García-Peñalvo, F. J., Vázquez-Ingelmo, A., & García-Holgado, A. (2022). Fostering Decision-Making Processes in Health Ecosystems Through Visual Analytics and Machine Learning. In P. Zaphiris & A. Ioannou (Eds.), Learning and Collaboration Technologies: Designing the Learner and Teacher Experience. 9th International Conference, LCT 2022, Held as Part of the 24th HCI International Conference, HCII 2022. Virtual Event, June 26 – July 1, 2022. Proceedings, Part II (pp. 262–273). Springer Nature. https://doi.org/10.1007/978-3-031-05675-8_20

Fostering Decision-Making Processes in Health Ecosystems Through Visual Analytics and Machine Learning

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Abstract. Data-intensive contexts, such as health, use information systems to merge, synthesize, represent, and visualize data by using interfaces to ease decision-making processes. All data management processes play an essential role in exploiting data's strategic value from acquisition to visualization. Technological ecosystems allow the deployment of highly complex services while supporting their evolutionary nature. However, there is a challenge regarding the design of high-level interfaces that adapt to the evolving nature of data. The AVisSA project is focused on tackling the development of an automatic dashboard generation system (meta-dashboard) using Domain Engineering and Artificial Intelligence techniques. This approach makes it possible to obtain dashboards from data flows in technological ecosystems adapted to specific domains. The implementation of the meta-dashboard will make intensive use of user experience testing throughout its development, which will allow the involvement of other actors in the ecosystem as stakeholders (public administration, health managers, etc.). These actors will be able to use the data for decision-making and design improvements in health provision.

Keywords: Domain engineering · SPL · Meta-modeling · Information dashboards · Information systems · Healthcare · Health domain

1 Introduction

Information systems have become a critical factor in several contexts. They allow the unification, formatting, processing, and visualization of data through user-friendly interfaces [1]. Moreover, COVID-19 has accelerated the digital transformation in all the business domains such as education [2–6], political decision-making [7, 8], tourism [9, 10], and health systems [11, 12], among others.

Some data-intensive contexts, like the health context [13], present more complexities in their decision-making processes due to the heterogeneity of the data sources and the different formats involved (structured data, echocardiograms, magnetic resonances, etc. [14–17]). For these reasons, it is necessary to tackle these issues with robust methodologies that enable the development and collaboration of complex services.

This work presents a project focused on tackling data and knowledge management issues in complex contexts. The approach leverages meta-modeling, domain engineering, and artificial intelligence to generate information dashboards that assist decision-making processes.

The rest of this paper is organized as follows. Section 2 provides background for the project proposal. Section 3 outlines the objectives of AVisSA. Section 4 details the methodology followed, and Sect. 5 discusses the project's expected outcomes. Finally, Sect. 6 presents the conclusions derived from the work.

2 Background

Since 2012, the GRIAL Research Group [18] has been developing information technology (IT) solutions for the health sector in collaboration with outstanding partners such as Intras Foundation, which provides support for qualitative data analysis and the usability of solutions built around psychiatric care aspects, Salamanca University Hospital, which develops various software systems, and ArSoft, which researches medical image segmentation. Furthermore, the GRIAL Group is affiliated with the Institute of Biomedical Research of Salamanca (IBSAL).

Technological ecosystems are the natural evolution of IT systems. These ecosystems enable the development of highly complex services while maintaining their evolutionary nature. The main goal of the previous R&D project, the DEFINES project (A Digital Ecosystem Framework for an Interoperable NEtwork-based Society, ref.: TIN2016-80172-R), funded by the Spanish National Research Plan (that ended on June 2021), was to develop a framework of a technological environment as support of services for the management of corporate knowledge, dubbed technological ecosystem [19]. In the context of the TE-CUIDA project, this framework was established in a technological ecosystem for the care domain to provide comprehensive and distant assistance for the needs of official and informal care providers (e.g., family members) of dependent older people (TEchnological ecosystem for support for caregivers, ref.: SA061P17) [20].

