Development of a decision-support system in the primary care sector

Michiel Meulendijk[1]

Supervisors:
Prof. dr. S. Brinkkemper[1], Dr. M.R. Spruit[1], Prof. dr. M.E. Numans[3,4], Dr. P.A.F. Jansen[2]

[1]Department of Information and Computing Sciences Utrecht University, The Netherlands
m.c.meulendijk@uu.nl
[2]Department of Geriatric Medicine and Expertise Centre Pharmacotherapy in Old Persons, University Medical Center, Utrecht, the Netherlands.
[3]Department General Practice, VUmc-EMGO, Amsterdam, the Netherlands.
[4]Julius Center for Health Sciences and Primary Care, University Medical Center, Utrecht, the Netherlands.

Abstract. The use of multiple drugs by patients increases their risk of hospitalization. The medical Prescribing Optimization Method has been developed to aid GPs and pharmacists with the process of prescribing for patients using multiple drugs. This research thesis aims at reporting the results of developing a decision-support system in the primary care sector that facilitates and optimizes this method. Research questions in this project will encompass decision-support systems' optimization in areas including human-computer interaction, technology acceptance, semantic interoperability and knowledge discovery. The main question of researching the proposed system's effectiveness and efficiency will be answered as a result of the complete trajectory.

Keywords. Medical informatics, decision-support system, primary care, technology acceptance, human-computer interaction, semantic interoperability, knowledge discovery.

1 Introduction

In the Netherlands, seventeen percent of the chronically ill use more than five different drugs permanently; half of these are over seventy years of age [1]. This polypharmacy increases patients' risks to develop other health issues, which in turn leads to increased chances of hospitalization.

Recognizing these problems, the Prescribing Optimization Method (POM) was devised. This step-by-step method aims at assisting general practitioners (GPs) and pharmacists with determining the optimal medication for polypharmacy patients [2].

In this document, a research project is proposed that aims at investigating the development of a decision-support system that facilitates and optimizes the POM.

1.1 Problem Statement

The chronic use of multiple drugs increases patients' risks to experience any of these problems:

- adverse effects; using multiple drugs may cause patients to suffer their negative side-effects [3,4,5];
- under-prescription; as GPs become hesitant to prescribe drugs to a patient already using many, undertreatment becomes a possibility [6,7];
- overtreatment; the risk of patients using drugs that have not been prescribed (anymore) increases [8,9];
- decreased drug adherence; with the number of drugs increasing, the number of patients adhering to their medication schedule decreases [10].

Ultimately, using multiple drugs leads to an increased chance of hospitalization [4]; ten percent of hospital admissions of elderly people in the Netherlands is related to drug use [11].

Many of these problems in drug use are due to avoidable human errors GPs make during the prescribing process, including use of incomplete patient information, insufficient communication, and mistakes because of time pressure or carelessness [12,13].

Prescribing Optimization Method To cope with these problems, the Prescribing Optimization Method was devised, a step-by-step method to aid GPs in optimizing drug prescriptions for polypharmacy patients. In a preliminary test, this method significantly improved their prescriptions' quality and relevance [2]. The method addresses all aforementioned issues and is intended to be used by GPs and pharmacists cooperatively.

POM Platform The development of decision-support systems for the primary health care sector has seen a great surge in the last decade. Whether or not integrated with electronic medical records, computerized physician order entry (CPOE) systems have provided GPs with appropriate tools to facilitate their drug prescriptions. Being equipped with medical formularies and drug interaction databases, these systems can be modified to optimize the drug prescription process [14,15,16,17].

In order to fully enable the use of the POM, the POM Platform (POMP) has been envisioned: a decision-support knowledge system that facilitates the POM and is optimally incorporated into caretakers' systems and workflows.

The decision-support system would advise GPs and pharmacists on-demand with drug prescriptions and medicine compatibility, based on patients' specific medical records and actual use; through a medication review structured by the Prescribing Optimization Method they would determine actual use of drugs, identify superfluous ones, and detect untreated diseases. The system would base its advice on clinical guidelines, drug interaction rules, and best practices.

