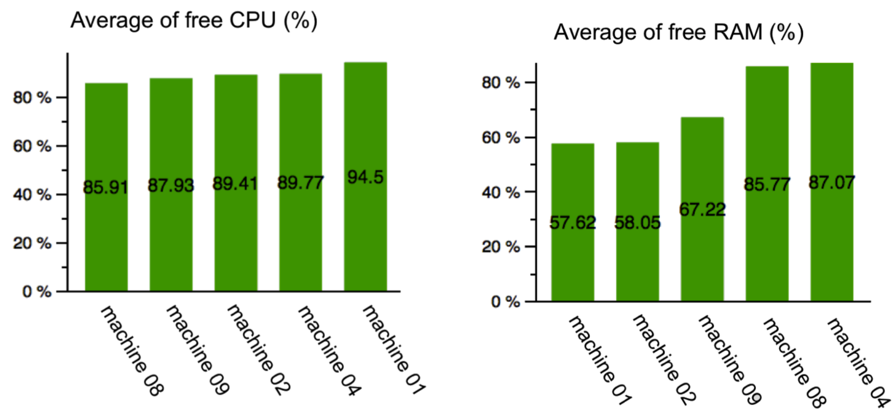

Fig. 2. AIDA machines workload (processor and memory utilization).

Relative to agents workload, it was possible to uncover that agents that are continually being executed and are responsible for archives transfer and provide web services, consume more RAM memory. That is the case of the machine 01 that only have agents with these functions. As it is possible see through Figure 2, the machine 01 is the one that consumes more RAM memory. In this case, talking about the machines prevention system, the administrators should lower the memory limits of this machine in the score table for machines (Table 3) in order to avoid being warned in regular situations.

The high number of agents that are executed in machine 08 justifies the high consumption of processor. In this machine are installed agents that are responsible for archives transfer, billing, requests processing and verifications. Besides the number of agents, most of these are often performed, which also justifies the elevated use of CPU in machine 08.

The machine 04 is the machine that has more resources available as it can be seen in the Figure 2. So, it may be concluded that when a new agent is created, it should be installed in this machine. This conclusion can be taken from the monitoring dashboards, which acts as a decision support system. These dashboards also enable to the system administrators to monitor the AIDA components in real time and to study their behaviours in the past, in a period selected by the user.

5.2 Preventing Systems Results

Database

During the period of this study, the database prevention system did not detect any situation with the total score more than four. However, abnormal situations for each performance indicator were detected. The memory utilization, the calls ratio, the amount of I/O requests and the number of transactions were the indicators with more occurrences: 377, 369, 362 and 352 respectively. The reason why there is no critical situation reported with a total score more than four and at the same time there is a high number of abnormal situations is explained through several facts: the abnormal situations are verified every minute and the total score is only calculated 15 in 15 minutes with the average values of this period; the average value of the indicators rarely is high; abnormal situations normally happen before and after regular situations; and usually when the performance indicators have high scores, it does not coincide with high scores of the other indicators.

Machines

During the study phase, the machines prevention system detected four critical situations, which are presented in the Table 6. For instance, the first critical situation detected on the 30^{th} July in machine 02 achieved the total score of six. Analysing this situation and remembering the Table 3 presented in the Section 4, it is verified that the high utilization of processor and memory implied the total score obtained. On the other hand, the occurrences of the machine 04 achieved a total score of four, because in both situations there was an increase of two values relative to the previous score. Although the total scores are lower than five, it was considered as a critical situation because the processor utilization had the maximum score and according the mentioned in the Section 4, these are situations propitious to faults. All four situations presented in the Table 6 were reported successfully to a system administrator who quickly identified and repaired the problem. In this way, he prevented bigger damages in the normal workflow of the AIDA.

Agents

The study phase for the agents prevention system lasted almost two months and it was realized after collecting data about the agents activity frequency during two weeks. Three maintenance situations were realized in different days during this phase. The process of maintenance, naturally, caused a stop in several agents activities. In all of these three situations, the agents prevention system detected

Table 6. Critical occurrences per machine.

Machine	Date-time	Free processor (%)	Free memory (%)	Free disk space (%)	Score
machine 02	30^{th} July 16:00-16:30	3	9	50	6
	24^{th}-25^{th} September 22:40-00:15	1	4	50	6
machine 04	27^{th} August 12:40	0	81	34	4
	5^{th} September 16:15-17:30	6	88	34	4

that those agents stopped. This fact proves that the system is capable of quickly detect an irregular situation of the agents, preventing bigger damages.

Ignoring the occurrences from maintenance situations, it was detected abnormal activities of some AIDA agents. In the Figure 3, it is visible the occurrences where certain agents reached the score four, triggering the sending of warning emails.

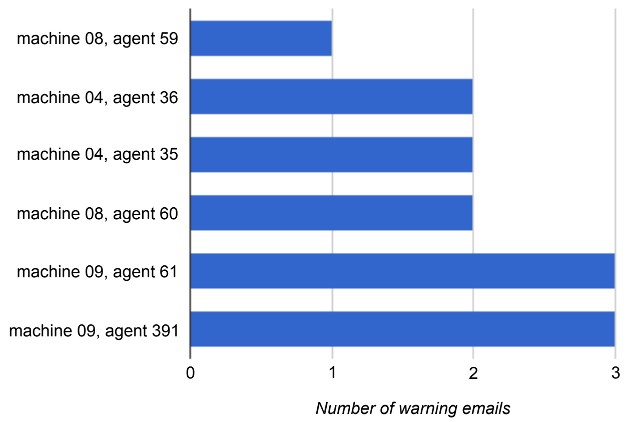

Fig. 3. Number of warning emails (critical situations) per agent during the study phase for agents prevention system. The occurrences relative to the maintenance situations are ignored in this graph.