In terms of technology, the significant outcomes of both projects allow for the solution of the problem through the design and development of a technological ecosystem that is in line with current software architectures. In this approach, we've proposed a generic framework with a solid evolutionary component, whose architecture can be used in various situations and allows for integrating other software tools and developing new services that add value to the ecosystem.

As an example of the strategy's relevance, it's clear that technological ecosystems in the field of health have sparked much interest in recent years, as evidenced by the several European-funded projects that use a similar approach [21].

However, during the previous projects' review of state of the art, a common lack was discovered [22]: despite their immense potential, technological ecosystems in the health sector face challenges when deployed in real contexts, resulting in the majority of concepts never progress beyond pilot testing.

Comparing the health field with other fields in which technological ecosystems are a reality, it was concluded that proposals in the health sector tend to ignore the evolutionary characteristic of the ecosystem. This capacity to incorporate new tools and services means that the data exchanged, and the knowledge generated in this type of solution has a high added value for other potential users of the ecosystem, beyond the users who are the primary objective of the solution. Besides, the challenge remains at the high-level interfaces to create control panels or dashboards that adapt to the evolving and changing nature of data.

In this light, the current project aims to create a fundamental pillar not only for the success of the ecosystem framework proposed in DEFINES and implemented in TE-CUIDA but also for the development of a solid ecosystem architecture that can be extrapolated with guarantees of success when implementing new services and incorporating new actors that contribute to the ecosystem's evolution. This pillar focuses on using information dashboards [23], which are tools for the graphic representation of the leading indicators involved in achieving the objectives within an ecosystem (e.g., degree of success in providing a service) designed to assist in decision-making processes. The goal is to encourage the extraction of knowledge inherent within the information flows between the ecosystem's components and actors by presenting tailored data for each type of user using visual metaphors.

Dashboards are powerful visualization tools capable of combining various heterogeneous data sources from the components of the ecosystem. Still, their development and configuration have a high degree of complexity due to the heterogeneity of the data, the particular needs of the final users of the dashboard itself, and the evolutionary nature of the technological ecosystems that causes the software components to change, be removed or added to meet the changing needs of the ecosystem itself [24, 25]. These characteristics directly impact manually-developed dashboards [26], which need to address the problem from a software perspective and consider the user experience and application (and data) domain.

This project, AVisSA, aims to develop an automatic dashboard generation system for decision-making in Health ecosystems.

3 Objectives

AVisSA will address the development of an automatic dashboard generation system that adapts to data analysis and knowledge management needs in heterogeneous contexts such as the health sector to improve these processes within the health system, impacting decision-making processes.

The automatic generation of these tools will be based on domain engineering and artificial intelligence techniques to obtain customized products with lower development costs.

Identifying the primitive elements of a dashboard and visualization (such as the scales, axes, visual marks, etc.) allows for greater flexibility when setting up an automatic dashboard generation. It determines the influence and usefulness of the various visual elements according to the context.

On the other hand, branches of artificial intelligence as Machine Learning approaches [27–29] can be applied in conjunction with this paradigm to obtain tailored tools. These tools are fed by the particularities of the user, offering the most suitable components to gain insights and for the achievement of their particular objectives [30].

To achieve the main objective of the project, a set of specific goals are proposed:

- O1. Establishing automatic mechanisms for collecting and analyzing knowledge in the technological ecosystem.
- O2. Developing methods for the storage and anonymized (or pseudo-anonymized) treatment of data. Since medical data may be combined with data related to platform usage, best practices will be established to ensure compliance with privacy regulations and legislation.
- O3. Automatic generation of indicators, metrics, and tools that facilitate decision-making for different types of users in the technology ecosystem (e.g., health professionals, managers, and administration members).
- O4. Using artificial intelligence techniques for automatic customization of data visualization forms to suit the application domain and the preferences and characteristics of each user.
- O5. Providing simulation spaces for training or diagnosis processes based on automatically generated dashboards, including machine learning capabilities with the presented data and learning analytics of the educational actions.
- O6. Evaluating dashboard usability and satisfaction (in terms of the capacity of software to be understood, learned, used, and appealed to the user).
- O7. Evaluating the evolutionary and adaptive capacity of the architecture through its implementation in two sufficiently differentiated case studies: the healthcare field and the monitoring of medical tests based on images.