2 Research Approach

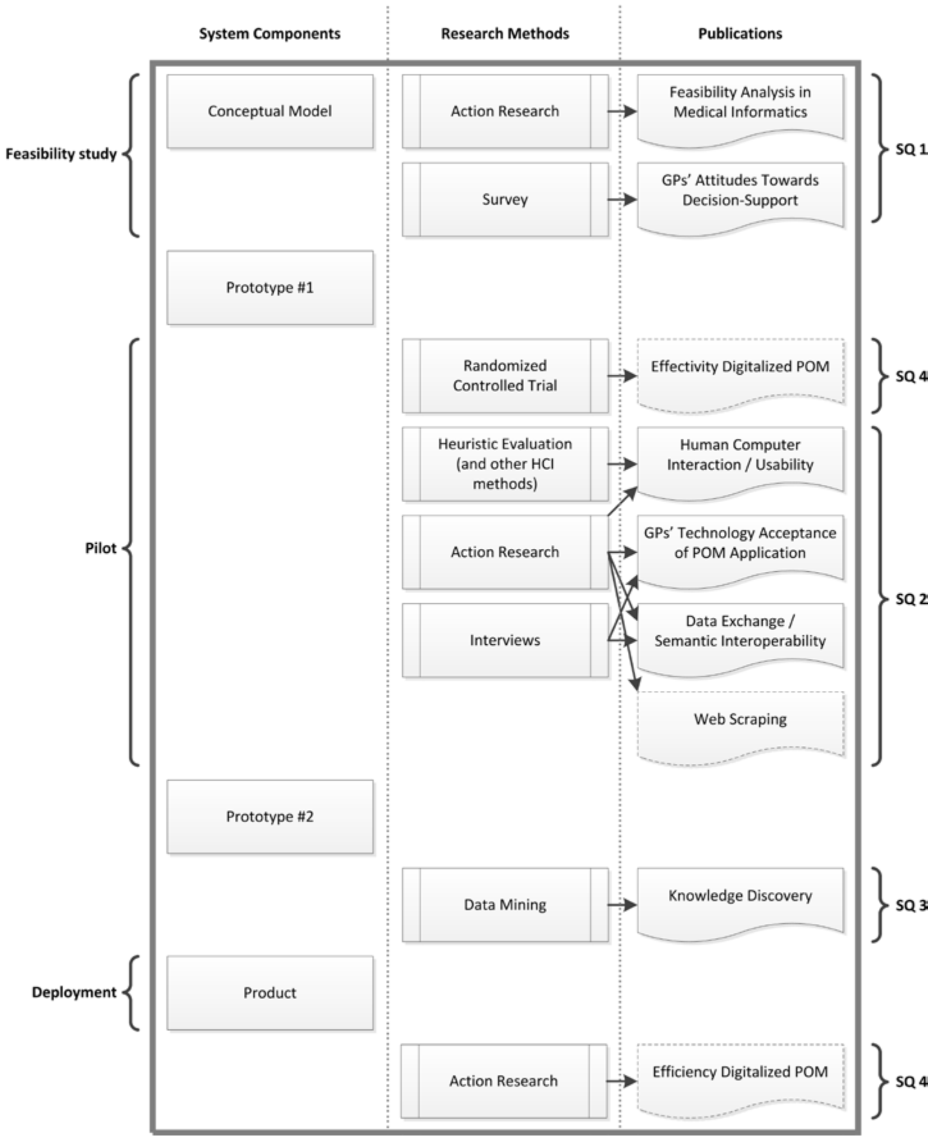

Fig. 1. Overview of the research process, including the system components, the research methods and the resulting publications.

2.1 Research Questions

The following main research question will be investigated in the project:

- To what extent can an electronic version of the Prescribing Optimization Method contribute to more efficient and more effective geriatric care through integration of high-end information and communication technology (ICT)?

