Clinical decision support: distance-based, and subgroup-discovery methods in intensive care
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Chapter 6. DECISION SUPPORT TELEMEDICINE SYSTEMS: A CONCEPTUAL MODEL AND REUSABLE TEMPLATES


Barry Nannings, Ameen Abu-Hanna
6.1. Abstract

6.1.1 Objective

Decision support telemedicine systems (DSTSs) are systems combining elements from telemedicine and clinical decision support systems (CDSSs). Although emerging more strongly these days, these types of systems have not been given much attention in the literature. Our objective is to define the term DSTS, to propose a general DSTS model, and to propose model-based templates to aid DSTS development for three medical tasks.

6.1.2 Materials and methods

The definition, general model and model-based templates are based on a systematic literature search. To build the model we use UML (Unified Modeling Language) class models. The models were supplemented by class-attributes stemming from a recently suggested set of DSTS characterizing properties. We tested the applicability of the templates to new DSTSs found in a separate limited literature search.

6.1.3 Results

We provide a definition of DSTS, propose a conceptual model for understanding DSTSs and synthesize a set of reusable templates, and examples for using them. The templates are shown to be relevant and are likely useful for modeling new systems.

6.1.4 Conclusion

Our definition combines and harmonizes the various existing definitions. The conceptual model and the reusable modeling templates are demonstrated to be useful in understanding and modeling DSTSs during the early stages of their development.
6.2. Introduction

In response to information overload, data overload and problems pertaining to communication between health providers, healthcare has witnessed the emergence of promising information communication technology we call decision support telemedicine systems (DSTSs). DSTSs are a hybrid of telemedicine and clinical decision support systems (CDSSs). Telemedicine is exemplified by tasks such as telemonitoring and telediagnosis. Continuous improvements in techniques for data capturing, recording, communication, and data accessibility, boost the usability of telemedicine. Examples of CDSSs are systems aiding with diagnosis and systems that generate drug-interaction alerts [1]. Especially decision support based on clinical guidelines is receiving increased attention due to the recent focus on Evidence-Based Medicine. A hybrid system that conveys information of patients at home to a monitoring center and provides support in interpreting and making decisions about the monitored information is an example of a DSTS.

Software development in various domains is facilitated by using frameworks, conceptual models, templates, patterns, reference models, and standards that serve as blueprints to understand the domain, develop software components, and denote agreements about representation and communication. In this light the development of standards such as Health Level 7 Reference Information Model (RIM) [2] and European Committee for Standardization (CEN being the French acronym) pre-standard ENV (which stands for EuroNorm, Vornorm, meaning a pre-standard) 13606 [3] and the modeling framework initiative Three-layer Graph-based meta model (3LGM²) [4,5] are examples of efforts in health care that are aimed at facilitating a systematic approach to software development in health care.

The examples above concern efforts aimed at the development of software for general use in health care. In this paper we aim at providing a conceptual model which is specific to the family of DSTS applications. In particular, we focus on the anatomy of these systems: the identification and separation of the parts of such a system in order to ascertain its structure and the relations between its parts. Our model can be used in conjunction with the other, more general approaches in the sense that it provides the specific contents, or ontology, describing the DSTS.

6.3. Materials and methods

6.3.1 Literature search

We performed a systematic literature search, focusing on both telemedicine and CDSSs. We used the Ovid search engine to perform a search on Medline (1966-May 2004), Embase (1980-May 2004) and Cinahl (1982-May 2004). The search was restricted to articles in English-language journals. The keywords used were: ‘decision support’, ‘expert system’, ‘telemedicine’, ‘telehealth’, ‘e-health’, ‘review’, ‘overview’ and ‘framework’. We used Medical Subject Headings whenever possible. A total of 1584
studies were identified. Then, based on the titles and abstracts, we applied the following inclusion criteria:

- Articles should address telemedicine, CDSSs or both topics.
- Articles should be (systematic or non-systematic) reviews or overviews, or contain frameworks to describe them.
- Articles should not be limited to one specific system.

Application of these criteria resulted in the inclusion of 65 full-text articles in our study. While reviewing the literature, special attention was paid to definitions, models, and conceptual frameworks. More information about the search queries and the articles included can be requested from the authors.

