Computerized decision support to improve guideline implementation in cardiac rehabilitation: the CARDSS project
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Chapter 3

Development of a guideline-based decision support system with explanation facilities for outpatient therapy


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Abstract

For effective guideline implementation it is recommended to develop and apply carefully designed implementation strategies and instruments. Computerized decision support systems (CDSSs) are such instruments as they can improve guideline adherence by providing advice at the point of care. To improve the implementation of the Dutch cardiac rehabilitation guidelines a CDSS, named CARDSS, was developed. CARDSS actively provides care professionals with patient-specific, guideline-based treatment recommendations at the onset of a patient’s rehabilitation trajectory. To maximize the chances of acceptance, CARDSS also provides explanation facilities and other additional information management services, and takes the working procedures specific to multidisciplinary outpatient care into account. CARDSS is currently used in over 40 Dutch cardiac rehabilitation outpatient clinics. This paper describes the development of the CARDSS system. In particular, technical issues are discussed concerning the delivery of active decision support, and the provision of advice rationales to users while taking account of dynamic clinical contexts and changing guidelines.
Introduction

Although clinical practice guidelines propagate best practices for specific healthcare conditions [1], adherence to guidelines in clinical practice is often low [2]. Apparently, it is not sufficient to provide care professionals with paper guidelines to enforce the required change in practice. For this reason, several authors have argued that effective guideline implementation requires that a carefully designed implementation strategy be followed [3;4]. One such strategy that has been advocated in the literature is the deployment of a computerized decision support system (CDSS) that provides advice to care professionals based on the guideline’s recommendations. Systematic reviews have shown that these CDSSs can improve guideline adherence [5;6].

The scientific literature discusses various aspects of guideline-based CDSS development. First, the paper guideline has to be translated into a computer-readable format in order to provide computerized guideline-based decision support [7], a process called guideline formalization. Second, design aspects of the CDSS should be carefully considered as several CDSS characteristics have shown to significantly contribute to their success [5;8]. These include providing decision support to professionals automatically, integration of the CDSS with other information systems, and provision of advice at the time and location of decision making. In addition, CDSS developers should consider letting the CDSS provide additional information management services, including providing professionals with the recommendation rationales and scientific foundations [8;9]. Finally, CDSSs should be optimally integrated into the existing working procedures of healthcare professionals which requires considering domain and application specific issues [9].

Many studies have focussed on the effects of guideline-based CDSSs on guideline adherence and patient outcomes [5]. However, success factors of CDSSs are still poorly understood [5;8-10], partly because descriptions of these systems are scarce. The literature has therefore called for a better reporting of design and development aspects of CDSSs [8].

This paper describes the development of an electronic patient information system with a CDSS for cardiac rehabilitation, named CARDSS (CArdiac Rehabilitation Decision Support System). Cardiac rehabilitation is a multidisciplinary outpatient therapy for patients that suffered a cardiac incident (e.g., myocardial infarction or cardiac surgery). The therapy aims to favourably influence the cause of disease, and to ensure that patients are in the best possible physical, psychological and social position to return to their normal place in society [11]. CARDSS was developed concurrently with a revision of the Dutch national guidelines for cardiac rehabilitation [12], with the aim to improve the implementation of these guidelines in clinical practice. It comprises a guideline-based CDSS that automatically provides guideline-based
treatment recommendations to professionals at the onset of a patient’s cardiac rehabilitation trajectory. Specific attention is spent to the design and realization of explanation facilities, needed to support the decision making during weekly multidisciplinary team meetings. CARDSS can provide its users with advice rationales that remain consistent when clinical data or guidelines have changed.

This paper is organized as follows. The next section provides a review of the literature on the development, architecture and success factors of guideline-based CDSSs. Section 3 discusses the principle design considerations for CARDSS, while section 4 provides a description of its architecture and functionalities. The current status of CARDSS’ implementation is described in section 5, followed by a discussion of the lessons learned from this project. Finally our plans for further research are described.

Background

Guideline formalization

One particular challenge in contemporary medical informatics is to foster adherence to practice guidelines by providing guideline-based computerized decision support at the point of care. To this end, the guideline in question must be translated into a computer-interpretable form that can serve as the knowledge base of a CDSS [7;13]. Also an associated guideline execution engine that is able to execute and reason with this formalized knowledge, must be deployed [7].

