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**MSC EPIDEMIOLOGY IN RESEARCH DATABASE MANAGEMENT**

**TITLE:**

**INTEGRATED LONGITUDINAL DATA VISUALIZATION AT INDEPTH NETWORK SITES**

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# INTRODUCTION

Visual analytics tools are used to synthesize information and glean insight from massive, dynamic, ambiguous and often conflicting data. Visual Analytics (VA) is often referred to as a means for dealing with complex, large information sources that require human judgment to identify the expected and discover the unexpected. It is a multidisciplinary field whose core areas are analytical reasoning techniques, visual representation and interaction techniques, data representations and transformations as well as production, presentation and dissemination [1].

Analytic reasoning techniques enable users to get deep insights which support assessment, planning and decision making. It also allows users to assimilate large amounts of information at once [2]. In a healthcare setting expected outcomes include more efficient and effective clinical performance monitoring and improvement as well as improved modelling of patient flow and management. Additionally, one can expect increased quality of care, improved safety and efficiency and better support for clinical costing and resource coordination. It can also lead to better planned growth and competitive advantage [3].

VA is referred to as “the science of analytical reasoning facilitated by interactive visual interfaces” [1]. Map based community health visualizations have provided a comprehensive and powerful interface for scientists and policy makers to visualize health care quality, public health outcomes and access to care. This has helped in making evidence-based decisions about improving healthcare [4–7].

Multi-panel graphs have also been used to good effect in a graphical tool for epidemiological studies to reveal the distribution of an outcome by time and age simultaneously [8].

The growth of surveillance systems in both quantity of data and variety of outcomes is likely to necessitate constant innovations in data processing, synthesis, and communication [8]

Therefore, techniques to support production, presentation and dissemination of analytic results will allow us to communicate the information in the appropriate context to a variety of audiences.

## PROBLEM STATEMENT

One critical requirement for successful public health surveillance is the ability to analyse and present data so that it is understandable to a range of public health stakeholders. In public health, VA can be viewed as the bridge between the availability of surveillance data in database architectures and useful information derived from this available data [9].

INDEPTH Health and Demographic Surveillance Sites (HDSS's) deal with complex longitudinal data and, as a result, knowledge transfer to stakeholders is challenging. Better visualisation of this data is therefore required in order for potential scientific users to maximise exploratory data analysis and hypothesis generation. It would also aid decision-makers and the society at large to visualise this information in terms understandable by them. Such a visualization tool will also improve field work research activities by providing summary data of operational progress, e.g. fieldwork data collection progress, data entry progress, or other parameters such as data quality. This will serve to improve operational decision making and data quality. However, datasets at HDSS sites are normally under-visualised. These HDSS sites currently have no generalizable framework for implementing a data visualization platform to be used at these sites.

## MOTIVATION

The current under-visualization of HDSS datasets shows little promise of improvement in a harmonised way (across multiple sites) unless specific research efforts are directed towards finding a generalizable solution for delivering interactive visualizations, supporting exploratory analyses and real-time displays of operational progress. Furthermore, there is a paucity of research specifically on the technologies and tools which can be used to create a data visualization [10].

# LITERATURE REVIEW

The topic of visualization of public health data was identified in 2009 by the CDC as one of six major concerns which must be addressed by the public health community in order to advance public health surveillance in the 21st century [9]. However, very little has been researched in terms of standardization of the workflow and linking technologies for heterogeneous data sources needed specifically for visualizations in public health science [10].

Of crucial importance when dealing with large datasets is the need for the users of the data be they scientists and other stakeholders to be able to discover the relations among and between the results of data analyses and queries [10]. However, due to bottlenecks resulting from resource cost and lack of required skills, data visualization becomes an end product of scientific analysis rather than an exploration tool which facilitates scientists to generate better hypotheses in the continually more data-intensive scientific process [10]. The use of such visualizations are usually utilised in business analytics, open government data systems, and media infographics but have generally not been used in public health. However, the capabilities currently being seen by Web-based tools may be the breakthrough in resolving the scientific visualization bottleneck.

A lot of work has been done on spatial visualizations for public health [4,6,7]. The feasibility of creating poverty maps for Indonesia at various administrative levels to help with the implementation of programs which target the poor was investigated in [6]. Their focus however was on a new methodology for imputing per capita consumption for each household in the population based on data collected from household surveys and data collected from population censuses. Their report however did not focus much on how the visualization platform was to be built. The final product though, after all the computations is the visualization, the poverty map of the country.