6.3.2 Developing a conceptual model and modeling templates

To construct the conceptual model pertaining to the anatomy of these systems, we first derived relevant concepts encountered in the literature. As an example we show the concepts that were extracted from the article Teledermatology: a review, by D.J. Eedy and R. Wootton [6]. This article presents a review of teledermatology contrasting the real-time with the store-and-forward mode of communication. The article compares these two forms with respect to diagnostic accuracy, equipment, patient and physician satisfaction, cost-effectiveness and issues such as security and privacy. Anatomical concepts that were frequently mentioned in this article were: agents (patients, medical specialists and general practitioners) and their sites, data being transferred (images, video), data capture/review/storage equipment (camera, monitor, CD-ROMs), data editing software, the network being used, the medical setting (dermatology and radiology) and tasks performed in this setting (diagnosis, management and education). This kind of general concept extraction was performed for each of the 65 selected papers. The final selection of concepts to include in the models was based on the frequency of their occurrence in the papers we included.

We then created UML class-models to represent a general DSTS and the task-specific templates, drawing the classes from the anatomical concepts that were extracted from the literature. We chose UML as this is the de facto standard for modeling architectures and complex processes in the database and software engineering communities. We have added attributes to these classes originating from a set of DSTS characteristics that we have identified in [7]. In [7] a list of characterizing properties of DSTSs was presented that can be used for typing, classifying and clustering these systems. Examples of such characteristics are adviceMode, having the values ‘suggestive’ and ‘critiquing’ specifying the mode of giving advice in the decision support component, and synchronicity having values ‘real time’ and ‘store-and-forward’ describing how entities inter-communicate. Reusable templates were then defined as groups of cohesive classes in the conceptual model, including default or typical attribute values. Templates correspond to specific medical tasks, such as monitoring, and can be reused in various medical specialties.
Templates were validated by applying them to model DSTS descriptions we encountered in a new separate literature search. This limited search was based on abstracts and titles in the latest issues of the Journal of Telemedicine and Telecare (June 2004 to September 2005) and resulted in two papers about DSTSs related to prevention and two about DSTSs related to monitoring [8-11].

6.4. Results

6.4.1 Definitions

The definitions of Telemedicine (see Table 1) were not mutually consistent in the literature, for example regarding the medical task that is facilitated.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition of telemedicine</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC DG XIII, Research and Technology Development on Telematics Systems in Health Care [12]</td>
<td>Rapid access to shared and remote medical expertise by means of telecommunications and information technologies, no matter where the patient or the relevant information is located.</td>
</tr>
<tr>
<td>Coiera [13]</td>
<td>The exchange of information at a distance, whether that information is voice, an image, elements of a medical record, or commands to a surgical robot. It seems reasonable to think of telemedicine as the remote communication of information to facilitate clinical care.</td>
</tr>
<tr>
<td>The World Health Organization [15]</td>
<td>The delivery of healthcare services, where distance is a critical factor, by healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, and for the continuing education of healthcare providers as well as research and evaluation, all in the interest of advancing the health of individuals and their communities.</td>
</tr>
<tr>
<td>Ried [16]</td>
<td>Including the use of telecommunication technology to exchange health information which provides access to health care across time, social and cultural barriers.</td>
</tr>
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Table 1. Definitions of telemedicine

We harmonized these definitions into one addressing the what, who, how, and why questions relating to telemedicine: “A process involving the remote communication of medical information by health care professionals and/or patients, using any electronic
medium to facilitate clinical care”. We further specify that the term ‘remote’ implies crossing geographical or organizational boundaries. In some cases one may wish to extend upon this specification of the term remote by considering issues such as responsibility, intellectual property rights, and legal issues.

