Eco-Sustainability and Efficiency of Healthcare Complex Systems

Ilaria Angela Amantea[1][a] and Marinella Quaranta[1,2][b]
[1]*Computer Science Department, University of Turin, Turin, Italy*
[2]*Department of Law, University of Bologna, Bologna, Italy*

Keywords: Healthcare, E-Health, Digitalization, Complex System, Simulation, BPM.

Abstract: Healthcare is one of the most difficult complex systems to optimize. The challenge is in the multiple factors to balance. Some are common to many other industries, while some are riskier, and the whole system must be well-balanced to flow and ensure the functioning of a vital service for the citizens. The close interconnection between the various factors means that making changes on one aspect will have cascading effects on many other aspects. Therefore, the optimization must not be done considering a single parameter, but considering the whole chain. According to the European objectives of digitalization and eco-sustainability, in this paper we present an overview of the impact of digitalization of certain paper documents on process activities, times, costs, and spaces of archives.

1 INTRODUCTION

Healthcare structures are ”complex systems”. Namely, a complex system is a system made of (i) interacting component parts and (ii) exhibits dynamical behavior that cannot be inferred from the behavior of the parts themselves (Motter, 2004). Complex systems have also been defined as an ensemble of many elements that interact in a disordered way, resulting in robust organization and memory (Ladyman et al., 2013). Thus a complex system is a collection of interconnected elements that present emergent behavior, which means that a whole system displays properties and behaviors that are not directly predictable from each behavior of individual parts. They also include non-linear dynamics (small changes lead to impacting effects), and properties that may be difficult to anticipate or control. This also makes them vulnerable to some failures (e.g. cascading failures) and unpredictable behavior.

Generally, in healthcare, there are a relevant amount of features to take into account. There are medical norms, medical guidelines, and medical protocols that are strictly related to the diagnosis, cure and prevention of conditions, diseases and pathologies. These elements are not only regulated by the law but also by practical elements, e.g. the ability to manage emergencies and criticalities that fall outside the guidelines. Healthcare structures have a large number of variables, thus, there is a multitude of tasks that could suffer from bad management, as for less visible criticalities and bottlenecks. Once they become visible, they can be optimized.

Time can be pivotal in healthcare structures, but reducing time in tasks generally leads to an increase in number of patients to be taken care of. With a new load of patients, staff get overloaded with work or might have to work under pressure, as usually an increase in workload does lead to a congruent adjustment in staff employment. Human staff cannot be subject to machine-like rhythms, they need and have the right to rest. They are also entitled to balanced and reasonable work shifts. Such conditions are needed not only to be compliant with contracts but also because a tired physician could make mistakes in treating patients. Less rest impacts on risk of clinical and treatment errors. Cost is also pivotal in healthcare structures. Normally cost optimization is linked to cutting staff or services, but this enhances the issue of the quantity and quality of care services provided to the citizen, and again, it impacts the workload of the remaining staff. Times, costs, and qualities are the three features to be balanced in healthcare structures. Depending on the goal, it is possible to optimize two of such features, which inevitably deteriorates the third feature. It is not possible to optimize all three features if available resources continue

[a] https://orcid.org/0000-0003-1329-1858
[b] https://orcid.org/0000-0003-2691-0611

Amantea, I. and Quaranta, M.
Eco-Sustainability and Efficiency of Healthcare Complex Systems.
DOI: 10.5220/0012857400003758

In *Proceedings of the 14th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2024)*, pages 423-430
ISBN: 978-989-758-708-5; ISSN: 2184-2841

to stay the same. This scenario could lead to new generalized problems (long attendance lists, delays, daily errors, etc.). Optimizing all three features only become possible in case available resources increase.

The European Union has been pushing for years towards the digitalization of public systems, public administration, courts, healthcare etc. and member states are following along.

The European Union prioritizes digitalization, particularly in public administrations, and has made significant progress through the "NextGenerationEU" recovery plan, which includes numerous digitalization projects(Amantea et al., 2023). In the e-health sector, the European Commission has proposed the European Health Data Space, aiming to facilitate the free movement of citizens by ensuring health data accessibility across member states. Despite high-level legal norms and national legislation supporting digitalization, effective implementation requires internal protocols within healthcare infrastructures. Without these protocols, traditional paper processes may persist(Amantea et al., 2022a). Therefore, especially for public facilities like hospitals, digitalization will mean compliance with European prescriptions.

In Italy, hospitals currently print an enormous amount of paper for prescriptions, informed consents, medical forms, clinical documents, reports, internal organizational documents, etc. In terms of costs, these printing costs in the long run can weigh on the total budget of a hospital, while in time terms, the time used in printing these papers significantly lengthens waiting times for patients. These documents must be kept in the possession of healthcare facilities for a certain amount of time set by the law (on average from 2 to 10 years depending on the type of document). This also means that several rooms must be saved as archives and cannot be used for clinical care. There are further obligations set by the law on these kinds of documents: paper documents (such as medical reports) must be physically collected from the patient, while the physical search and distribution of medical reports implies additional time for the administrative staff of the hospital, the existence of an office with designated personnel, an archive, the presence of patients and physical waiting queues in structure. Also, in case long-archived documents are needed, a manual search through a considerable amount of paper is needed.

Our research is based on a collaboration with healthcare facilities in Piedmont, our collective aim is to ease the digitalization process. We will refer to the digitalization of the "Azienda Sanitaria Locale Torino 3 - ASLTO3", which is a local health care service, a public health entity working in the Piedmont Region. The goal of this paper is to show how digitalization could come as a solution: by digitizing some documents that are currently on paper, it could be possible to maintain the same quality of service while reducing costs. This would also be possible due to the already existing server and information system. However, this specific function of the system is not yet in use.