Along a similar spatial theme, [7] looked at how the agents of parasitic diseases are spatially distributed using map visualizations. The tools of interest used in their research were the two closely linked Google products, Google Earth and Google Maps. Though there is a little more implementation details, the mix of tools used are not all open-source.

Other research on implementing a data visualization platform for community health assessment (CHA) used open source technologies but was limited to a desktop application and could not be accessed online [11]. Web based tools have been seen as the preferred platform of choice for public health researchers as they permit distributed access, reduced software implementation costs and wider exposure of public health information for public dissemination [4,12,13]. The report also gives scant details of the actual open source tools used and how they were put together in a way which would allow recreation of the steps.

The use of multi-panel graphs to illustrate trends and anomalies which would otherwise be obscured by traditional epidemiological visualization techniques such as pyramids and time-series plots was explored in [8]. Under future developments in their report however, they acknowledge that two other features if incorporated to these graphs would enhance their impact, namely the dynamic display of data and interactivity.

Existing tools offer a range of features and functions to allow for exploration, analysis and visualization of public health users data, but the tools are often for siloed applications incapable of reciprocal operation with other, related information systems. They are isolated to the jurisdictions and organisations which developed them limiting their widespread adoption by other agencies or organisations[13]. Interoperability of the visualization tools has been identified in a systematic literature review of infectious disease visualization tools as a prominent theme, due to challenges associated with increasingly collaborative and interdisciplinary nature of disease surveillance, control and prevention [13].

The CDC’s inclusion of VA as one of its six areas of focused research in public health lends credence to the importance of this research project. Furthermore there is little that has been researched in terms of standardisation of the workflow, tools and linking technologies for visualizations in the public health domain, as well as few existing web based tools for health related data visualization [4,10]. This research will add to the body of literature broadly in the subject of tools and technologies for data visualization in general, and specifically for implementing a data visualization platform which is generalizable for all INDEPTH HDSS sites with the aim of allowing it to become a central piece of the scientific process. It will also augment on work already done [8] by incorporating dynamic display of data and interactivity into multi-panel graphs for epidemiological research [8].

# RESEARCH AIMS AND OBJECTIVES

## OVERALL AIM

The overall aim is to increase the utilization of data in INDEPTH sites through visualization, aimed at improving hypotheses generation and increase operational awareness.

## SPECIFIC OBJECTIVES

The specific objectives of this research are:

1. To design a data visualization platform for the Africa Centre for Health and Population Studies (ACHPS).
2. To build a data visualization platform for ACHPS in order to increase data utilization and hypotheses generation at the site.
3. To create a developer manual for data visualization so that the process for building the platform can be reproduced.
4. To evaluate the usability of the developed platform for easy integration into the operational research cycle of the site.

# RESEARCH METHODS

## SCOPE OF RESEARCH

The scope of the intended research is limited to the integration, transformation and visualization or datasets from clinical research data, demographic surveillance data and electronic health record data (EHR). This research will not include an evaluation component to assess the impact of the use of the system. Future work will involve designing a detailed study which enables the measurement of the impact of the data visualization module on insight and hypotheses generation at INDEPTH HDSS sites.

## OVERVIEW OF THE PROPOSED SOLUTION

At the beginning of this research potential types of visualizations will be identified with the help of a domain expert on site (e.g. visualizations on morbidity, mortality, types of outcome pyramids, poverty maps, health facility density, etc.). These will form the initial backbone of the data visualization module. The solution will build on work already done by creating multi-panel graphs with dynamic display of data and interactive capabilities [8]. These graphs weave together temporality and demographics and they use time-series plots, image plots and outcome pyramids. It will also add the extra spatial dimension missing from their workallowing the user to choose geographic areas at different granularities and generating the multi-panel graphs for those granularities interactively and dynamically*.* The final system will then allow for the capture of suggestions from domain experts and the data users on additional visualizations and features which can be added over time.

