Towards Distributed Sociotechnical System for Reporting Critical Laboratory Results

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Abstract: In healthcare domain, reporting of laboratory results by biomedical scientists to caregivers is a common practice. Many healthcare centres follow different kind of guidelines for reporting laboratory results for the purpose of improving the process. In this paper, we first analyze current procedure for reporting Critical Laboratory Results (CLRs) followed by North Estonia Medical Centre (NEMC) located in Estonia. We then identify weaknesses and argue that reporting of CLRs requires advanced mechanisms because a patient with CLRs is always in need of a prompt treatment or decisions on medication from the appropriate caregiver. We then critically analyze a problem of reporting CLRs to caregivers with the aim to support this process by appropriate sociotechnical system. We do this by using the approach of agent-oriented modelling. The analysis is followed by models for designing a distributed sociotechnical system for managing CLRs.

1 INTRODUCTION

In today's world, we interact with an ever-increasing array of mobile devices such as smart phones and personal digital assistants. Such devices are changing the way people in today's society behave and communicate (Hellström and Tröften, 2010). The abundance of mobile technologies has enabled a promising direction in today's healthcare. In the healthcare domain, monitoring and reporting of laboratory test results to an appropriate caregiver (physician, nurse, midwife, etc.) is a common practice. The laboratory test results have two main categories – Normal Laboratory Results (NRLs) and Critical Laboratory Results (CLRs) (Kuperman et al. 1998). NRLs represent the medical condition of a patient that does not require a prompt response from a caregiver while CLRs are any values or their interpretations for which delays in reporting can result in serious adverse outcomes for patients. Thus, patients with CLRs need prompt treatment or decisions on medication by the appropriate caregiver (Tate et al., 1995); (Kuperman et al., 1996); (Hanna et al. 2005).

The advancement of mobile technologies provides opportunities for designing intelligent distributed systems that support reporting of CLRs to appropriate caregivers. Because of the distributed nature of the healthcare domain, we are interested in designing intelligent systems that support each healthcare professional according to the role played by her/him at a given time in a given location. Such systems can be termed as distributed sociotechnical systems. Sterling and Taveter (2009) have suggested an approach called Agent Oriented Modelling (AOM) for designing distributed sociotechnical systems made up of humans and their intelligent digital assistants, which are respectively termed as human agents and man-made agents. These agents should be able to sense the environment via, for example, medical sensors, reason, act and socialize with one another when achieving objectives of the sociotechnical system.

The contribution of this paper is twofold: from the medical perspective, we have critically analyzed different mechanisms for reporting CLRs from existing literatures together with the actual practice carried out at the North Estonia Medical Centre (NEMC). Then, we recommended a combined usage of specialty, medical knowledge, and availability information of the caregiver, which, to the best of our knowledge, is a new approach for choosing an appropriate caregiver for receiving CLRs. From the technological perspective, we presented the analysis and design models of the intelligent distributed sociotechnical system consisting of human agents

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and man-made agents by using the previous-mentioned AOM approach for designing sociotechnical systems (Sterling and Taveter, 2009).

The rest of this article is organized as follows. Section 2 presents the problem of efficiently handling of CLRs experienced by NEMC. The models for the analysis of the problem domain are then discussed in Section 3 with the help of AOM. Likewise by means of AOM, Section 4 describes the design of a sociotechnical system for reporting CLRs to appropriate caregivers. Section 5 discusses related work and Section 6 draws the conclusions and presents the future work.

2 PROBLEM DOMAIN

Among the objectives of any healthcare centre is to provide patients with a better quality care. In achieving its objectives, the exchange of medical information between caregivers, who are naturally distributed and have different responsibilities, should be handled efficiently. In this paper we focus on the actual procedure followed by North Estonian Medical Centre (NEMC) laboratory during the process of reporting CLRs to an appropriate caregiver. NEMC is the foremost Estonian hospital with main buildings situated in different locations of Tallinn and Kose counties. The hospital has 3626 employees, including 590 doctors, 1352 of nursing staff, and 862 other caregivers. At any given time, there are over 100 resident physicians in the hospital.