As in the case of telemedicine, definitions of Clinical Decision Support also include recurring elements, but are not mutually consistent (see Table 2) for example regarding the case specificity of the advice. Using the same structure of definition as used for defining telemedicine, we define a CDSS in this paper as: “Any computer-based system providing problem-specific output that aids health care professionals and or patients in decision-making”. It is worth noting that this definition differs from that of Shortliffe [18] in two respects: we exclude systems providing a very general level of support such as simple text-editors, and we include patients as users of a CDSS.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition of Clinical Decision Support System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortliffe [18]</td>
<td>Any computer program designed to help health professionals make clinical decisions.</td>
</tr>
<tr>
<td>Wyatt and Spiegelhalter [19]</td>
<td>Active knowledge systems which use two or more items of patient data to generate case-specific advice.</td>
</tr>
<tr>
<td>Wyatt [20]</td>
<td>A computer program that provides reminders, advice or interpretation specific to a given patient at a particular time.</td>
</tr>
<tr>
<td>Musen [21]</td>
<td>Any piece of software that takes as input information about a clinical situation and that produces as output inferences that can assist practitioners in their decision making and that would be judged as “intelligent” by the programs’ users.</td>
</tr>
</tbody>
</table>

Table 2. Definitions for Clinical Decision Support System.

Based on the definitions above, we define a DSTS as: “A computer-based system aiding health care professionals and patients in making decisions by providing problem-specific advice involving the remote communication of medical information.” A further specification of the term ‘remote’ was given above.

6.4.2 General model

The conceptual model for DSTSs appears in Fig. 1. The attributes of the classes stem from the characterizing property set for DSTSs that we suggested in [7].
Figure 1. Conceptual model of decision support telemedicine systems.

The class DSTS appears at the top of Fig. 1. A DSTS is associated with a specific (medical) setting and incorporates at least a network and one CDSS, this is shown using the UML cardinality notation. Cardinality belonging to a relationship between classes A and B expresses a constraint on the number of objects from class A that can be associated with objects in class B. For example consider the relationship has between Network and Interface in Fig. 1, the notation 2..* at the Interface end means that a network has at least two interfaces. The Network class represents the set of physical connections that are used in the DSTS. Note that a network can consist of other (sub) networks. This recursive relation allows for a clear distinction between different types of networks within a specific DSTS. An example is a network that is used for exchanging e-mail between healthcare practitioners and a network that is used for teleconferencing between healthcare practitioners and patients within one DSTS.

The Host class is connected to the network using a network interface and is used to represent devices such as workstations and servers but also devices such as mobile phones or faxes. Examples of network interfaces are a modem and a network interface card. When an agent using the host is a human agent, an Input/Output device (I/ODevice) is used to transfer information between the host and the human agent. Examples of I/O devices are a keyboard, a screen, and a mouse. When agents communicate with each other using messages, a connection (a specific part of the network) is reserved for them. A connection is represented by the association class Connection. It should be noted that the class: Message could be further specialized into classes such as Advice and Information when this is deemed useful. Hosts and agents can have a data resource or a data-capture device at their disposal. Examples of data

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1 This part-of relationship, which denotes aggregation, is represented in UML by a link with a small diamond attached to the aggregate class.
resources are databases containing patient information, while digital cameras and blood-glucose measurement devices are examples of data-capture devices.

The Agent class is specialized into three classes: HumanAgent, CDSS, and their aggregate HumanAgentAndCDSS\(^2\). The HumanAgent class is specialized into patient and medical professional, and can be extended to other types of users. The class CDSS is modeled as an aggregate of components for reasoning and storing knowledge. About half of the classes contain properties from the characterizing property list of earlier work [7].

6.4.3 Templates

We propose reusable templates corresponding to three important medical tasks: prevention, diagnosis, and monitoring. A template is essentially a selection of classes and their inter-relationships from the conceptual model. In addition, some of the class attributes have been set to default values that are specific for the respective type of DSTS.

**Prevention DSTS template**

Prevention DSTSs share a number of important traits. They are usually publicly available through the Internet, for example from the patient’s home and passive (rather than proactive) needing to be prompted for advice. They often provide suggestive feedback after having the user’s input but prior to the user making a decision, and thus are not critiquing systems. The communication with the system is usually asynchronous (store-and-forward).

The diagram in Figure 2 shows the prevention template. It consists of 11 classes from the conceptual model. Classes have been given new names where this clarified the template followed by the original class names between parentheses. Some attributes have been given default values. The prevention DSTS template essentially consists of a network linking an autonomous decision support tool for prevention purposes with a ‘patient user’ who can be located anywhere.