Central to the aim of the research is the extraction of data from multiple sources, its transformation and finally visualization of the data. Three data sources will require integration; DSS data, clinical trial data and Electronic Medical Records data (EMR). Each has a different storage format using different technologies. After the extraction stage, the data will go through the necessary transformations and automated data validation and cleaning processes, after which the Extract, Transform Load (ETL) tool will then load the data onto a visualization database ready for rendering.

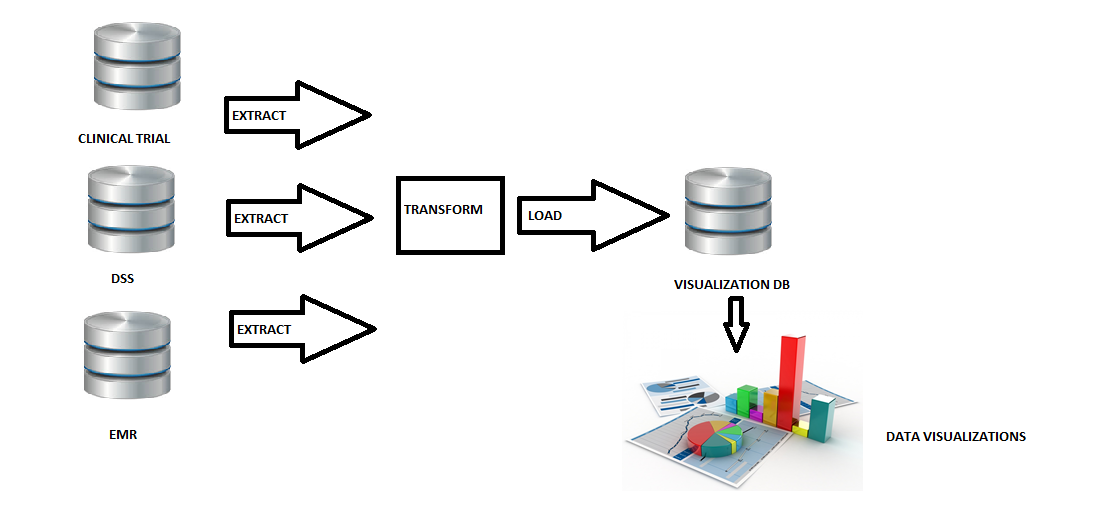


Figure : Proposed Solution

The Extract-Transform-Load steps will be automated to allow streaming of data from the various data sources into the visualization database. This will ensure that the visualizations stay current and will facilitate real time monitoring.

The platforms usability will be assessed using the USE Questionnaire. This questionnaire measures usability in 3 dimensions, Usefulness, Satisfaction and Ease of Use using Likert scales per question. For internal systems it is suggested to split Ease of Use into Ease of Use and Ease of Learning [14]. In our case we will measure responses in the 4 dimensions (see Questionnaire in Appendix C).

Results will be described by calculating the median scores to give us a measure of central tendency for each of the 4 dimensions. An overall median score will also be calculated. Non-parametric statistical tests for paired data (Wilcoxon signed rank test) will be used to assess the data for changes from first use to last use.

HDSS sites have their data cleaning and validation procedures which handle the issue of missing data. Techniques used to handle missing data at the site will be incorporated into the visualization database where necessary. These techniques will be documented as part of the report.

## LIMITATIONS

The expected outcome of the research is a working data visualization platform which fosters improved hypotheses generation (which is tightly coupled with insight generation). However, the definition of insight has not been formalized, compounding the complexities around its measurement. The limitations envisaged are our lack of expertise in the theory and implementation of evaluating data visualizations insight generation capacity. How to measure the baseline level of insight generation in order to compare it to the level of insight generation after the tool goes live may prove difficult.

# EXPERIMENTAL SETUP, MODELS AND VALIDATION

In this section we look at how we will set up our proposed solution, so that it can be replicated, as well as how we propose to validate the framework developed.

## EXPERIMENTAL ENVIRONMENT

A test environment with known databases, tables and test data will be set up as well as a battery of established benchmark validation queries created. Integration of these heterogeneous sources into the visualization database will be performed using Pentaho Data Integration 5.1. Pentaho is chosen as it has been proven to support all aspects of Business Intelligence [15,16]. This is ideal as it creates opportunities for future expansion into other types of data analytics, such as data mining and predictive analysis, which may interest the INDEPTH sites in the future. Pentaho is also the tool used to generate the datasets used in INDEPTH’s iShare data repository [17], and data managers from 17 HDSS sites have currently already been trained on using the tool with more expected to be trained in the future.