The NEMC laboratory has written guidelines for reporting laboratory results. These guidelines describe procedures for verification of results and reporting them to appropriate caregivers. The Laboratory Information System (LIS) uses Process Systems Manager (PSM) middleware software for receiving orders from the Hospital Information System (HIS) and sending them to the medical equipments in a laboratory for the purpose of conducting laboratory tests. When the tests are complete, the PSM receives results from the medical laboratory, auto-verifies the results, and sends them to the HIS, where they are stored in the appropriate patient record. Auto-verification means that the PSM system checks the results against various pre-specified criteria and proactively decides how to proceed with the results. The results that comply to the pre-specified criteria are automatically released and stored in the patient record in the HIS, while other results are blocked to be reviewed by a biomedical scientist.

In the PSM critical values are described for several laboratory tests, such as S-P, fS-Gluc, fS-K, fS-Ca, fS-Mg, fS-Na, B-Hct, B-Hgb, B-WBC, B-RBC, and P-INR. When CLRs are detected, the system blocks them and marks by red background. A biomedical scientist then reviews all blocked results. For each of the identified CLRs, the corresponding laboratory tests will be repeated by using a different medical equipment to check for analytical errors. If the outcomes of the repeated laboratory tests are detected as CLRs for the second time, a biomedical scientist will call to inform the physician who ordered the tests. The NEMC laboratory guidelines require the laboratory staff to report the detected CLRs within 30 minutes to the physician who ordered the tests. If the physician who ordered the tests is unavailable, the laboratory staff is supposed to report to the departmental nurse. The laboratory staff will try three times and if upon all three times neither physician nor departmental nurse is available, the laboratory staff will stop trying to contact them and the CLRs will be transmitted electronically as NRLs to the HIS. In case of either successful or unsuccessful attempt to reach the physician or the departmental nurse by phone, the guidelines require the laboratory staff to record the reported CLRs on the paper-based registration form.

We have identified several weaknesses in the current procedure of reporting CLRs at the NEMC laboratory. Firstly, the procedure of reporting CLRs involves many people. This leads into two major problems: (1) high risk of human errors (2) delay in reporting CLRs. For instance, due to a human error, in some cases the order form for laboratory results does not contain the phone number of the corresponding physician, which causes a delay in reporting CLRs detected. By automating the reporting process by means of a new information system, data integrity will be ensured while the integration of the new information system with the existing laboratory systems will reduce human errors as well as the time required to report CLRs. Secondly, when the physician who ordered the laboratory tests is unreachable, the laboratory guidelines suggest the laboratory staff to make a phone call to the departmental nurse who will then try to find another appropriate physician. If the departmental nurse is also unreachable, the CLRs will be sent to HIS as NLRs. We highly recommend improving this procedure for reporting CLRs because the current practice allows significant risks for human lives, which can be avoided. We suggest to improve the current system by introducing a new information system that takes advantage of the

advancement in mobile technologies, such as the use of location sensors that can accurately identifythe appropriate physicians. We propose to design a new information system as a sociotechnical system – a software intensive system that has defined operational processes followed by human operators and which operates within an organization (Sterling and Taveter, 2009). In a sociotechnical system envisioned by us, humans acting in specific roles in healthcare organizations, such as laboratory technicians, biomedical scientists, and physicians, are supported by software agents. The most essential feature of the proposed sociotechnical system lies in the software agents' behaviors to be described in Section IV. The behaviours of agents are designed and implemented by applying Artificial Intelligence (AI) reasoning techniques such as abduction and deduction, which enables a software agent to act proactively when choosing an appropriate physician for receiving CLRs. As a result, if the physician to receive a report on CLRs is not available, the agents in the system will proactively identify and suggest other most appropriate physicians according to their availability, location, medical knowledge, and specialty. The last observed weakness is the use of paper-based forms for the registration of CLRs. Paper-based forms should be replaced by automatically generated log files that include information about: (1) reported CLRs (2) CLRs received by caregivers (3) delivery time (4) acknowledgment time. This will also provide an efficient method for quality control.