It will be answered through the investigation of these sub questions:

SQ1 How can an electronic version of the POM be developed that meets all specifications?
SQ2 How can the POM application be integrated transparently into existing information systems in the primary care?
SQ3 To what extent can the POM application be optimized to improve its efficiency using data mining and social media?
SQ4 To what extent is the POM application more efficient and effective in daily use than the usual care?

In Figure 1 the system components that will be developed during the process are displayed, along with the accompanying research methods and resulting publications; the publications with dashed lines are either optional or written in close collaboration with partners to emphasize different (e.g. medical) aspects.

The system will be created according to the principles of the pragmatic strategy of agile system development, which includes iterative and incremental development and flexible response to change. Approaches from the methods of Prototyping and Dynamic Systems Development Method will be combined to optimally guide the application's design. The agile approach has been preferred over more traditional approaches such as the Systems Development Life Cycle because it allows for flexibility and continuous partner collaboration in an evolving field such as polypharmacy treatment and clinical decision-support systems.

Before the writing of this research proposal, a feasibility study was already employed to investigate the project's requirements and create a conceptual model. When the first prototype has been developed, a pilot amongst potential users will be carried out, ultimately resulting in several papers. The prototype will be refined with the input gathered during the pilot, then used for the knowledge discovery phase. Finally, all knowledge gathered during the process will be worked into a final version of the application, which can then be marketed as a software product.

The main research question will be answered as a result of the complete trajectory. During the feasibility analysis the first sub question was answered by investigating requirements and developing a conceptual model. The second sub question will be answered with results from the pilot phase, whereas the third sub question on optimization will be answered by the knowledge discovery research. Finally, the fourth sub question on evaluation will be answered both during the pilot phase – the effectiveness aspect – and when the final product has been deployed – the efficiency aspect.

2.2 Scientific Relevance

Within this research project, several areas of information science will need to be investigated in order to satisfactorily answer the central question. The three pillars of the project are:

- exchange of data between the newly proposed system and existing third-party ones, encompassing areas of data integration and semantic interoperability;
- user interaction with and use of the system, encompassing areas such as human-computer interaction and technology acceptance; and
- knowledge discovery and management, in order to optimize the advice provided through analysis of earlier data.

2.3 Societal Relevance

Apart from the scientific value, the results of this research project have vast societal relevance as well. The project will lead to the creation of a decision-support system that will aid GPs and pharmacists with prescribing drugs, and as such has the potential to improve the polypharmacy problems described earlier. In the feasibility study executed for this project, calculations were made to estimate the decreased mortality and morbidity rates, and the reduced financial burden on society; after implementation of the decision-support system, on a national level mortality can be expected to decrease by 3 to 19 persons on a yearly basis, morbidity by 4 to 28 persons, and the financial cost by 10 to 45 million euros per year.

3 Theoretical Foundation

3.1 Technology Acceptance & Human-Computer Interaction

The field dedicated to studying users' motivations to use software is the one of technology acceptance. In general, GPs are expected to have conservative attitudes when it comes towards technology adoption; this would be caused by the individual nature of their jobs and their lack of time to spend learning new systems' interfaces [18,19]. In a survey that was conducted during the feasibility study for this project, GPs indicated welcoming the idea of a facilitating method to aid them with prescribing. Especially quality improvement and time consumption were indicated as important determinants of their motivations whether or not to use the newly proposed system.

One of the most renowned theories in the field of technology adoption is the Technology Acceptance Model (TAM) by Davis [20]. It has a long history of being applied in the field of medical informatics [21,22,23]. When applied to the field of primary care, it appears that one of the most influential factors common in technology adoption, users' perceived ease-of-use of new systems, has no impact on their motivation to use them. Instead, systems' perceived usefulness seems to be of greater importance, especially regarding job relevance and quality improvement [24,25].

In the survey, however, existing decision-support systems in the primary care sector appeared to be underused. More than half of the respondents who indicated owning such a system rarely or never use them. This finding was echoed in literature [26]. Pevnick, et al. [27] report that GPs owning decision-support systems use them for only one quarter of their prescriptions. Additionally, McInnes, Saltman, & Kidd [28] add that, while virtually all of their adopting respondents indicate using decision-support tools for drug prescriptions, only twenty percent of them actually employ them during consultations.