Achieving these objectives will provide the following benefits:

- Providing tools that allow decision-making based on the visualization of heterogeneous data, regardless of the application domain (e.g., medical data, treatment adherence, patient behavioral trends, etc.).
- Attracting new actors to the ecosystem, providing new services, and adding value to the existing solution (public administration, companies in the health sector, etc.).
- Establishing new synergies with other areas of the health sector (e.g., research networks interested in available data).
- Opening new business channels that allow the commercialization of the solution.

4 Methodology

4.1 Coordination

It is essential to define and plan the tasks adequately, to correctly manage the complexity of the project's objectives and its interdisciplinarity and multidisciplinarity. Six activities are proposed in a 48-month window.

Activity 1 is devoted to the project coordination based on the PRINCE2 (PRojects IN Controlled Environments) project management methodology [31].

4.2 Systematic Literature Review

Activities 2 and 3 represent technological innovation. They will start with in-depth research in the recent advances within the particular context of the automatic generation of dashboards in healthcare environments through SLRs (Systematic Literature Reviews) [32, 33]. Also, the categorization of the data to be extracted, KPIs, and metrics suitable for the different ecosystem actors and users will be addressed in this stage. Based on the best practices and challenges, action-research cycles [34] using SCRUM [35] will be applied. These activities will result in a meta-dashboard implemented and tested in a controlled context, also considering the data life cycle.

4.3 Dashboard Generator

For the conceptualization of the dashboard generator, a meta-modeling approach will be used, allowing extraction of the characteristics of the dashboards domain to obtain a dashboard meta-model that contains the abstract and generic features of these tools. Also, the meta-model will focus not only on the dashboards' technical characteristics and functionalities but also on the human factor.

This allows establishing both a practical framework when developing dashboards and a theoretical work on the technical and end user-related elements that should be considered when designing these tools. Among the details related to the end-user, there exist many determining factors for the correct interpretation of the information displayed: level of data domain knowledge, visual literacy, or even potential biases. Although these factors may seem abstract, it is possible to categorize them to obtain user profiles to build visual tools that allow effective visualization and understanding levels.

The Software Product Lines (SPL) paradigm will be used to develop the meta-model. This paradigm offers a development framework of reusable components based on a previous domain analysis (domain engineering phase) to combine them to obtain customized products adapted to different contexts. Two significant benefits can be attained using this paradigm in conjunction with meta-modeling. The first one is the decrease in the development time of these visual tools since they are generated through the composition of previously developed software assets. The second is the flexibility in the generation process.

Specifically, identifying the primitive elements of the dashboards allows improving their scalability. Once the software assets are designed, it is only necessary to assemble them to obtain any dashboard with any number and type of displays. Besides, because the elements identified are generic, the data domain is not a determining factor when generating dashboards. The high-level layer provided by the meta-model allows to abstract more specific aspects of the information to be displayed, allowing this solution to be adapted to any data set. Finally, thanks to this abstraction of information, it is possible to establish connection mechanisms between the dashboard and the elements of any ecosystem [36].

4.4 Evaluation

During activity 4, a mixed approach (quantitative-qualitative) was chosen for the evaluations because not all observations are susceptible to quantitative measurement when working in terms of the user experience. Therefore, results analysis requires differentiation not only in terms of quantity (quantitative) but also in terms of quality (qualitative). A priori, neither quantitative nor qualitative research is superior to its counterpart and responds to the same inferential logic: both can be equally systematic and provide similarly helpful information [37]. Moreover, if both types of data are integrated and converge, the validity of the obtained generalizations is reinforced.

Activity 5 is devoted to using the meta-dashboard created in activity 4 to generate simulators for training and diagnosis processes, including machine learning capabilities to help students or professionals analyze the medical data they are visualizing and learning analytics functionalities to have comprehensive information about the simulator usage.

Regarding the experimental phases (activities 4 and 5), this research work will make intensive use of the usability laboratory funded by the network of Networked Infrastructures of Castilla y León (INFRARED - ref. USAL05), of which the GRIAL group is a collaborating member.