3 DOMAIN ANALYSIS

As was already mentioned at the end of Section II, the envisioned system is a sociotechnical system where humans playing certain roles are supported by appropriate intelligent digital assistants, which may also be termed as agents. Analysis of such systems should follow an appropriate methodology due to its complexity. There are various Agent Oriented Software Engineering (AOSE) methodologies available, such as Tropos (Bresciani et al., 2004), MaSE (Wood and DeLoach, 2001), and Prometheus (Padgham and Winikoff, 2003). However, they all put the emphasis on designing systems consisting of software agents rather than sociotechnical systems, where software agents support humans. Sterling and Taveter (2009) proposed a suitable approach that includes features similar to AOSE methodologies but is geared towards designing socio-technical systems consisting of humans and software agents, which are respectively termed as human agents and man-made agents (Sterling and Taveter, 2009). A sociotechnical system proposed in this paper consists of healthcare professionals and intelligent software agents that assist them with the aim of improving the reporting of CLRs. We next give a brief overview of agent-oriented modelling. This is followed by the description of how agent-oriented modelling has been applied to designing the socio-technical system for reporting CLRs.

In the centre of AOM lies the viewpoint framework represented as Table 1. The viewpoint framework is the conceptual framework that consists of a matrix with three rows representing different abstraction layers – analysis of the problem domain, design, and implementation – and three columns representing the viewpoint aspects of interaction, information, and behaviour (Sterling and Taveter, 2009). Each cell in this matrix represents a specific viewpoint by mapping one or more model type(s) of AOM. This paper presents the analysis and design of sociotechnical system by using two analysis models and three design models.

Table 1: The model types of Agent-Oriented Modelling.

	Viewpoint aspect		
Abstraction layer	Interaction	Information	Behaviour
Analysis	Role models and organisation model	Domain model	Goal models and motivational scenarios
Design	Agent models, acquaintance models, and interaction models	Knowledge models	Scenarios and behaviour models
Platform-specific design	Platform-specific design models		

We start by overviewing goal models. Generally, goal model serves as a container for three main components: functional goals commonly referred as goals, quality goals, and roles. Similarly to other kinds of systems, a socio-technical system is described by functional requirements as well as non-functional requirements, which are captured in a goal model by goals and quality goals, respectively. Goals and quality goals can be further decomposed into sub-goals and sub-quality goals, where each sub-goal represents some aspect of achieving its parent goal. Goal models serve as communication mediums between technical and non-technical stakeholders and provide both with a better understanding of the problem domain.

Figure 1 describes the goal model for managing CLRs. The top level goal represents the purpose of the sociotechnical system to be designed, which is to report CLRs. This goal is characterized by the quality goals of maximal patient safety and minimal delay. The latter means the process of reporting CLRs should take very little time, while the former targets at improving patient safety.

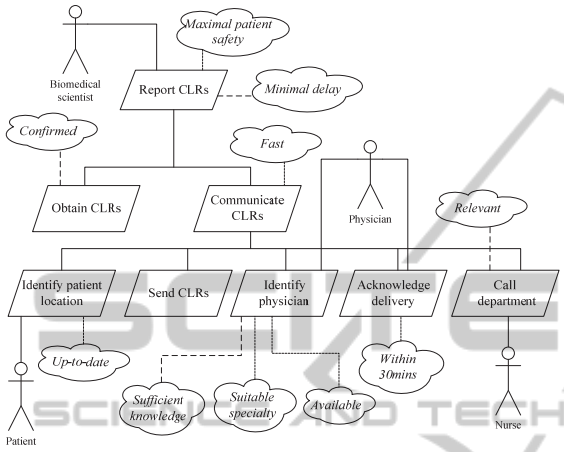

Figure 1: Goal model for the problem analysis.

As seen in Figure 1, the highest-level goal has been decomposed into two sub-goals – obtain CLRs and communicate CLRs. The latter has the quality goal "Fast" to make note of the non-functional requirement that the whole process of communicating CLRs should take as little time as possible. How to ensure the speed is a design issue, which is not considered during the analysis phase. The "Communicate CLRs" goal is then further decomposed into five sub-goals: identify patient location, send CLRs, identify physician, acknowledge delivery, and call department. The remaining quality goals are attached to the lowest level sub-goals as represented in Figure 1. The figure also includes the roles – Biomedical scientist, Patient, Physician, and Nurse – that are required for achieving the functional goals to which they are attached and their subgoals.