Thus, while decision-support systems can potentially optimize GPs' prescribing behavior, their adoption is lacking [14,15,16,17]. To try and explain this phenomenon, investigating users' attitudes to the newly proposed system in this project is an objective. Perceived ease-of-use, being traditionally one of the main determinants of adoption, will be taken into account as well. This will encompass the field of usability engineering, which is occupied with optimizing user interfaces [29]. Especially the interface's integration with existing third-party software will be explored, in order to find whether users respond differently to interfaces contained within their familiar systems than completely separate ones, even if those systems have not been optimized for use performance.

3.2 Data Exchange & Semantic Interoperability

In order to successfully realize a decision-support system in the primary care sector, relevant data on which to base advice needs to be readily available. In the case of the proposed system in this research project, the required data encompasses patient information (such as diseases suffered and medicinal drugs used) and continuously updated clinical guidelines.

The patient data is stored locally through GPs' and pharmacists' computerized physician order entry (CPOE) systems. An early field study and questionnaire showed that in the Dutch market alone more than ten different CPOE systems for GPs are in use. Standardized data exchange formats that can handle all this data do not exist, nor are the applications' infrastructures similar. This makes data exchange between the newly proposed system and third-party software difficult.

Aspects such as data exchange and semantic relations between data units are the objects of study in the field of semantic interoperability, which strives to optimize data sharing. Semantic interoperability ensures that the exchange of services and data between software systems "make sense", i.e. "that the requester and the provider have a common understanding of the 'meanings' of the requested services and data" [30]. In the primary care sector researchers have recognized the need for standardized approaches for data exchange; Shah, et al. [31] stress the importance of "allow[ing] two-way data exchange between the CDSS and the EMR, which requires the EMR also to expose a set of interfaces".

3.3 Knowledge Discovery

The advice provided to GPs by the intended system will be based on patient data, such as used drugs and diseases, and clinical guidelines. These guidelines comprise proven interactions between drugs or between drugs and certain diseases.

In order to optimize the advice generated by the software application, techniques from the area of knowledge discovery will be put to use. Multiple sources of information are to be consulted, including official guidelines, histories of GPs' earlier decisions, and recommendations of expert panels. Additionally, social media can be employed to optimize the system's decision-support capabilities. Specified collegial forums or interactive (micro)blogs such as Twitter can yield relevant information.

The main technique that will be employed in the knowledge discovery process is data mining. It is the process of discovering new patterns from large data sets by extracting knowledge in a human-understandable structure [32]. In this research project, especially association rule mining will be relevant, as it involves the analysis of large quantities of data to extract previously unknown patterns [33].

The knowledge discovery process will be structured around the Three-phases model which integrates and extends the CRISP-DM and KDD models into an extensive implementation phase and a clear role distribution. The data mining step within the KD process revolves around the process of the actual discovery of new patterns from large data sets by extracting knowledge in a human-understandable structure [32]. This research project will especially focus on association rule mining, as the output in the form of symbolic rules are common and thus familiar to MDs.

4 Methods

A wide variety of methods are available to investigate the issues related to the creation and implementation of a decision-support system in the primary care.

The whole project, as a logical consequence of solving a real-world problem in a practical environment, is driven by action research. In an early paper on this topic, action research was defined as "diagnosis of a social problem with a view of helping improve the situation" [34]. Action research is closely related with the postmodern school of thought and is based on the assumption that "complex social interactions cannot be reduced for meaningful study" [35]. Following a holistic approach, human organizations should be studied within their contexts, not by isolating their parts [36]. When the researcher then intervenes into the research setting, he becomes part of the study, resulting in “the realignment of the roles of researcher and subject into more collaborative and synergistic forms” [35]. Consequently, action research is well-suited to reflectively exploring processes in which the researchers’ and actors’ roles overlap.