In the last decade, several research groups have developed various guideline-formalization languages such as the Arden Syntax [14], ASBRU [15], GLIF [16], and others [17]. Although all guideline-formalization languages have their own specialties and features, most build on a hierarchy of guidelines and guideline steps (e.g., decisions and actions) that unfold over time, using concepts defined in domain-specific ontologies [18].

Several guideline-formalization languages come equipped with software tools to support the design, realization, and deployment of CDSSs. Examples are the Protégé editor to encode guidelines in GLIF [19] and the GLIF3 execution engine [20]. Moreover, several CDSS-development frameworks exist to support the entire engineering life-cycle of these systems, such as the PROforma [21], SAGE [22], and GASTON [23] frameworks.

Prior to the development of a guideline-based CDSS it should be decided which guideline-formalization language and tools will be used. Developers can develop some components themselves, use a separate guideline-formalization language, guideline modelling tool, and guideline execution engine, or use an existing CDSS-development framework.
Architecture of CDSSs

Generally speaking, if medical CDSSs are introduced in an existing application architecture, they must communicate with a host system and one or more (patient) databases [24;25]. The host system is the front-end application used by healthcare professionals in daily practice, which uses the services the CDSS provides (e.g., a computerized physician order entry (CPOE) system). When introduced in such architecture, the CDSS can operate in several ways. One possible mechanism is that the CDSS is triggered by the host system whenever a user's action requires verification or advice from the CDSS. This does require that the host system is functionally designed to support interaction with an (external) CDSS when necessary. However, there currently exist no communication or interface standards for this purpose and most host systems do not support such interaction [26]. Therefore triggering of the CDSS usually requires the deployment of an event monitor component, which actively monitors one or more clinical databases for the availability of new information that is relevant to the CDSS. However, this solution is inefficient as it leads to unnecessary network and database service utilization.

After the CDSS has been triggered, its recommendations or warnings should be communicated to the appropriate decision makers (e.g., in the case of a drug prescription, the prescribing doctor or pharmacotherapist). One possibility is to let the host system communicate these recommendations or warnings directly to its users. Again, this requires that the host system is functionally designed to accept messages from (external) systems such as a CDSS. However, also standardization on this issue is lacking and this type of functionality is therefore rarely supported by existing host systems. In these situations the use of a notification server is required, which handles the communication of CDSS recommendations to the decision makers through, for example, e-mail, pop-ups, or pager.

CDSS success factors

During the last two decades, a large number of studies have addressed the effects of CDSSs on clinical practice. Systematic reviews found that active CDSSs, which provide unsolicited advice during the end-user's routine working procedures (e.g., while electronically ordering medication), are significantly more effective in improving practitioner performance than passive systems, which require end-users to recognize that consulting the CDSS would be useful [5;8]. In the systematic review by Kawamoto et al. [8], also system function turned out to contribute to effectiveness: therapy recommendations have more clinical impact than diagnostic advice. Also, the provision of decision support at the time and location of decision making, and CDSS
integration into the clinicians’ workflow, have been found to contribute to the success of CDSSs [8;9;13].

In their systematic review on guideline-implementation CDSSs, Shiffman et al. [9] conclude that many factors influence their success or failure, and it is yet unclear which factors are decisive. They however state that, to increase the probability of success, users should be given something of value to compensate for the time required to learn and use the system. To maximize the usefulness of guideline-implementation CDSSs, Shiffman et al. recommend considering the implementation of various information management services [27], including explaining the rationale for guideline topics and recommendations via for example literature citations.

### Design Considerations

To determine the requirements of CARDSS, one of the authors (RG) visited six cardiac rehabilitation outpatient clinics and participated in all meetings of the cardiac rehabilitation guidelines development committee in which requirements for the system were regularly discussed. The information management services described by Shiffman et al. [27] formed the starting point to determine the functional requirements of CARDSS.