During the process of analyzing a problem domain, the knowledge to be handled by the system is captured by domain model. Domain model represents the environment(s) in which the system is to be situated, the types of resources produced and stored by them, as well as the existing relationship between the roles, environment(s), and resources. Figure 2 presents a domain model that contains six information resources, which are produced and used in the healthcare environment to facilitate interactions between agents performing the roles of Biomedical scientist, Physician, Nurse, and Patient, in order to achieve the goals of the sociotechnical system. For example, in Figure 2 the information resource "Physician location information" is produced by the role Physician and is directly utilized by the role Biomedical scientist for the purpose of achieving the overall goal of the sociotechnical system to report CLRs with maximal patient safety and minimal delay.

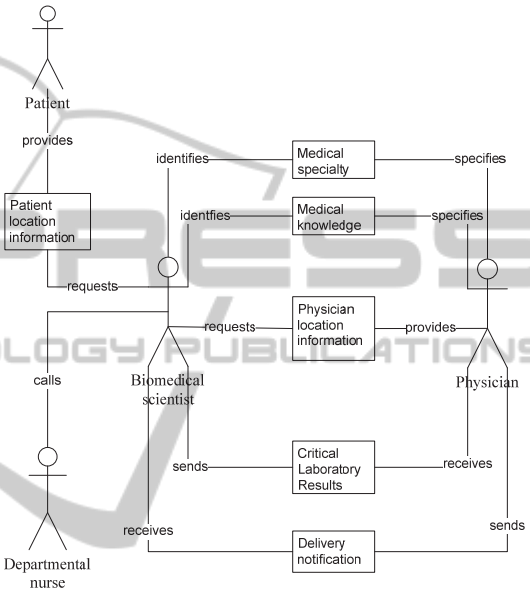

Figure 2: Domain model for analysing knowledge handled by the sociotechnical system.

4 DESIGN MODELS FOR THE SOCIOTECHNICAL SYSTEM

In this section, we present design models of a distributed sociotechnical system for the problem domain that was analyzed in Section 3. The design of a sociotechnical system is guided by AOM model types under the three viewpoint aspects of platform-independent design – interaction, information and behaviour – described in Table 1. As introduced in Section 2, the sociotechnical system to be designed consists of both man-made and human agents. The latter are people such as physician, biomedical scientist, and nurse found in any healthcare institution, while man-made agents are intelligent digital assistants implemented in software that can run on hand-held devices for the purpose of executing some or all of the responsibilities of the roles of the sociotechnical system. An intelligent

digital assistant normally interacts with the corresponding human agent. For example, the intelligent digital assistant of a physician interacts with the physician when performing the Physician role in the sociotechnical system. The decision on mapping system roles to human agents or/and man-made agents is documented by agent models, while the design of interaction pathways between agents of the decided types is captured by the agent acquaintance model.

Figure 3 represents a merged agent model and the agent acquaintance model. According to the model depicted in Figure 3, some responsibilities of the roles Biomedical scientist and Physician of the sociotechnical system are carried out by man-made agents of the type Laboratory Intelligent Assistant and Physician Intelligent Assistant, respectively, while the responsibilities of the patient role are executed by man-made agent of the type Patient Intelligent Assistant. The responsibilities of the role Patient that the patient intelligent assistant has to fulfil include identifying the patient location and communicating the location information to the laboratory intelligent assistant. The remaining responsibilities of the system roles are then carried out by human agents playing the roles of Physician, Biomedical scientist, and Nurse. With the combination of agent models and agent acquaintance model, we have decided the backbone of the socio-technical system. Figure 3 also represents interaction pathways between decided agent types.

