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Implementation of Emergency Department Performance Benchmarking Using R and LaTeX

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Abstract. The German Emergency Department Data Registry (GEDD-registry, AKTIN) provides an infrastructure for collecting and querying up-to-date medical records in a distributed manner. Within this framework, a benchmark report on cross-institutional comparison using the program R is prepared using routine data of participating hospitals. Currently, 16 emergency departments (EDs) routinely transfer data of 1,200 to approximately 5,000 patients per month to a federated GEDD-registry datawarehouse. Using various packages in the R environment, hospitals receive a monthly visual report on their data among all participating hospitals. Graphical representations are implemented using column diagrams and box plots. Reports currently contain 25 tables and 40 graphs. Benchmark reports are created in R-Studio and exported using Portable Document Format, PDF. Quarterly expert meetings with the heads of participating EDs are currently performed for further improvements. Preparation of external benchmarking reports with R enables a detailed data presentation for participating hospitals and ED managers.

Keywords. Benchmarking, Emergency Service, Hospital, GNU R, LaTeX, Emergency Department,

1. Introduction

1.1. Background

An external benchmark is essential for an emergency department (ED) to compare its performance and efforts with other institutions [1]. Improvements in morbidity and mortality could be achieved through continuous external benchmarking [2]. The goal of the publicly funded AKTIN project (DRKS-ID DRKS00009805) is the implementation of a German Emergency Department Data Registry (GEDD-registry) for quality management, health services research, and surveillance using e-health standards for

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processing routine medical data. The underlying data definition is the German Emergency Department Medical Record (GEDMR) by the German Interdisciplinary Association of Critical Care and Emergency Medicine (DIVI e. V.), that aims to create a clinical documentation standard for emergency patients. The Data Protection Working Group of the Technology, Methods, and Infrastructure for Networked Medical Research (TMF e. V.) has approved the privacy policy of the GEDD-registry. Project AKTIN was approved by the Ethics Committee of Otto-von-Guericke-University, Medical Faculty, Magdeburg (160/50-23.11.2015 Chair: Prof. Dr. med. C. Huth).

1.2. Requirements for Benchmarking

Quality management is important for optimizing patient treatment [3]. Through internal control mechanisms of hospitals, EDs can regularly assess their own quality of care and performance. However, to further improve existing performance, external benchmarking, i.e. comparison with other EDs, may serve as a tool for quality improvement. Such a comparison needs to fulfill certain requirements. First, except the own ED, participating EDs must not be identified. Second, the comparison must be based on valid and meaningful data, which can only be defined by clinical experts. Parameters of interest may be certain time spans or proportion of performed measurements of documented vital signs according to specific presenting complaints.

2. State of the art

Yet, routinely collected data across institutions cannot be used to draw conclusions regarding the state of emergency medicine in Germany based on daily ED documentation [4]. Paper-based documentation cannot be used for secondary usage without expensive digitalization. Although electronic data documentation exists, ED data cannot be used across institutions without further refinements [5]. Emergency Department Information Systems (EDIS) by different vendors are not compatible on the data or database level. Even in hospitals using the same brand product, systems differ owing to customized configurations based on different individual ED requirements. Furthermore, secure telematics infrastructure to access ED data is non-existent. In comparison, the German TraumaRegister® DGU registers the severely injured. An annual report comparing hospitals is presented thereof [6]. But data entry in a centralized data warehouse is primarily performed manually.

In the USA, the Emergency Department Benchmarking Alliance (EDBA) has been established since the early 1990s; it currently includes more than 1,700 hospitals. Each year, the EDBA creates a report to highlight the performance metrics of EDs, such that members can assess their EDs to improve medical care and patient satisfaction [7].