As described in §2.3, a CDSS should interact with a front-end application (host system) and patient databases in order to provide patient-specific recommendations to the appropriate decision makers. However, the requirements analysis showed that no information system or database specific to cardiac rehabilitation yet existed in the Netherlands; most centres relied on paper-based or simple electronic (e.g. spreadsheet-based) patient records/registries. This circumstance required that, to implement a CDSS, also a host system a database had to be developed as a part of CARDSS.

Based on the requirements analysis it was decided that, to maximize the chances of acceptance, CARDSS was to support the entire process of cardiac rehabilitation. However, the focus of CARDSS was to support the process of assessing patients’ needs for rehabilitation therapy and to improve adherence to the guidelines at this point. The guidelines describe a needs assessment and therapy indication procedure during which 15 to 40 patient items are assessed, which should be conducted for all cardiac patients two weeks after discharge from the hospital [12]. The needs assessment procedure is either conducted multidisciplinary, or by a single multidisciplinary team member (e.g., rehabilitation nurse, physiotherapist, rehabilitation specialist, dietician, psychologist, and social worker). During the needs assessment procedure, a preliminary therapy plan is formulated. The actual therapy decisions are made during
a weekly multidisciplinary meeting, after which patients start their rehabilitation programme, generally lasting six to sixteen weeks. The effect of therapy on patient recovery is individually assessed at the end of the rehabilitation programme.

**Principal CDSS requirements**

To foster adherence to the needs assessment procedure as described in the guidelines, it was decided to let CARDSS actively guide its users in conducting this procedure through a structured dialogue, prompting the user to enter the required patient information. Before making a decision on a patient’s rehabilitation programme, the CDSS should automatically show the rehabilitation therapies proposed by the guidelines (‘consulting model’, [28]).

It was also decided that, to support multidisciplinary needs assessment, it should be possible to start, interrupt, and continue the CDSS consultation at any time, and by different users. This requires that the status of the needs assessment process of individual patients can be reconstructed by the system. Multidisciplinary CDSS consultation also requires that data is stored on a central database server that is accessible to multiple client systems. However, simultaneous CDSS consultation for the same patient should never lead to inconsistent CDSS recommendations or database inconsistencies.

**Explanation of relevance**

The requirements analysis also pointed out the need to provide users access to relevant guideline sections and literature references during decision making: professionals indicated they are sometimes unaware of the relevance of certain needs assessment tasks, or of how these tasks should be interpreted. Scientific studies have shown that clinical users rarely consult clinical knowledge sources, even though they often have clinical information needs during patient encounters [29]. The reason is that it takes too much time to find the answers. By providing links to context-relevant resources, integrated into clinical information systems (infobuttons), clinical performance can be improved [29;30]. However, the literature on infobuttons mainly focuses on their integration with clinical information systems [29], and does not discuss how such functionalities should be implemented in a guideline-based CDSS.

The implementation of infobuttons in CARDSS first required that the cardiac rehabilitation guidelines were converted to an electronic, linkable format. Second, links to relevant guideline sections for individual guideline steps needed to be included into the CDSS’s knowledge base. Most guideline-formalization approaches allow for doing so, although this issue has received little attention in the literature.
Chapter 3. Development of CARDSS

[18]. Third, the CDSS should be able to communicate the links, relevant to a specific needs assessment topic, to the host-system, which should provide this information to its users upon request. Therefore, a close coupling of the CDSS and the host-system is necessary.

Explanation of rationale

The actual decision making on a patient's therapy plan is made during the multidisciplinary meeting, based on the needs assessment conducted several days before. If the CDSS is to support this multidisciplinary decision making, it should also provide insight into the reasons for recommending particular therapies (i.e. answering the 'how'-question in traditional expert systems). Although it is recognized in the literature that providing such explanation facilities is important for CDSS adoption and guideline implementation [8,31], mechanisms to implement such functionalities are not discussed in the literature. To provide insight into the rationale for a recommendation, the 'chain of guideline steps' resulting in that recommendation needs to be reconstructed. As multiple paths in the guideline can lead to the same recommendation, this is not a trivial matter.

Accounting for changing clinical data

A relatively easy mechanism to reconstruct a recommendation's rationale is to let the CDSS re-execute the guideline, using the patient data available in the database. However, this may lead to inconsistencies if the clinical data underlying the recommendation have changed. In many clinical domains, it is a natural phenomenon that clinical data change over time as most clinical observations and measurements are inherently temporal. To avoid such inconsistencies, it is necessary to store some characteristics of recommendations.