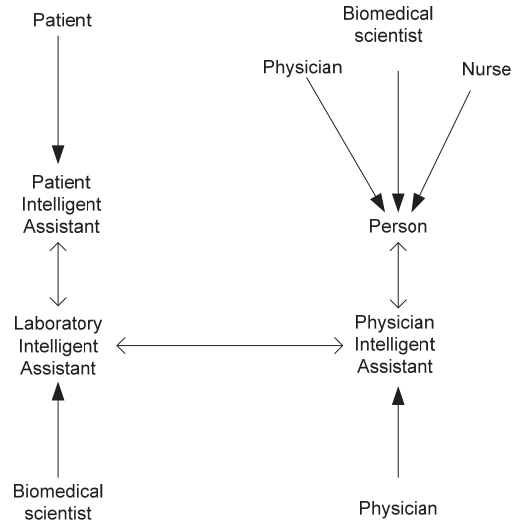

Figure 3: A merged agent and acquaintance model.

In order for an agent to autonomously and intelligently respond to events originating in its environment or in other agents, a set of rules is normally created, presenting the agent's behaviours. Together with the information about specialty, medical knowledge and location of physicians and other healthcare professionals, which is stored in the sociotechnical system, behaviour model for each of involved man-made agents needs to be designed.

The behaviour model of agents of the type Laboratory Intelligent Assistant contains rules that provide agents with capabilities to proactively suggest appropriate choice of an alternative physician. For instance, in cases when the responsible physician leaves the healthcare premises or the responsible physician is located at a significant distance from the patient of interest, this information is instantly updated in the system. After completion of the updating process, the AI reasoning techniques of abduction (Kakas et al., 1992) and and/or deduction may be used to proactively assign

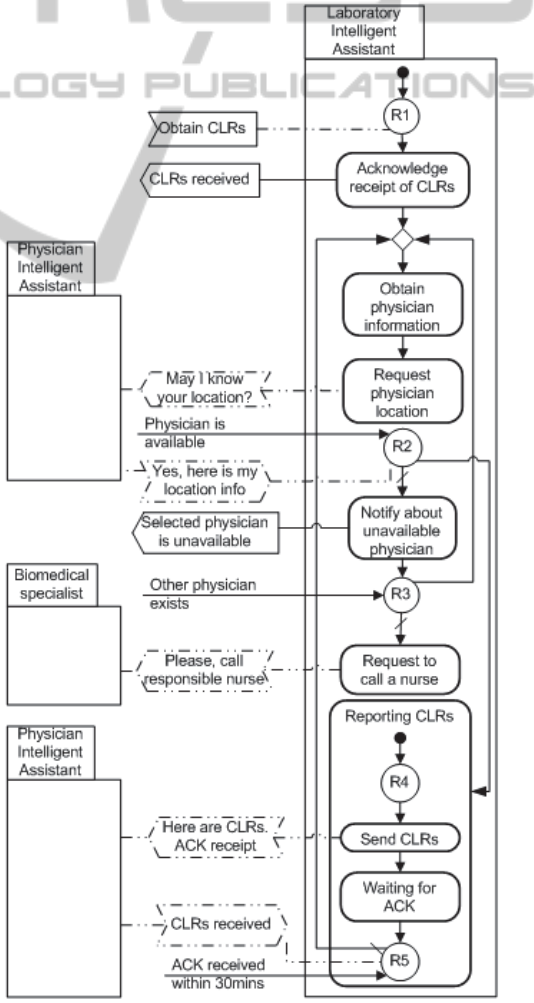

Figure 4: Agent behaviour model of a laboratory intelligent assistant.

the responsibilities of the responsible physician to another physician who is most appropriate at the given time without any intervention by humans. In some rare cases when the laboratory intelligent assistant is not able to suggest an appropriate physician, it proactively alerts a biomedical scientist to call a departmental nurse, following the current procedure of reporting CLRs.

Behaviour models enable both proactive and reactive behaviours of agents in the sociotechnical system to be captured. Figure 4 represents the behaviour model of an agent of the type Laboratory Intelligent Assistant. Figure 4 models a proactive behaviour of a laboratory intelligent assistant, where a message of the type "May I know your location?" is sent to the appropriate physician intelligent assistant. Checking the availability of another appropriate physician is modelled with the help of rule R3. This rule R3 is triggered by the unavailability of the responsible physician, which is computed from the values of knowledge items embedded in the database of the sociotechnical system. As an example of reactive behaviour, an activity of type "Acknowledge receipt of CLRs" in figure 4 is triggered by rule R1 after obtaining detected and confirmed CLRs from PSM. The corresponding event "Obtain CLRs" is modelled as a non-action event originating in the environment.