In all occurrences shown in the Figure 3, the agents presented an abnormal behaviour. They remained too long without performing their tasks. These situations must be carefully analyzed to determine if is necessary to modify these agents or other components.

6 Conclusions and Future Work

The adaptation of the model MEWS in medicine for the AIDA main components (database, machines and intelligent agents) was conceivable, detecting critical situations conducive to failures. However, it is very important to refer that is essential have a high knowledge of the system to make possible this adaptation and the development of the monitoring and prevention systems. Through the process of monitoring, these systems should be accompanied and refined continually. Furthermore, the monitoring of these components assists in making decisions about the system and it enables a better resource management of each of these components.

Relative to workload results, it may be concluded that the AIDA database of the CHP has a high workload, mainly between 11:00 and 12:00. According to the results obtained in the Section 5, the machine 08 and the agents that it executes, deserve a special attention from system administrators. This is due to the fact that a great number of agents perform their tasks in the machine 08. The machine 02 should be observed frequently, once critical situations were detected either for the machine or for the agents that run there. The workload of the AIDA agents and machines demonstrated that the system resources are well balanced. However, minor repairs could be made such as the transfer of one or more agents of the machine 08 to the machine 04. Thus the high importance of high availability of the machine 08 would be decentralized, i.e., if this machine failed, the damage would not be as great.

It also may be concluded that the monitoring systems contribute to the improvement of AIDA integrity, because they provide a greater control on AIDA main components.

The prevention systems presented in this paper, contribute to increase the AIDA availability, once these systems avoid critical situations where failure can arise easily. They allow the administrators repair irregular situations quickly, ensuring the best performance of the AIDA platform. In this way these systems contribute to assist the system administrators to manage the AIDA platform and consequently, to the improvement of the healthcare information systems quality.

As future work will be possible to give mobility to agents so that they can migrate from a machine to another depending on the resources there are available. The warning module will be improved through the sending of messages via SMS in extreme cases or when a critical situation lasts long. The data mining process should be applied to the data that concerns about these three main components. In order to recognize correlations and standards in the components behaviour.

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References

1. Palazzo, L., Sernani, P., Claudi, A., Dolcini, G., Biancucci, G., Dragoni, A.F.: A multi-agent architecture for health information systems. In: International Workshop on Artificial Intelligence and NetMedicine. (2013) 41
2. Reichertz, P.L.: Hospital information systems-past, present, future. International Journal of Medical Informatics **75**(3-4) (2006) 282 – 299 Electronic Health Record, Healthcare Registers and Telemedicine and European Potential for Building Information Society in Healthcare.
3. Miranda, M., Salazar, M., Portela, F., Santos, M., Abelha, A., Neves, J., Machado, J.: Multi-agent systems for hl7 interoperability services. Procedia Technology **5** (2012) 725–733
4. Miranda, M., Duarte, J., Abelha, A., Machado, J., Neves, J.: Interoperability in healthcare. In: Proceedings of the European Simulation and Modelling Conference (ESM 2010). (Belgium, 2010)
5. Machado, J., Abelha, A., Novais, P., Neves, J., Neves, J.: Quality of service in healthcare units. International Journal of Computer Aided Engineering and Technology **2**(4) (2010) 436–449
6. Duarte, J., Salazar, M., Quintas, C., Santos, M., Neves, J., Abelha, A., Machado, J.: Data quality evaluation of electronic health records in the hospital admission process. In: Computer and Information Science (ICIS), 2010 IEEE/ACIS 9th International Conference on. (aug. 2010) 201 –206
7. Rodrigues, A.: Oracle 10g e 9i: Fundamentos Para Profissionais. FCA, Lisboa (2005)
8. Bertino, E., Sandhu, R.: Database security - concepts, approaches, and challenges. Dependable and Secure Computing, IEEE Transactions on **2**(1) (2005) 2–19
9. Kim, S., Cho, N., Lee, Y., Kang, S.H., Kim, T., Hwang, H., Mun, D.: Application of density-based outlier detection to database activity monitoring. Information Systems Frontiers (2010) 1–11
10. Drake, S., Hu, W., McInnis, D., Sköld, M., Srivastava, A., Thalmann, L., Tikkanen, M., Torbjø rnsen, O.y., Wolski, A.: Architecture of Highly Available Databases. In Malek, M., Reitenspieß, M., Kaiser, J., eds.: Service Availability. Volume 3335 of Lecture Notes in Computer Science. Springer Berlin / Heidelberg (2005) 1–16
11. Portela, C.F., Santos, M.F., Silva, Á., Machado, J., Abelha, A.: Enabling a pervasive approach for intelligent decision support in critical health care. In: ENTERprise Information Systems. Springer (2011) 233–243
12. Devaney, G., Lead, W.: Guideline for the use of the modified early warning score (MEWS). Technical report, Outer North East London Community Services (2011)
13. Albino, A., Jacinto, V.: Implementação da escala de alerta precoce - EWS. Technical report, Centro Hospitalar do Barlavento Algarvio, EPE, Portimão (2010)
14. Boudec, J.: Performance Evaluation of Computer and Communication Systems. Computer and communication sciences. EPFL Press (2010)
15. Chan, I., et al.: Oracle database–performance tuning guide, 10g release 2(10.2). Redwood City, Oracle Corporation **474** (2005) B14211–01
16. Dimitropoulos, X., Hurley, P., Kind, A., Stoecklin, M.P.: On the 95-percentile billing method. In: Passive and Active Network Measurement. Springer (2009) 207–216
17. Tereso, M., Bernardino, J.: Open source business intelligence tools for smes. In: Information Systems and Technologies (CISTI), 2011 6th Iberian Conference on, IEEE (2011) 1–4