Most of the aforementioned research areas require querying of people in various roles, including potential users of the newly proposed system and manufacturers of CPOE systems. In order to do that, a selection of traditional and more specific research methods will be applied. Both quantitative and qualitative approaches can yield useful results in the areas of interest described above.

In the feasibility study conducted prior to the writing of this proposal, a quantitative approach has already been employed. A survey among 500 GPs was used to investigate their attitudes towards the newly proposed system, thereby exploring the area of technology acceptance. Similar questionnaires may be employed at later phases in the research project, especially in order to answer the last sub question regarding evaluation.

While surveys are well suited to gather large amounts of data or to generalize findings, qualitative research is generally more suited to exploratory research [37]. In this project, especially semi-structured interviews will be employed, because of the ability of freely associating they provide the respondents with.

More specific methods will be employed in the field of human-computer interaction and usability engineering, which are specifically designed to test users’ responses and attitudes towards systems’ interfaces. Among these are heuristic evaluation and rapid prototyping, which provide the ability to quickly expose users to interface improvements based on usability guidelines [29].

The data mining step in the knowledge discovery process mentioned earlier will be employed to discover patterns in the history of advices. The method can analyze large data sets and discover patterns among variables, which can then be used to optimize recommendation provided by the decision-support system [32]. For example, in an early study Agrawal, Imielinski, & Swami [38] employed association rules to discover regularities in customers’ purchasing behavior in supermarkets; this approach of relating products is comparable to our case in which patterns between drugs and diseases are expected.

Finally, the actual effectiveness of the digital version of the medical POM method will be measured through a randomized controlled trial, which is common in medical fields [39]. With this method, possible improvements a new approach may have are measured by subjecting a group of patients to it, while another group is treated regularly to correct for random results. This method will be applied in close collaboration with medical project partners.

4.1 Appendix: Progress Report

Prior to the writing of this proposal a feasibility study has already been conducted, which was mainly concerned with investigating the problem and finding GPs' attitudes towards the newly proposed system. This resulted in the following papers:

- Meulendijk, M., Drenth-van Maanen, A., Jansen, P., Brinkkemper, S., Numans, M., & Spruit, M. (forthcoming). Introducing the CORETEST feasibility analysis in medical informatics: a case study of a decision-supportive knowledge system in the Dutch primary care sector. In I. Miranda, & M. Cruz-Cunha, Handbook of Research on ICTs for Healthcare and Social Services: Developments and Applications. IGI Global.
- Meulendijk, M., Spruit, M., Drenth-van Maanen, A., Numans, M., Brinkkemper, S., & Jansen, P. (submitted 3/19/2012). General practitioners' attitudes towards decision-supported prescribing: an analysis of the Dutch primary care sector. Informatics for Health and Social Care.

In this phase of the research project, the feasibility study (as can be seen in Figure 1) has been completed. Based on the conceptual model that was conceived through it, a first prototype is being built. This will be tested in a real life environment by GPs and pharmacists in the pilot phase, which is planned to be held in late 2012. In this pilot, aspects including the POM's effectivity, technology acceptance and human-computer interaction will be investigated.

In later phases, based on the outcomes of the pilot research, an improved prototype will be developed. Except for measuring its effectiveness and efficiency, its main purpose is facilitating the process of knowledge discovery, which will result in decision rules to optimize the application's performance.

The completion date for the PhD thesis is November 2014.

Bibliography

1. Stichting Farmaceutische Kengetallen. Polyfarmacie ('Polypharmacy' in Dutch). Pharmaceutisch Weekblad. 2005 August 12; 140(32).
2. Drenth-van Maanen AC, van Marum RJ, Knol W, Van der Linden CM, Jansen PA. Prescribing Optimization Method for Improving Prescribing in Elderly Patients Receiving Polypharmacy. Drugs & Aging. 2009; 26(8): p. 1-15.
3. Björkman I, Fastbom J, Schmidt I, Bernsten C. Drug-drug interactions in the elderly. The Annals of Pharmacotherapy. 2002; 36(11): p. 1675-81.
4. Frazier SC. Health outcomes and polypharmacy in elderly individuals; an integrated literature review. Journal of Gerontological Nursing. 2005; 31(9): p.