5 RELATED WORK

Over many years different kinds of studies and researches across the world have been conducted in the area of managing CLRs (Shabot et al., 1990); (Tate et al., 1995); (Kuperman et al., 1996); (Iordache et al., 2001); (Poon et al., 2002); (Park et al., 2008); (Guidi et al., 2009); (Bromuri et al., 2011). Among the objectives of this paper is analyzing the procedures suggested by different studies for reporting CLRs to caregivers. In the study conducted at Taipei Veterans' General Hospital (Chen et al., 2002), physicians received CLRs, while the study at the LDH hospital (Tate et al., 1995) suggested and used nurses as appropriate caregivers to receive CLRs. At Brigham and Women's Hospital (Kuperman et al., 1996), the list of appropriate staff to receive CLRs included telephone operators who have little medical knowledge but who are always available. When CLRs were received by telephone operators, they manually identified appropriate caregiver according to their knowledge and thereafter made telephone calls to inform about the CLRs. When comparing these three studies (Tate et al., 1995); (Kuperman et al., 1996); (Chen et al., 2002) and considering advanced mobile technologies that facilitate location identification, real-time interactions, and advanced ways of knowledge management, we recommend physicians as appropriate choice of caregivers for receiving CLRs due to the need of prompt treatment or decision on medication.

Although we recommended physicians as appropriate choice of caregivers for receiving CLRs, the major challenge here is working out selection mechanisms for identifying the physician. We have suggested three main factors that are expected to lead to a better choice of a physician to receive CLRs. Firstly a physician should have sufficient medical knowledge. This is due to noticeable knowledge variations between different levels of a physician, from interns to experts. The second feature is medical specialty. There are many specialties in a healthcare domain, such as haematology, gynaecology, and paediatrics. This suggests that CLRs detected from pregnant woman are more meaningful and can be efficiently utilized when reported to gynaecologists rather than other types of specialized physicians. The third feature is the availability of a physician. The availability feature was also discussed in the study conducted by Dighe et al. (2006). In that study, the response time of a physician concerning Intensive Care Unit (ICU) patients with CLRs was much lower than that for non-ICU patients. This was because the availability of a physician is guaranteed for ICU patients, while the case is different for non-ICU patients. Following this observation, Dighe et al. (2006) recommended more research work on the ways for reducing response time to CLRs for non-ICU patients.

6 CONCLUSIONS AND FUTURE WORK

We have addressed the ways of improving the mechanisms for reporting CLRs to appropriate caregivers after being detected in the medical laboratory. The distributed nature of the problem domain together with the need of designing software systems that would be intertwined with social processes motivated the choice of AOM (Sterling and Taveter, 2009) as a suitable approach for the analysis of the problem domain and design of an appropriate sociotechnical system. We also recommended physicians as the best choice among caregivers for receiving CLRs because of the need

for prompt treatment or decision on medication. In this article, three main features for choosing appropriate physicians were suggested, discussed, and presented as quality goals in the goal model – specialty, medical knowledge, and availability. The problem domain was further analysed by means of the domain model of AOM. The domain model was used to capture the knowledge handled by the sociotechnical system.

In Section 3, we conducted the analysis of the problem domain by means of AOM analysis models. In Section 4, the design of the sociotechnical system was presented and related to the outcomes of the domain analysis discussed in Section 3. In particular, an agent and acquaintance model was used for mapping the domain roles to human agents as well as to the types of man-made agents and for identifying interaction pathways between the agents. This was followed by discussing the modelling of proactive and reactive behaviours of agents, which we illustrated by an agent behaviour model of the laboratory intelligent assistant.

With the ultimate goal of introducing a distributed sociotechnical system for reporting CLRs, we have categorized the future work into three main phases. Firstly, we will improve the behaviour model presented in Section 4 by applying abduction (Kakas et al., 1992) and/or deduction AI reasoning techniques that optimize information about specialty, medical knowledge, and availability for choosing an appropriate physician. Secondly, the prototype of a sociotechnical system consisting of intelligent digital assistants suggested in this paper will be developed. Finally, the issues related to the interoperability of healthcare systems will be considered due to the need of integrating the proposed sociotechnical system with the existing healthcare systems.