3. Concept

3.1. Concept of AKTIN

The aim of project AKTIN is to create a uniform and standardized electronic data collection of ED patients in participating hospitals and to use these routinely collected treatment data for quality management and research. To date, the GEDD-registry has been implemented in 16 hospitals across Germany [9]. GEDMR was modeled and implemented using HL7-CDA as a standardized interface [10–12] in eight different EDIS. Currently, project hospitals routinely transfer data of 1,200 to approximately 5,000 patients per month to a federated GEDD-registry with local datawarehouse (DWH) instances and centralized query infrastructure. Hospitals enter data into their EDIS implemented either as a stand-alone system or as part of the Hospital Information System routine medical documentation. Data are transferred to the local DWH instance implemented with i2b2 through standardized HL7-CDA-interface by the RESTful protocol [5,10,13,14]. Data queries are reviewed first by a scientific board and subsequently forwarded to participating hospitals. Data retrieval and transfer must be approved by a local executive. Anonymized data exports from local DWHs are pooled and processed centrally [15]; data flow is shown in Figure 1.



Figure 1 Submission of emergency department CDA document to the local data warehouse with generated logs and status reports [16].

3.2. Concept of benchmarking reports

SPSS, SAS, STATA, Python and R are popular statistical software programs. Commercial high-priced programs such as STATA and SAS are powerful solutions, but not compatible with limited financial project resources. SPSS was inapplicable owing to insufficient technical features. For open-source solutions, R and Python offer numerous functionalities that correspond to the project requirements. R was favored owing to personal experience with the environment. R-Studio and LaTeX were used to create a visual representation of a monthly benchmarking report for cross-institutional comparison. R-Studio is an integrated development environment and graphical user interface for R. LaTeX is a software package that simplifies text typesetting system TeX using macros to generate PDF files. Another possibility to present data to the ED is a web application such as R-Shiny. This was omitted because data security, which is crucial when using clinical data, was not guaranteed.

4. Implementation of benchmarking reports

Data collection for benchmarking reports follows the data flow described in the concept. Currently, data queries use the following data elements of the GEDMR:

- Gender and age in years
- Date and time of admission, acuity assessment (triage), first physician contact, and discharge/disposition
- CEDIS presenting complaint [17], triage category
- Type of: referral, transport to ED, admission, discharge, and transfer
- Oxygen saturation and pain measurement using numeric rating scale

Comparability between hospitals is achieved by creating a large dataset containing all information of all hospitals. Individual variables are assigned fixed formats to avoid data loss. Hospitals are identified by numeric IDs. The ID corresponds to the hospital server number assigned in the project for linking data. Data are provided to the Data Analyzing Center separately for each hospital as a comma-separated file (csv). Data import and processing utilize different R packages from the Tidyverse collection. For data import, package readr with command read_delim is implemented. Package dyplr is used to filter (filter), group (group_by), or summarize data. Package data.table is applied for selecting partial datasets. Package "lubridate" facilitates date field editing. Package "tidyr" addresses missing data (NA - not available) through delete (drop_na) or replace (fill) NAs [18,19]. Visual representation of individual graphs is realized through graphics package "ggplot2" [20]. In the report, the respective hospital is highlighted red in each diagram with the anonymous reference hospitals marked blue. Furthermore, corresponding bars, box plots etc. are marked with "your hospital" (see **Figure 2**).



Figure 2 Hospital marked with "your hospital" shown in the example of the graphic count of patient contacts per month.