Once the integration procedures are completed, the queries which were ran before integration on the original data sources are re-ran on the integrated data to verify that the pre-integration results and post integration results are the same. Additionally, the numbers being displayed for any particular outcome on the visualizations shall be verified independently by a domain expert for accuracy. By doing so, we shall assert data integrity and validity of the integration framework and the rendered visuals.

The visualization database will be on MySQL 5.0 [18] with the visualization rendering implemented in one of the following technologies: Pentaho Dashboard [19], D3.js [20], or Bokeh [21].

The proof of concept will run on a Lenovo T420 with 8 GB of RAM, an Intel Core i5 CPU at 2.5GHz, on a 64 bit operating system (OS). The OS will be Ubuntu 12.04 LTS (an open source OS).

Code development is a laborious process, and without a good revision control environment code changes can break the system and debugging can eat into development time. We will be using Git, an open source revision control and collaborative programming tool [22].

The onsite implementation set up will use the current available servers. The candidate server will have a minimum 16 GB of RAM and will run the Ubuntu 12.04 OS.

The data integration process requires validation. In order to reduce risk and guarantee that data has been transformed and integrated properly, it is important to have a quality assurance and validation strategy. Methods employed for data migration validation testing include sampling [23] and writing MINUS queries [24]. In sampling, the assumption is made that errors are uniformly distributed (which is not necessarily true). When sampling, a smaller subset from the larger dataset is selected and the information gathered from the smaller dataset will allow inferences to be made on the larger datasets data quality and validity. However, the sampling technique is highly inefficient, error prone and the final results are not entirely reliable [24].

Writing MINUS queries is a process which will allow us to ascertain what records are in the source dataset and have *not* been migrated to the target dataset. The tool which performs the ETL process will have validation rules which filter out invalid data from the source and write these error rows to a separate file. This means that when writing the minus queries we should be aware that some records will not be migrated as they break some validation rules, and as such cannot be considered a failure of the integration framework.

We will go one step further and run analytical statistics on the pre-integrated data sets, e.g. calculation of person-years in the DSS site between two defined periods. The same analyses will also be run post-integration to ascertain that the integration is not affecting key analyses. These analytical queries will be identified in the planning stage.

## DATA SOURCES

The crux of this research project is reliant on data, and lots of it. The scope of this research is limited to patient records (EMR data), longitudinal demographic surveillance data and clinical research/clinical trial data. Thus, in developing the proof of concept, copies of the databases which will be found at the INDEPTH site of implementation will be availed to us.

## SOFTWARE ENGINEERING PRACTICES AND PUBLIC ACCESSIBILITY

The development of software needs to be engineered and managed. As such, we will develop the project software using the Agile Methodology. The emphasis will be on delivering on small features in short iterations (weekly) with continual integration. Defensive programming will be employed in the form of Test Driven Development which has been shown to reduce production code defects by 40% without impacting on the team productivity [25].

Furthermore, the code base will be available on a Git server hosted at the University of the Witwatersrand. This will enable collaborative programming as well as a version control environment.

The production ready code base as well as all accompanying documentation will be hosted on GitHub, as an open source project for collaborative improvement of the integration framework.

Black box testing will be done with selected users and by ourselves with each new functionality added. White box testing will be accomplished by using Test-Driven Development to continuously and exhaustively test the code-base whenever a new functionality is integrated.

Dissemination of the project outcomes will be done mainly through publishing in peer reviewed journals, presentations at INDEPTH conferences as well as other relevant conferences.

# ETHICAL CONSIDERATIONS

Permission will be obtained from the Africa Centre for Health and Population Studies to implement the system. All individual level data which is going to be used during the research, design and implementation process will be de-identified before being made available to us, giving us no access to identifiers. Additionally, the data visualizations themselves will be on aggregate level data and no individual level data is exposed to the end user.

# PROJECT MANAGEMENT, RISK MANAGEMENT AND BUDGET

In software projects without a comprehensive risk management plan, there is a heightened risk of failure, running over budget, or running off schedule. The table in Appendix A shows potential risks as well as the corresponding mitigation strategies. Appendix B shows the project timelines.