The user experience studies will be of an ex-post nature, and within this modality of designs, we will opt to carry out a descriptive study of exploratory nature. On the one hand, combined methods such as Conductor and Thinking Aloud will be employed to test the developed tools' use. Besides, a descriptive study using surveys will be carried out and analyzed using correlation techniques. Thus, the research questions will be answered in descriptive terms and in terms of the relationship between variables and after a systematic information collection. This will ensure the rigor and validity of the obtained information.

For the survey-based research, three phases will be established [38]:

1. Theoretical-conceptual: setting out objectives and research hypotheses
2. Methodological: selecting the sample and the variables under study; formulating and preparing the experimental environment.
3. Conceptual statistics: codification and data analysis to obtain results from which generalizations can be made. Furthermore, integrate the conclusions drawn into the initial theoretical framework.

Finally, and thanks to the specific facilities of the usability laboratory, a logging process of the users' interactions with the system will be carried out. These loggings will be correlated with the results obtained in the other investigation and survey stages. The relevance of the results will be verified, on the one hand, from the point of view of usability by experts of the GRIAL design research team, and on the other hand, from a socio-health point of view by members of the research team with experience in this field.

Activity 6 is oriented to disseminating results and exploiting the developed meta-dashboard.

4.5 Team

The team comprises 16 members (7 in the research team, 9 in the work team). 71.43% of the research team members are males, 28.57% of the members are females. 87.71%

of the members of the research team have a Ph.D. degree. 44.44% of the work team members are males, 55.56% of the members are females. 66.67% of the members of the work team have a Ph.D. degree. From the global perspective (16 members, including both research and work teams), 56.25% are males, 43.75% are females, and 75% have a Ph.D. degree. The roles of software engineer, medicine, and neuropsychology mean interdisciplinarity, an expert in educational technologies, and academic researcher suggest multidisciplinary. Finally, manager and data manager roles are the technician profiles for supporting research.

5 Expected Results

5.1 Scientific and Technical Impact

The achievement of the objectives of the present proposal will have a substantial impact on the promotion and generation of frontier knowledge. Specifically, in the following areas:

- Scientific impact and international leadership in the field. The automatic development of dashboards, through a meta-model, allows obtaining visual analysis tools adapted to any domain, facilitating the exploitation of data. Due to the flexibility and adaptability of the dashboards generated using artificial intelligence techniques, the best configuration and design according to the context can be attained. The proposal is at the frontier of state of the art, not only in the health field.
- The innovation of the ideas on which it is based. The systematic studies show no such solution in healthy ecosystems, and meta-dashboards are just developing in other fields. Different techniques have been proposed in the literature to create and adapt dashboards (among them, meta-modeling). Still, most of their applications have not been produced or evaluated in authentic contexts.
- Interdisciplinary and multidisciplinary scientific approach. The approach of the project requires the collaboration of various areas of knowledge. Different experts are involved in domain engineering-based software development, in human-computer interaction for the evaluation of the user experience in the usability lab, and technical staff with expertise in socio-sanitary technologies given the scope of the ecosystem.

More specifically, it is worth noting that the challenges faced by the currently available solutions in the province of dashboards are more accentuated in the field of the health sector. Technological ecosystems and, more specifically, dashboards are a domain that is still in the early stages of development, especially in Spain. With the current health information systems, the static characteristics of performance reporting in the health care sector have resulted in inconsistent, incomparable, time-consuming, and static performance reports that can transparently reflect a round picture of performance and effectively support healthcare managers' decision-making processes. So, the healthcare sector needs interactive performance management tools such as performance dashboards to measure, monitor, and manage performance more effectively.

Software solutions such as dashboards have been commonly related to Business Intelligence (BI) [39]. They allow their users to better manage their data by providing data analysis, information presentation, and integration with other business development environments through metadata management.