One possibility is to store a recommendation together with its time of generation in a database, which makes it possible to use the original clinical data, underlying the recommendation, to re-execute the guideline and reconstruct the path of the guideline steps. This solution requires little additional data to be stored, but does involve, and places an additional load on, the CDSS’ execution engine.

A second possible method to provide a recommendation’s rationale is to simply store the recommendation and all the guideline steps that led to it. This solution does not require any involvement of the execution engine, and is therefore not affected by dynamic clinical data. However, for this solution more information needs to be stored in the database.
Accounting for changes in guideline content

Another important issue in the development of CDSSs is dealing with changes in guideline content [32]. As evidence from clinical studies accumulates, clinical practice guidelines often need revision in order to ensure that they still reflect the prevailing clinical opinion. When this happens, also the knowledge base of an associated guideline-based CDSS needs to be revised accordingly. Again, by simply re-executing the guideline, such changes in the system may lead to inconsistencies when the rationale of a past recommendation is requested, and the guideline steps on which the recommendation was based have changed. Dealing with this issue also requires that information concerning recommendations is stored.

One solution is to store each recommendation made by the system and the associated guideline version number in a database. Then, when a past recommendation’s rationale is requested by a user, the CDSSs can put the proper version of the formalized guideline into operation and re-execute it. This solution does need to be complemented with a mechanism that accounts for the problem of changing clinical data described in the previous subsection, and also requires that the CDSS’ execution engine is able to manage and reason with different guideline versions.

However, it is also possible to use the second mechanism to provide robust explanation facilities that was proposed in the previous subsection. When we store all recommendations inclusive of their underlying guideline steps in a database, the list of guideline steps underlying a specific recommendation can always be reconstructed, irrespective of whether the formalized guideline was updated: Updating the content of the guideline in the CDSS does not affect the information of the previously generated recommendations stored in the database. Again, this solution does require that more information is stored, but does not require any involvement of the CDSS’ execution engine to reconstruct the recommendation’s rationale.

Although both solutions are equally valid, in CARDSS we decided to implement a mechanism that did not require guideline re-execution, as the tools used to build CARDSS were unable to put different guideline versions concurrently into operation. The implemented mechanism is further explained in section 4.2.4.

Additional information management services

The requirements analysis pointed out that also documentation, registration, and presentation facilities [27] had to be incorporated in CARDSS to increase the chances of a successful adoption of the system by its users. To be able to evaluate progress in patients’ conditions during their rehabilitation programme, longitudinal assessment of patient data needed to be supported as well. Also, cardiac rehabilitation outpatient
clinics should be allowed to locally extend the standard data model with additional clinical or administrative data items, to make CARDSS usable as an electronic patient record. Finally, CARDSS had to support the analysis of group-based statistics related to demographic, cardiac rehabilitation, and guideline adherence information.

**System Description**

**The CARDSS Architecture**

To provide all the required functionalities, CARDSS consists of three different components, namely a CDSS, a host system, and a database. We will refer to the host system as Patient Information Management System (PIMS). The system architecture is shown in Figure 1. The concurrent development of the CDSS, the host system and database, made the development of separate (inefficient) clinical event monitor and notification server components unnecessary. These components would have been required if the CDSS were to communicate with existing host systems and databases in different outpatient clinics.

**CDSS development**

To facilitate the development, maintenance, and implementation of the CDSS, the GASTON CDSS-development framework [23;24] was used. GASTON is a state-of-the-art framework for building decision support systems, and consists of (i) an ontology-based guideline representation language, (ii) a guideline modelling tool that enables guideline authors to formally describe and easily modify practice guidelines visually, and (iii) a guideline execution engine. The designers of the GASTON framework were willing to provide personal assistance in the development of CARDSS.