Tables in LaTeX format are created using "xtable" (Figure 3 and Figure 4). Reports are compiled using LaTeX in the R-Studio (sweave) environment and converted into PDF file format for distribution to hospitals.

```
% latex table generated in R 3.5.1 by xtable 1.8-2 package

% Thu Mar 07 08:56:57 2019

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Figure 3 Table created with "xtable" in LaTeX.

Ihre Klinik Mean	SD	Ref-Kl Min	Q1	Median	Q3	Max	Mean	SD
50	25	42	48	53	55	60	52	6

Figure 4 Final table of figure 3 in the report.

Benchmark reports have been created monthly since May 2018. Owing to varying compliances, the number of hospitals contributing data varied between 10 to 16 hospitals per month. Graphical representations are implemented using column diagrams and box plots. Current benchmarking reports for EDs currently comprise 40 graphs and 25 tables with various evaluations on individual data points of GEDMR. The reports include for example, patient numbers per month or patient characteristics, such as gender and age (Figure 5).



Figure 5 Age of patients in comparison.

Primary focus is the evaluation of data according to ED requirements by heads of participating ED. This includes average patient admission per hour, acuity assessment, presenting complaint with associated vital signs, and patient disposition. Some of these points are placed chronologically to better represent patient flow in EDs. Box plots in **Figure 6** show average number of admissions per hour calculated in a month. The red line corresponds to the average value of all hospitals. A further indication in this diagram is the maximum number of contacts per hour and how often this maximum occurred (N_{max}) in a month.



Figure 6 Average admission numbers per hour, maximum per hour and how often this maximum occurred (N_{max}) .

Figure 7 shows the average time a patient had to wait for acuity assessment (triage). In addition, the number of patients of the ED in question who received an acuity assessment, based on all cases considered, is provided. In this case, negative times can occur if a patient was assessed before admission.



Figure 7 Length of time to acuity assessment (triage) and count of patients who received an acuity assessment.

5. Lessons learned

Implementation of an external benchmarking based on the infrastructure and federated databases of the GEDD-registry with R, R-Studio, and LaTeX is presented herein. Several descriptions of benchmark tool implementation have been published, but they do not mention the programs that were used to create those tools [21–23]. R packages were selected based on common basic design philosophy, grammar, and data structure; thus Tidyverse [18] and other packages were selected. With these, regular data

integration, management, and visualization for ED physicians were feasible for the previous 10 months. Integration of packages into R improves the possibilities of providing EDs with a visualized representation of their performances. Particularly, "ggplot2" is a valuable tool for data presentation integrating different data frames. Using R allows for high-grade automatization and requires only little effort for adapting graphics and tables, while R-Studio creates benchmarking reports with LaTeX [24]. Report presentation quality depends on the quality of data provided as well. Quarterly expert meetings with head managers of participating EDs are crucial for further improvements. Discussion of reports uncovers data quality problems, different interpretations of data definitions, and differing processes within participating EDs. Furthermore, report discussions are important for constant improvements in data analysis and presentation. The authors considered creating and providing an R package to avail their benchmark to other users. Owing to the special requirements of ED data, the authors will not use a general R-bundle and instead will avail the source code as a free and open-source software on GitHub: https://github.com/aktin/benchmark. The current solution requires anonymized data to leave the EDs and to be processed at the Trusted Data Center. However, for data protection reasons, the aim is to aggregate data within EDs by implementing distributed computing. Further calculations and report creation will then be performed centrally based on aggregated data using the R-Script presented herein.

6. Conclusion

To achieve a cross-institutional comparison between EDs, uniform data documentation is required. A corresponding infrastructure was implemented by AKTIN. Creating external benchmarking reports using R and R-Studio was feasible in a federated registry environment and allowed for detailed data presentation to participating hospitals. Additionally, programs such as R facilitate saving resource reduction by processing large amounts of data and creating visually appealing diagrams using additional packages like LaTeX. Possibility for source code adaption to ED requirements in R and LaTeX is an appealing advantage of these open-source programs. To date, implementations presented are primarily pilot benchmarks. Currently, a benchmark is primarily used to analyze, compare, and improve data quality. Once sufficient data quality is achieved and relevant quality indicators are established, ED performances can be compared based on these benchmarks. In 2003 Schwappach et. al. demonstrated the importance of benchmarking in a study involving 12 Swiss hospitals, thus resulting in improved performance measures. For example, the median duration between ED admission and documentation of post-ED disposition reduced from 137 min in 2001 to 130 min in 2002 [8]. Wind et al. analyzed projects pertaining to benchmarking in the hospital sector. They identified 1,817 articles and demonstrated that the benchmarks in areas of eye clinics, EDs, and oncological clinics were developing significantly. However, publications on benchmarking in German EDs are unavailable [1]. Results of benchmarking reports enable ED managers to guide their staff, improve processes, and indicate possible problems to the hospital's executives and, if possible, eliminate them.

Advantage of the AKTIN benchmarking is the variety of participating IT-systems and hospitals, which are distributed nationwide and belong to all levels of care. This enables to describe quality of care and identify general problems on a monthly basis.

Independency from particular IT-systems and platforms allows for additional hospitals to be integrated into the AKTIN infrastructure without much effort.

Conflict of Interest

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