4-11.

5. Shi S, Mörike K, Klotz U. The clinical implications of ageing for rational drug therapy. European Journal of Clinical Pharmacology. 2008; 64(2): p. 183-99.

6. Sloane P, Gruber-Baldini A, Zimmerman S, Roth M, Watson L, Boustani M, et al. Medication Undertreatment in Assisted Living Settings. Archives of Internal Medicine. 2004; 164(18): p. 2031-2037.

7. Wright R, Sloane R, Pieper C, Ruby-Scelsi C, Twersky J, Schmader K, et al. Underuse of Indicated Medications Among Physically Frail Older US Veterans at the Time of Hospital Discharge: Results of a Cross-Sectional Analysis of Data From the Geriatric Evaluation and Management Drug Study. The American Journal of Geriatric Pharmacotherapy. 2009; 7(5): p. 271-280.

8. Claxton A, Cramer J, Pierce C. A systematic review of the association between dose regimens and medication adherence. Clinical Therapeutics. 2001; 23(8): p. 1296-310.

9. Kuyuma M, Endo H, Umegaki H. Factors influencing nonadherence with medication regimens in the elderly. Nippon Ronen Igakkai Zasshi. 2000; 37: p. 363-70.

10. Steinman M, Landefeld C, Rosenthal G, Berthenthal D, Sen S, Kaboli P. Polypharmacy and prescribing quality in older people. Journal of the American Geriatrics Society. 2006; 54(10): p. 1516-23.

11. Leendertse A, Egberts A, van den Bemt P, Stoker L. Frequency of and Risk Factors for Preventable Medication-Related Hospital Admissions in the Netherlands. Archives of Internal Medicine. 2008; 168(17): p. 1890-1896.

12. Sayers Y, Armstrong P, Hanley K. Prescribing errors in general practice: A prospective study. European Journal of General Practice. 2009; 15(2): p. 81-83.

13. Velo GP, Minuz P. Medication errors: prescribing faults and prescription errors. British Journal of Clinical Pharmacology. 2009; 67(6): p. 624–628.

14. Ammenwerth E, Schnell-Inderst P, Machan C, Siebert U. The effect of electronic prescribing on medication errors and adverse drug events: a systematic review. Journal of the American Medical Informatics Association. 2008; 15(5): p. 585-600.

15. Kuperman GJ, Bobb A, Payne TH, Avery AJ, Gandhi TK, Burns G, et al. Medication-related clinical decision support in computerized provider order entry systems: a review. Journal of the American Medical Informatics Association. 2007; 14(1): p. 29-40.

16. Seidling HM, Schmitt SPW, Bruckner T, Kaltschmidt J, Pruszydlo MG, Senger C, et al. Patient-specific electronic decision support reduces prescription of excessive doses. Quality and Safety in Health Care. 2010; 19(5).

17. Shamliyan T, Duval S, Du J, Kane RL. Just What the Doctor Ordered.

Review of the Evidence of the Impact of Computerized Physician Order Entry System on Medication Errors. Health services research. 2008; 43(1 Pt): p. 32–53.

18. Bhattacherjee A, Hikmet N. Physicians' resistance toward healthcare information technology: a theoretical model and empirical test. European Journal of Information Systems. 2007; 16(6): p. 725–737.

19. Yarbrough A, Smith T. Technology Acceptance among Physicians: A New Take on TAM. Medical Care Research and Review. 2007; 64(6): p. 650-672.

20. Davis F. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly. 1989; 13(3): p. 319-340.

21. Hu PJ, Chau PYK, Sheng ORL, Tam KY. Examining the technology acceptance model using physician acceptance of telemedicine technology. Journal of Management Information Systems. 1999; 16(2): p. 91-112.

22. Meulendijk M, Van De Wijngaert L, Brinkkemper S, Leenstra H. AmI in good care? Developing design principles for ambient intelligent domotics for elderly. Informatics for Health and Social Care. 2011; 36(2): p. 75-88.