Prevention covers triaging, as exemplified by the National Health Service Direct Online [22], and patient education, as exemplified by the website of the Mayo clinic providing online CDSSs such as a heart-disease calculator [23]. In the case of the Mayo heart-disease risk calculator, the HumanAgent class of Fig. 2 is instantiated by the person visiting the website. Through a keyboard, mouse and monitor (I/O Devices) this consumer interacts with his or her PC (ClientPC). A NetworkInterfaceCard connects the consumer’s computer to the Internet, and to the Webserver hosting the heart-disease calculator Clinical Decision Support System (PreventionCDSS). Based on information supplied by the consumer, the heart-disease risk calculator provides an estimate of risk of heart-disease and sends this back to the consumer immediately. For a review of public prevention DSTSs see [24].

\(^2\) Specialization is denoted in UML by an open-headed arrow.
Diagnosis DSTS template

We expect most diagnostic DSTSs to be introduced in ‘visual’ medical specialties such as dermatology and radiology, and therefore the data-type of the images that are sent will be mostly still images, although video clips could also be added, and the mode of communication is mostly store-and-forward. Compared to prevention DSTSs, the users of the systems are more likely to be medical experts situated in care settings such as a hospital or a general practice. These systems often provide suggestive advice to support expert decision-making although critiquing systems can also be employed.

The diagnostic template is shown in Figure 3. It consists of a network linking two medical experts, one in the role of a medical specialist requiring advice, and the other in the role of consultant, having access to a diagnostic CDSS.

Figure 3. Template for diagnosis DSTSs.
An example of a diagnostic DSTS is a system in which a general practitioner (HumanAgent, class appearing at the right side of Fig. 3) sends electronic images of a patient’s skin suspected of having a melanoma (Message), that the general practitioner captured using a digital camera, (DataCaptureDevice) to a dermatologist (HumanAgent, class appearing at the left side of Fig. 3) using a PC (I/O Devices, ClientPC and NetworkInterfaceCard) which is connected to the Internet. The dermatologist can view these images using his or her PC which is also connected to the Internet. The dermatologist analyzes these images using a CDSS (DiagnosisCDSS). This system performs automatic image analysis to augment certain features in the images to help the dermatologist to reach a conclusion about the state of the patient. The dermatologist then provides the general practitioner with feedback. E.g. the general practitioner can provide care to the patient, or refer him or her to the dermatologist.

Monitoring DSTS template

Monitoring DSTSs usually link the home of the patient and a site where the patient data is monitored, such as a hospital or a monitoring centre. In some cases these kinds of systems bridge multiple hospitals varying in their specialization as exemplified in some intensive care units [33,34]. Monitoring DSTSs can be described as being active, providing alerts at any time. This can be contrasted with the relative passivity of the prevention and diagnosis DSTSs. Both synchronous and asynchronous communication forms are encountered.

The template shown in Figure 4 represents a DSTS in which a patient is being monitored by a data capture device. The data are then sent to a remote monitoring center for analysis by a CDSS. If there is reason for alarm, an alert is generated to trigger problem-solving actions.
An example of a monitoring DSTS is one in which a patient with risk of cardiac failure (HumanAgent, appearing at the right side of Fig. 4) is monitored using a portable ECG device (DataCaptureDevice) that sends its data via the patient’s PC (I/O Devices, ClientPC and NetworkInterfaceCard), over the Internet to a Webserver, hosting monitoring software (MonitoringCDSS). The data is stored in a database (DataResource) and is automatically monitored by the monitoring software (MonitoringCDSS) for abnormalities. In the case of abnormal data, the software alerts a local medical specialist (HumanAgent, class appearing at the left side of Fig. 4). This medical specialist can then take actions as required. Another example is a system in which elderly people are monitored by a camera of which the images are analyzed by a Decision Support System (DSS) to detect fall accidents. Currently numerous remote sensing devices are commercially available such as electronic stethoscopes, electronic blood pressure monitors and pulse oximeters [25]. For a review of monitoring DSTSs see [26].

6.4.4 External validation of templates

To validate the templates we applied them to DSTSs encountered in a separate limited literature search. This search yielded two articles related to prevention DSTSs and two articles related to monitoring DSTSs (we did not encounter diagnostic DSTSs). The first article about prevention DSTSs concerns so called interactive health communication applications for chronically diseased patients, which are information packages offering at least one interactive component such as peer support, decision support, and behavior change support [8]. The second article is about what is referred to as web-based wellness management programs [9]. The first article about monitoring DSTSs is about a system performing automated fall detection [10], whereas the second one is about remote monitoring of diabetic patients [11].