In terms of budget, the entire project uses open source tools. Furthermore, all the necessary hardware and software is already available for developing the proof of concept. For site implementation, the infrastructure and servers already exist. As such the project requires no additional budget.

# SUMMARY

Crucial to the success of public health surveillance is the ability to analyse and present data so that it is understandable to a variety of public health stakeholders. In 2009 the CDC declared the visualization of public health data as one of its six areas of focus for the improvement of public health surveillance in the 21st century. The current under-visualization of HDSS data needs to be addressed with targeted efforts and this research will form the foundation towards the use of data visualizations in these sites as part of their scientific process rather than as an end-product. The work done by Chui *et al* will be improved upon by the addition of interactivity to the visualizations as well as dynamism and spatial dimension.

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APPENDIX A

| **Risk** | **Risk Level**  **Low(L)/Medium(M)/High(H)** | **Likelihood of Event** | **Mitigation Strategy** |
| --- | --- | --- | --- |
| Limitations in technical skills in the project team | **M:** Project assumes that technical skills are in place | Somewhat likely | Relevant skills to be acquired in the 2 month period prior to project start |
| Project running off schedule | **M:** Project is tied to a hard deadline | Somewhat likely | Using Agile methodology to break project artifacts into features to be delivered on weekly schedules. A one month buffer window will be incorporated to cover any unforseen schedule overruns. Monthly face to face with the primary supervisor will also ensure oversight. |
| Non availability of data sources | **M:** assumes no derailment | Somewhat Unlikely | The criteria for choosing the implementation site includes availability of the required data for integration |
| Change of supervision | **L:** Well-defined | Unlikely | N/A |
| Acquiring cartographic boundaries (for map based visualizations) from the relevant authorities may not be straightforward or timely | **M:** Assumes cartographic data already on site | Somewhat likely | Communicate with site supervisor early to know whether this data is available. |

APPENDIX B

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Activities  2014-2015 | October | November | December | January | February | March | April | May | June |
| Protocol submission to Wits Ethics Committee |  |  |  |  |  |  |  |  |  |
| Receive Standard Datasets from INDEPTH site |  |  |  |  |  |  |  |  |  |
| Creation of analytical queries for pre and post integration for validation purposes |  |  |  |  |  |  |  |  |  |
| Creation of Data Cleaning scripts to be used during ETL processes |  |  |  |  |  |  |  |  |  |
| Set up ETL solution |  |  |  |  |  |  |  |  |  |
| Writing data integrity programs for post integration validation |  |  |  |  |  |  |  |  |  |
| Create visualization engine |  |  |  |  |  |  |  |  |  |
| Document generalizable data visualization implementation processes |  |  |  |  |  |  |  |  |  |
| Write research report |  |  |  |  |  |  |  |  |  |
| Submission of research report |  |  |  |  |  |  |  |  |  |
| Prepare articles for submission to peer reviewed journals |  |  |  |  |  |  |  |  |  |

APPENDIX C – USE Questionnaire

**Usefulness**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1. It helps me be more effective | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 2. It helps me be more productive | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 3. It is useful | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 4. It makes the things I want to accomplish easier to get done | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 5. It saves me time when I use it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| 6. It meets my needs | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| 7. It does everything I would expect it to do | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |

**Ease of Use**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 8. The system is easy to use | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 9. It is simple to use | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 10. It is user friendly | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 11. It requires the fewest steps possible to accomplish what I want to do with it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 12. It is flexible | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 13. Using it is effortless | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 14. I feel comfortable using this system | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 15. The organization of information on the system screen is clear | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 16. Overall, I am satisfied with how easy it is to use this system | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 17. I am able to efficiently complete tasks using this system | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |

**Ease of Learning**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 18. I learned to use it quickly | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 19. I easily remember how to use it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 20. It is easy to learn to use it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |

**Satisfaction**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 21. I am satisfied with it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 22. It works the way I want it to work | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 23. It is pleasant to use | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 24. I feel I need to have it | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |
| 25. Overall, I am satisfied with this system | | | | | | | | |
| strongly disagree | 1 | 2 | 3 | 4 | 5 | 6 | 7 | strongly agree |
| □ | □ | □ | □ | □ | □ | □ |

26. What would you add/remove from to the system in order to improve it?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_