23. Tung FC, Chang SC, Chou CM. An extension of trust and TAM model with IDT in the adoption of the electronic logistics information system in HIS in the medical industry. International Journal of Medical Informatics. 2008; 77(5): p. 324-335.

24. Chismar W, Wiley-Patton S. Does the Extended Technology Acceptance Model Apply to Physicians. In HICSS '03 Proceedings of the 36th Annual Hawaii International Conference on System Sciences (HICSS'03); 2003; Washington: IEEE Computer Society. p. 160.1.

25. Holden R, Karsh B. The Technology Acceptance Model: Its past and its future in health care. Journal of Biomedical Informatics. 2010; 43(1): p. 159-172.

26. Donyai P, O'Grady K, Jacklin A, Barber N, Franklin BD. The effects of electronic prescribing on the quality of prescribing. British journal of clinical pharmacology. 2008; 65(2): p. 230-237.

27. Pevnick JM, Asch SM, Adams JL, Mattke S, Patel MH, Ettner SL, et al. Adoption and use of stand-alone electronic prescribing in a health plan-sponsored initiative. The American journal of managed care. 2010; 16(3): p. 182-191.

28. McInnes DK, Saltman DC, Kidd MR. General practitioners' use of computers for prescribing and electronic health records: results from a national survey. Medical journal of Australia. 2006; 185(2): p. 88-91.

29. Nielsen J. Usability engineering: Morgan Kaufmann; 1994.

30. Heiler S. Semantic interoperability. ACM Computing Surveys (CSUR). 1995; 27(2): p. 271-273.

31. Shah H, Krishnan G, Williams P, Vogler A, Allard RD, Nadkarni PM. Interoperability and Integration Considerations for a Process-Oriented Clinical Decision Support System. In Services (SERVICES), 2011 IEEE World Congress on; 2011; Washington, DC: IEEE. p. 437-442.

32. Fayyad U, Piatetsky-Shapiro G, Smyth P. From data mining to knowledge discovery in databases. AI magazine. 1996; 17(3): p. 37-54.

33. Agrawal R, Srikant R. Fast algorithms for mining association rules. In Proc 20th Int Conf Very Large Data Bases VLDB; 1994: Citeseer. p. 487-499.

34. Blum FH. Action Research--A Scientific Approach? Philosophy of Science. 1955; 22(1): p. 1-7.

35. Baskerville RL. Investigating information systems with action research. Communications of the AIS. 1999; 2(1): p. 4.

36. Checkland P, Holwell S. Action Research: Its Nature and Validity. In Checkland P, Holwell S. Information Systems Action Research.; 2007. p. 3-17.

37. Hart H', Boeije H, Hox J. Onderzoeksmethoden Amsterdam: Boom Onderwijs; 2005.

38. Agrawal R, Imielinski T, Swami A. Mining Association Rules Between Sets of Items in Large Databases. In SIGMOD '93 Proceedings of the 1993 ACM SIGMOD international conference on Management of data; 1993; New York: ACM. p. 207-216.

39. Moher D, Hopewell S, Schulz KF, Montori V, Gotzsche PC, Devereaux PJ, et al. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. Journal of clinical epidemiology. 2010; 63(8): p. e1-e37.

40. Meulendijk MC, Drenth-van Maanen AC, Jansen PAF, Brinkkemper S, Numans ME, Spruit MR. Introducing the CORETEST feasibility analysis in medical informatics: a case study of a decision-supportive knowledge system in the Dutch primary care sector (accepted). In Miranda I, Cruz-Cunha M. Handbook of Research on ICTs for Healthcare and Social Services: Developments and Applications.: IGI Global; 2012.

41. Meulendijk MC, Spruit MR, Drenth-van Maanen AC, Numans ME, Brinkkemper S, Jansen PAF. General practitioners' attitudes towards decision-supported prescribing: an analysis of the Dutch primary care sector (submitted 3/19/2012). Informatics for Health and Social Care. 2012.