For the prevention DSTSs the explicit architecture of the systems was not described, although they are web-based systems and thus are likely to fit the prevention DSTS template we propose. As a rule, all the values of properties reported in the articles did indeed match those in the template, but some important properties which appear in the template are left unreported in the article. The system described in [9] formed an exception to the rule, as it reports on active reminders sent to the patients, in contrast to the passive advice mode as suggested in the template. For the monitoring DSTSs, the architectures matched our monitoring template fairly well. In the case of the remote fall detection however, the decision support component of the system is (for reasons of privacy) located at the patient’s home, whereas in our template this component resides on a remote server and is linked to the patient’s home using a network. In the diabetes management DSTS the architecture specifically contains a database at the monitoring centre. Although this is not part of our template, it is part of the conceptual model, and adding it to our template is straightforward. Also the characteristics described as typical for monitoring DSTSs turned out to be correct.
Through provision of classes, their relations and attribute values, this modeling exercise demonstrates that our templates would be of aid during the analysis and preliminary design of these systems prior to their implementation, since the concepts that were needed in the template, were readily available in the general DSTS model of Figure 1. In addition, the templates helped us pose important questions about the systems being described. In the article about the remote fall detection for instance, little is mentioned about the mode of communication. An example of an important question resulting from use of the template would be: “what kind of communication technology will the system use to relay the alerts to the monitoring center?” In the articles about prevention little is mentioned about the specifics of the decision support that is used. An example of a question arising from the template is: “In what way is decision support delivered, will it be a suggesting or critiquing system?” Although this was not the focus of the article, these issues do become important during the development of such a system.

6.5. Discussion

Decision support telemedicine systems (DSTSs) represent an emerging important technology that is expected to expand rapidly. Information overload, data overload, and problems pertaining to communication between health providers trigger the need for such systems. Moreover, there is a continuous improvement of electronic recording facilitation, data integration, and the accessibility of the resulting data. Finally, the advent of evidence-based medicine is likely to give an impetus for decision support techniques like guideline-based expert systems and data mining-based interpretation techniques. We believe that the provision of conceptual models pertaining to DSTSs contributes towards their understanding and development within the discipline of telemedicine and medical informatics in general. We are unaware of such models in the literature. In this paper we propose three new extensible conceptual components to enhance the understanding of decision support telemedicine systems and their development: a definition of a DSTS, a conceptual model thereof, and model-based templates for three types of DSTSs. The models have been validated and demonstrated to be usable and useful.

Our approach builds on and is consistent with existing CDSSs and telemedicine conceptual models. In particular it selectively merges both into one conceptual model and defines model-based templates to describe DSTSs. As for existing general frameworks for developing medical information systems, such as the modeling framework initiative 3LGM² [4,5], our models are not meant to replace them but rather to be used in conjunction with them: our models contribute a DSTS-specific ontology, that is e.g. not yet part of 3LGM². Some limitations of our work include the following. We included only review articles in our literature search and it is possible that we missed some other relevant articles. Moreover, the selection of the classes to be included in the conceptual model is necessarily partially subjective but we believe that the conceptual model is robust.

Our validation efforts do provide insight into the usability and usefulness of the model-
based templates and the conceptual model but we did not externally validate diagnostic DSTSs. Besides, these efforts are preliminary as we have used only a small number of validation cases.

The most important further work includes a more extensive validation effort, the examination of other kinds of templates, and using the framework to detect decision-support opportunities to be integrated within existing “pure” Telemedicine systems.

In conclusion, we believe that the proposed conceptual components in this paper are usable and useful for attaining a better insight into DSTSs and of getting an initial design thereof. The models are useful because they allowed us to formulate the important characteristics of DSTSs we found in the literature and, as reference models, allow the researcher, developer, and user to pose relevant questions about DSTSs. The models are usable because the template-based formulation process of a DSTS was straightforward: all major classes needed to express the design were already in the model, and the selection of the correct class was easily facilitated by the distinct functionalities provided by the individual classes.

6.6. Acknowledgements

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6.7. References