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REFERENCES

Bresciani, P., Perini, A., Giorgini, P., Giunchiglia, F. and Mylopoulos, J., 2004. Tropos: An agent-oriented software development methodology. Autonomous Agents and Multi-Agent Systems, 8(3), pp.203–236.

Bromuri, S., Schumacher, M. I., Stathis, K. and Ruiz, J., 2011. Monitoring gestational diabetes mellitus with cognitive agents and agent environments. In Proceedings of the 2011 IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology-Volume 02. pp. 409–414.

Chen, H. T., Ma, W. C. & others, 2002. Design and implementation of a real-time clinical alerting system for intensive care unit. In Proceedings of the AMIA Symposium. p. 131.

Dighe, A. S., Rao, A., Coakley, A. B., Lewandrowski, K. B., 2006. Analysis of laboratory critical value reporting at a large academic medical center. American journal of clinical pathology, 125(5), pp.758–764.

Guidi, G. C., Poli, G., Bassi, A., Giobelli, L., Benetollo, P. P. and Lippi, G., 2009. Development and implementation of an automatic system for verification, validation and delivery of laboratory test results. Clinical Chemistry and Laboratory Medicine, 47(11), pp.1355–1360.

Hanna, D., Griswold, P., Leape, L. L., Bates, D. W., 2005. Communicating critical test results: safe practice recommendations. Joint Commission Journal on Quality and Patient Safety, 31(2), pp.68–80.

Hellström, J. & Tröften, P. E., 2010. The innovative use of mobile applications in East Africa, Swedish international development cooperation agency (Sida).

Iordache, S. D., Orso, D. and Zelingher, J., 2001. A comprehensive computerized critical laboratory results alerting system for ambulatory and hospitalized patients. Studies in health technology and informatics, (1), pp.469–473

Kakas, A. C., Kowalski, R. A. and Toni, F., 1992. "Abductive logic programming," J. Log. Comput., vol. 2, no. 6, pp. 719–770,1992.

Kuperman, G. J., Teich, J.M., Bates, D. W., Hiltz, F.L., Hurley, J. M., Lee, R. Y., Paterno, M. D., 1996. Detecting alerts, notifying the physician, and offering action items: a comprehensive alerting system. In Proceedings of the AMIA Annual Fall Symposium. p. 704.

Kuperman, G. J., Boyle, D., Jha, A., Rittenberg, E., Ma'Luf, N., Tanasijevic, M. J., Teich, J. M., Winkelman, J., Bates, D.W., 1998. How promptly are inpatients treated for critical laboratory results?, Am Med Inform Assoc.

North Estonia Medical Centre, Information. Available at: http://www.regionaalhaigla.ee/?op=body&id=180 [Accessed October 23, 2012].

Padgham, L. & Winikoff, M., 2003. Prometheus: a methodology for developing intelligent agents. Agent-oriented software engineering III, pp.174–185.

Park, H. I., Min, W. K., Lee, W., Park, H., Park, C. J., Chi, H. S. and Chun. S., 2008. Evaluating the short message service alerting system for critical value notification via PDA telephones. Annals of Clinical &

Laboratory Science, 38(2), pp.149–156.
Poon, E. G., Kuperman, G. J., Fiskio, J., Bates, D. W., 2002. Real-time notification of laboratory data requested by users through alphanumeric pagers, Am Med Inform Assoc.
Shabot, M. M., LoBue, M., Leyerle, B. J., Dubin, S. B., 1990. Decision support alerts for clinical laboratory and blood gas data. Journal of Clinical Monitoring and Computing, 7(1), 27–31.
Sterling, L. & Taveter, K., 2009. The art of agent-oriented modeling, Mit Pr.
Tate, K. E., Gardner, R. M. & Scherting, K., 1995. Nurses, pagers, and patient-specific criteria: three keys to improved critical value reporting. In Proceedings of the Annual Symposium on Computer Application in Medical Care. p. 164.
Wood, M. & DeLoach, S., 2001. An overview of the multiagent systems engineering methodology. In Agent-Oriented Software Engineering. pp. 1–53.