To understand the value that this proposal brings by integrating processes and services available in the BI solutions market, it is essential first to identify the challenges that arise within the activities carried out to deploy this type of solution. In general terms, the current BI type solutions, and more specifically, dashboard development, present the following challenges for their deployment:

- Data collection guarantees data quality and consistency among different actors, lines, or processes, including mechanisms to restrict access to information.
- KPIs and Metrics.
- The visual component extrapolates the visualization structure to different processes, lines, or business models.
- To achieve the definition of the dashboard itself, the post-deployment activities are associated with the analysis of the information flows that are established between the ecosystem components and users.

The challenges mentioned above are accentuated when attempting to deploy dashboards in technological ecosystems since they have characteristics that are not present within the areas that traditional BI solutions focus on:

- Its evolutionary component, so that the ecosystem must adapt to changes, both in the context where the ecosystem is deployed and to the changing requirements of users.
- The human component is a fundamental part of the ecosystem at the same level as the software components.

For the above reasons, the success of the current proposal involves a series of improvements over existing solutions:

- The development of a meta-dashboard that can be incorporated into any technological ecosystem so that the definition of the dashboard itself is associated with the analysis of the information flows that are established between the different components of the ecosystem. As well as the interaction of users with the ecosystem technologies.
- The possibility of implementing it in the health environment that has differentiated needs and will improve the knowledge transfer.
- The above will open the market and promote interest in this type of solution from organizations that are part of technological ecosystems or technological solutions in the health sector and have not considered BI a key to their business or activity.
- Provide unified mechanisms to seek the integrity and quality of data from different sources and with varying quality criteria.

5.2 Socio-Economic Impact

The AVisSA technological ecosystems sought to satisfy the aging and care provision challenge, with the particularity of considering the differential characteristics of the Spanish population consisting of the geographical dispersion. Innovative solutions are needed in active aging, especially to allow for an autonomous life in their home environment for as long as possible. Besides, the implementation of the meta-dashboard will enable the incorporation of other actors as stakeholders (public administration, health managers, etc.) who will be able to access the data generated within the ecosystem for decision making and design improvements in health provision.

The exploitation of the data will make it possible to promote the ecosystem between primary users (doctors, caregivers, and patients) and secondary and tertiary users (managers, public administration, research networks), significantly increasing the viability of the initial proposal. Healthcare dashboards can be used for various purposes, including strategy analysis and execution, performance reviews, performance improvement, data comprehension, and scope opportunity.

On the other hand, from an economic perspective, the dashboard market has evolved from being a resource generally used by large companies to monitor their commercial departments to being used in diverse contexts. Each metric can be broken down, analyzed, and correlated with other information.

The main factor driving the growth of the dashboard software market is the increasing appearance of a large amount of structured and unstructured data that different organizations and companies must manage. One of the fundamental causes of this paradigm shift is that data generated by the interaction of users with companies through digital channels is experiencing a faster growth rate than conventional business data. This, together with the high competition between companies due to an increasingly globalized market, is one of the main factors driving the growth of the global dashboard market. Dashboards allow to show in real-time the trends of the different indicators of interest and offer information that can be used in strategic decisions of businesses and all types of organizations.

6 Conclusions

This work describes the AVisSA project, which will address the development of an automatic dashboard generation system (meta-dashboard) based on the data flow in technological ecosystems.

The meta-dashboard will automatically adapt to the needs of analysis and knowledge management in heterogeneous contexts such as the health sector, to improve these processes within the health system, with special impact on decision-making processes. The implementation of the meta-dashboard will make intensive use of user experience testing throughout its development, which will allow the incorporation of other actors in the ecosystem as new stakeholders (public administration, health managers, etc.).

These actors will be able to make use of the data for decision-making and improve the health provision. The exploitation of the data will make it possible to promote the ecosystem from its primary focus on primary users (caregivers and patients) to secondary and tertiary users (managers, public administration, research networks), significantly increasing the viability of the initial proposal. Thus, these tools that support decision-making will improve both the quality of the services provided and their economic efficiency.

Acknowledgments. This research work has been supported by the Spanish *Ministry of Education and Vocational Training* under an FPU fellowship (FPU17/03276). This research was partially funded by the Spanish Government Ministry of Science and Innovation through the AVisSA project grant number (PID2020-118345RB-I00).

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