To facilitate and improve guideline formalization, a medical informatics specialist (RG) participated in all meetings of the cardiac rehabilitation guidelines development committee, and co-authored the flowchart summarizing the needs assessment procedure, that accompanies the guidelines. Concept versions of the guidelines and the flowchart were used to build a domain-ontology in GASTON’s ontology editor. The summary flowchart was used as a basis for the formalization of the needs assessment procedure in GASTON’s knowledge acquisition tool, complemented with information from the written guidelines. Inconsistencies, omissions, or vague concepts that hampered proper formalization of the guidelines were discussed and adjusted during meetings with guideline authors. The resulting knowledge base was implemented in GASTON’s execution engine which together operated as a CDSS.
Figure 1. Architecture of the CARDSS software system. CARDSS consists of a CDSS, the PIMS (Patient Information Management System) host system, and the CARDSS database. The PIMS consists of a user-interface component, a business logic component, a database communication layer, and a CDSS communication layer that manages the communication between the PIMS and the CDSS.

**PIMS development**
The PIMS operates as front-end application that cardiac rehabilitation professionals use to conduct the needs assessment procedure and decide on cardiac rehabilitation therapies for their patients. To let CARDSS support professionals with conducting the needs assessment procedure via a structured dialogue, a direct communication interface between the PIMS and the CDSS was developed in cooperation with the vendor of the GASTON framework.

**CARDSS database development**
In CARDSS, the functionalities of the PIMS and CDSS are tightly interrelated, as it provides decision support to professionals through a structured dialogue. Therefore, we decided to store both clinical and CDSS-related information into a single database. This database consists of 26 tables and needs to be installed on each clinic’s main server machine where CARDSS is used.

**The functionalities of CARDSS**
Figure 2 provides an overview of CARDSS’ functionalities. On the left-hand side of the figure we find the four main functionalities, each of which is decomposed into several
sub-functionalities. CARDSS supports the work of cardiac rehabilitation professionals as follows. At the onset of a patient’s needs assessment procedure, the professional involved launches the CARDSS system and creates a new patient record in the PIMS by entering the patient’s demographic information. Subsequently the professional conducts the needs assessment procedure just like he or she used to, except that all relevant information is now recorded in CARDSS instead of onto paper. Several clinical assessment instruments, such as a quality of life questionnaire, are electronically available in CARDSS. The system automatically calculates and interprets their results. After the needs assessment procedure has been completed, the professional discusses the results with the patient, and records a preliminary rehabilitation plan in CARDSS. A paper report of the needs assessment can be printed.

In the weekly multidisciplinary meeting, the preliminary rehabilitation plan is discussed and a joint decision regarding the plan is made. During these meetings CARDSS can be consulted. The final rehabilitation plan, including the starting dates of the rehabilitation therapies, is subsequently recorded into CARDSS.

During and after the rehabilitation programme, professionals can use CARDSS to evaluate the progress in the patient’s health condition in various ways: by re-assessing his or her quality of life, by assessing the progress with respect to the patient’s rehabilitation goals, and by re-assessing other items added to CARDSS’ standard data model (e.g., heart rate in rest). The results can be visualized in tables and in several types of charts.

Finally, professionals can generate population statistics for a given period, using either self-defined queries or queries defined by an SQL expert, of which the results can be visualized in tables and charts.

Decision support during the needs assessment procedure

Assisting professionals in collecting all patient information relevant to the needs assessment procedure is implemented in CARDSS as follows. When a user initiates (or continues) a needs assessment procedure, the PIMS activates the CDSS. Subsequently the CDSS executes the first (next) guideline step for which patient information is required, and queries the PIMS for the necessary patient information. If the requested information is available in the database (hence it was already entered earlier in the needs assessment procedure) it is returned to the CDSS. If not available, the PIMS prompts the user to enter the necessary information. Based on the information provided by the CDSS to the PIMS, the PIMS dynamically builds up each screen of the needs assessment dialogue. After the user has entered the necessary information, the PIMS sends this information back the CDSS, which then evaluates the next relevant
guideline step. This process continues until the needs assessment procedure is completed or interrupted.

Figure 2. Visual representation of the functionalities of CARDSS. Boxes represent functionalities. Arrows show how functionalities decompose into sub-functionalities. The ellipse represents a feature, part of the functionality it is attached to. Italic font indicates that the functionality or feature is CDSS related. CR = cardiac rehabilitation.

Explanation of relevance
To provide professionals with context-relevant guideline information during the needs assessment procedure, the guidelines were first converted into HTML. Second, in GASTON’s knowledge acquisition tool, links to relevant sections of the guidelines were added to the properties of individual guideline steps. These properties are communicated by the CDSS to the PIMS, which processes them and, when appropriate, shows the user that explanatory information is available by showing an infobutton next to the requested patient information. If the infobutton is pressed, relevant guideline information is shown to the user.

Decision support in selecting cardiac rehabilitation therapy
During the conduction of the needs assessment procedure, the CDSS regularly provides the PIMS with guideline-recommendations based on the information entered
by the users. This PIMS collects and manages these recommendations. If needs assessment data changes or additional information is added, for example by another user, recommendations are dynamically updated by the CDSS and processed by the PIMS.

![Figure 3. Screen in which the rehabilitation programme is formulated based on therapy recommendations by the guidelines. The user can ask the system to provide the line of reasoning that has led to a particular recommendation by pressing the green ‘?’ button next. In this case the rationale behind the recommendation to give ‘Exercise therapy’ is shown.](image)

When the needs assessment procedure has been completed, professionals must decide upon the therapies that the patient in question will follow during the rehabilitation programme. At this point, the PIMS automatically shows the rehabilitation therapies that are recommended by the guidelines. A sample screenshot is shown in Figure 3. Professionals may always choose to deviate from the guidelines’ recommendations – for instance based on patient preferences, or availability of therapy facilities.
Figure 4. Entity-relation diagram of the PIMS data model to provide guideline recommendations’ rationales, with entity attributes omitted for convenience. The data model implements a singly linked list with backpointers designed to store all recommendations made by the system, including the underlying chains of reasoning. The weak entity ‘Patient_GuidelineStep’ is an intersection table to implement a many-to-many relationship between the ‘Patient’ and ‘GuidelineStep’ entities. The same goes for the weak entity ‘Patient_Recommendation’. Both the ‘Patient_Recommendation’ and ‘Patient_GuidelineStep’ entities hold an attribute that references to their preceding ‘Patient_GuidelineStep’.

**Explanation of recommendations’ rationale**

When deciding upon the rehabilitation therapies that a patient will follow, users can request insight into the rationale of each individual recommendation, as shown in Figure 3. The functionalities to do so are implemented in the PIMS as they could not be provided by the version of GASTON that was available during the development of CARDSS. We recall from Section 3.3 that it was decided to store all recommendations provided by the system in a local database, including the chains of reasoning that led to those recommendations. This was done because the available version of GASTON was unable to put different guideline versions concurrently into operation.

In the cardiac rehabilitation guideline, it is always a list of consecutive guideline steps that underlies, and justifies, a recommendation. Because the number and type of guideline steps required to reach a recommendation varies from patient to patient, we cannot store this type of information in a flat table. Therefore a relational data model was designed for this purpose; the corresponding entity-relation is shown in Figure 4. As appears from the figure, all guideline steps that are assessed, and recommendations that are generated during a patient’s needs assessment procedure,
are stored in the database. In addition, with each stored item a reference to its preceding (parent) guideline step is included. Therefore, this data model is actually an implementation of a singly linked list with backpointers. The model data supports chains of reasoning with variable length and supports the reconstruction of a recommendation's rationale irrespective of changed clinical data and updated guideline content.

**Status report**

**Pilot study**

A prototype version of CARDSS was tested during a two month pilot study in four different outpatient clinics in 2003 [33]. The number of patients enrolled in the pilot study was 134. During this pilot study the system was quickly accepted by its users and could be easily integrated into the clinical working procedures. From the pilot study several adjustments and additional functionalities to the system were formulated, including improvements in generating aggregated statistics, but also adding a message-board to improve the communication between the different healthcare providers and disciplines.

**Implementation**

In January 2004 the prototype version of CARDSS was presented concurrently with the release of the guidelines at a national conference. During workshops, the system was demonstrated to representatives of 62 different Dutch outpatient clinics. In July 2004 all 101 Dutch outpatient clinics were probed for their interest in using CARDSS for the organization of their cardiac rehabilitation. Hospitals could buy the system for €100,- or could participate in a cluster randomized trial to evaluate the effect of the decision support on guideline adherence. CARDSS was released in January 2005 and is currently being used in over 40 Dutch outpatient clinics.

**Lessons learned**

There exist a number of frameworks for implementing clinical practice guidelines in a computer-interpretable and executable format, such as PROforma/Arezzo [21], SAGE [22], and GASTON [23]. From a scientific point of view, the differences between these frameworks are small, and they would probably have been equally suitable for the development of CARDSS. In this project we decided to use the GASTON framework [23] as its developers were able to provide personal support during the development of CARDSS.
We have experienced that the tools from the GASTON framework can be successfully used to build a complete CDSS from guideline formalization to guideline execution. Its domain ontology editor and guideline modelling tools provide an easy and intuitive user-interface to formalize guideline knowledge. However, we had to involve the designers of the GASTON framework to build a custom communication interface that met our requirements to effectively integrate the decision support services provided by the GASTON execution engine in the PIMS.

As explained in Section 3, prior to CARDSS no information system was used in cardiac rehabilitation in the Netherlands, and therefore the system had to include not just decision support, but also a host system and database. This circumstance has considerably delayed the development process. However, it did enable the possibility to closely integrate CDSS functionalities with the host system, which was required to provide professionals with decision support concurrently with care. This type of workflow integration is known to be important for the effectiveness of CDSSs [8;9]. However, we did have to develop a custom communication interface as no standards existed for this purpose [26]. Recently a HL7 draft standard interface specification for CDSS services was developed, known as the HL7 Decision Support Service standard [34]. To facilitate and stimulate the future development and implementation of CDSSs, we encourage the further development and use of such standards for CDSS integration into existing application architectures.

In this project, we implemented a mechanism to provide explanation facilities to CDSS users in the PIMS that did not rely on re-execution of the guideline by the CDSS, but instead built on storing chains of reasoning steps into a local database. This was done for pragmatic reasons, as GASTON’s execution engine did not provide for such functionalities and could not put different guideline versions concurrently into operation\(^1\). However, the literature does not describe whether or how other CDSS execution engines can provide for such functionalities. Most CDSS come with explanation, and many studies have found that providing such facilities to CDSS users is important for improving guideline adherence [8;9;27;29-31]. Therefore, we recommend that more research should focus on the provision of explanation facilities, and that all CDSS execution engines should be equipped with such facilities. Also, we recommend that in future specifications of the HL7 Decision Support Service standard [34] the proposed communication interface includes provision of such explanation facilities.

Just as in many other western countries [35], the field of cardiac rehabilitation in the Netherlands is still professionalizing. Until the implementation of CARDSS, even no

\(^1\) GASTON’s current version does support these functionalities
electronic patient record specific to cardiac rehabilitation was used in most outpatient clinics. These factors most likely facilitated the implementation of CARDSS, as it could help outpatient clinics to improve adherence to national guidelines' recommendations. This assumption is supported by the fact that specialized rehabilitation clinics were less eager to implement CARDSS. These clinics had usually already developed a protocol for cardiac rehabilitation that was more detailed than the one described in the national guidelines. However, as standardization of cardiac rehabilitation was the aim of the Netherlands Heart Foundation, CARDSS does currently not support local guideline adaptations. As this has proven to be a barrier to the implementation of CARDSS in these specialized clinics, CARDSS should either support local guideline adaptations or the guidelines should be further elaborated to improve further implementation.

Another barrier limiting the implementation of CARDSS was that most Dutch specialized rehabilitation clinics already worked with information systems, but CARDSS was (and is) not interoperable with other information systems. Nowadays, also other CARDSS users often request such functionalities to avoid duplicate information entry. Therefore, future versions of CARDSS will support interoperability with other information systems to keep it being widely implemented.

**Future plans**

The reason for developing and introducing CARDSS was to improve adherence to the national cardiac rehabilitation guidelines. Although CARDSS was adopted by over 40 outpatient clinics in the Netherlands, this does not automatically mean that guideline adherence is increased. The cluster randomized controlled trial assessing the effect of the computerized decision support incorporated in CARDSS on guideline adherence is finished and its results are currently being analyzed. Results of this study will be reported elsewhere.

**Reference List**


Chapter 3. Development of CARDSS