The savings in costs could be used to increase human resources or equipment, which would lead to an improvement in the workload, an increase in the well-being of the working environment, and could lead to a decrease in times (e.g. printing times and times for searching in the archives). Finally, it could also increase the total number of visited patients.

The paper is structured as follows: Section 2 will outline the methodology and the background; Section 3 shows the case study experiments that imply processes, simulations, results, and related comments and observations; finally, Section 4 presents some conclusions.

2 METHODOLOGY

In medicine, the organization of health processes is a fundamental aspect to examine and it should be examined by taking a holistic and systemic approach. Also, computer science gained a relevant role in technical hardware and information systems improvements (Dumas et al., 2005).

To analyze the healthcare facilities' business processes, we used the business process management methodology (BPM) (Dumas et al., 2018) a discipline combining data science and management studies to perform business process improvement, modeling and simulation (Sulis and Di Leva, 2017). A key objective within BPM is change management (Amantea et al., 2020a). By emphasizing a process-centric methodology, we illustrate the business process through the standardized language of the Business Process Model and Notations (BPMN). The methodology takes a process-centric stance and involves a process-aware information system alongside the iGrafx simulation tool. These tools are used to reshape their business processes. Through the integration of these methods, we can scrutinize activities, resource allocation, timeframes, costs, delays, and bottlenecks (Martinho et al., 2016). These information are based on authentic data stored within the information system (IS). For all these reasons BPM methodology is one of the most used methodologies to optimize many aspects of healthcare system and/or regarding the e-health system processes (Amantea et al., 2020b; Amantea et al., 2022b; Amantea et al., 2021; Sulis et al., 2019).

The reorganization of processes involves three main stages:

- **The analysis of the context:** the analysis is needed to examine the current context of a process, in order to grasp which improvements are needed at different levels.
- **The business process analysis and simulation:** the analysis examines step by step a chosen process with the aim of creating the As-Is model of the process. The As-Is model is used for simulation and its performance indicators are used for validation.
- **The re-engineering and scenario analysis:** with the knowledge of delays, bottlenecks, and errors in the process, a new scenario (To-Be model) is proposed by building a process proposing different configurations in a *what-if* analysis. The final purpose is the optimization of the chosen process.

The specific functions and tasks of the process can be addressed by a set of process performance measures (also called key performance indicators or KPIs) (Van Looy and Shafagatova, 2016). These performance measures usually include time, costs and resources. The goal of business process analysis is to create and specify a visual representation of processes, such as a flowchart or a process map. The As-Is model depicts the state of the business process as it now exists, the graphics help in visualizing the flow of activities and several crossroads, which are called gateways. The gateways lead to different paths as a result of the decisions made. There is further integrated information such as the number of human resources carrying out the tasks, their attributes (aka schedule, expenses, and capacity), the duration of tasks, the policy management, and the real-life workload. As a result, the stakeholders may be able to test and validate the model by using the simulation to get an assessment of the performance metrics.

3 EXPERIMENTS AND RESULTS

The context of our experiment is the "Azienda Sanitaria Locale - Torino 3 (ASLTO3), which is one local healthcare service, a typical public health entity in Italy. It involves a number of hospitals and territorial hubs in specific areas of Italian regions. They provide public health services to the population of a specific area in Piedmont. In this paper we only take into consideration a department, the radiology department, of the ASLTO3. This means that our experiment has been conducted on all the radiology departments of hospitals and territorial hubs that fall under the authority of the ASLTO3. The digitalization experiment will take into consideration the paper process of administrative documents, not diagnostic documents or medical records. The medical staff is shared between hospitals and territorial hubs. All the medical staff pertain to the ASLTO3 as a whole and thus it operates in every structure. As for this centralization, the cost center and the archive are the same for all the radiology departments.

3.1 The Processes

Figure 2 shows the the current (As-Is) administrative process carried out both in the hospital and in the territorial hub in the radiology department. In both cases, they need to print the prescriptions and the informed consent for the exams in order to archive them. In particular, at administrative level, when the patient arrives he/she is asked what exam should be done, the identity documents, and the prescription. The patient can have printed or online prescription. If it is printed on paper, a code is printed for the specifications of the exam and the procedure of acceptance records the presence of the patient in the ward. If the prescription is digital, the administrative workers still have to print a paper version as the current legislation provides for the retention in paper of the prescriptions of any the exams carried out at the hospital. In the hospital and in the territorial hub the administrative procedure is almost the same, the difference is the amount of staff dedicated to such task. In the hospital 2 or 3 administrative workers are dedicated to it, while in the territorial hub there is just 1 administrative or even just the X-ray technician. Finally, there are different typologies of exams.

Figure 1 shows the To-Be process, an optimized version of the current process with the time, printing, and archiving adjustments. This scenario implies that the internal protocol is updated and harmonized with national and EU standards on digitalization, making full digitalization possible.

In detail, there can be two different scenarios because we are trying to digitalize two types of documents: the prescriptions and the informed constent. The prescriptions are easier to digitalize because they need a server for the storage (complying with the GDPR), some protocols and legal documents just at an internal level. The server already exists and informed consents need more legal adjustments at regional and national level. Therefore, being two different procedures, if we can digitalize the prescriptions, it does not automatically mean that informed consent can be digitalized as well. In conclusion, if everything

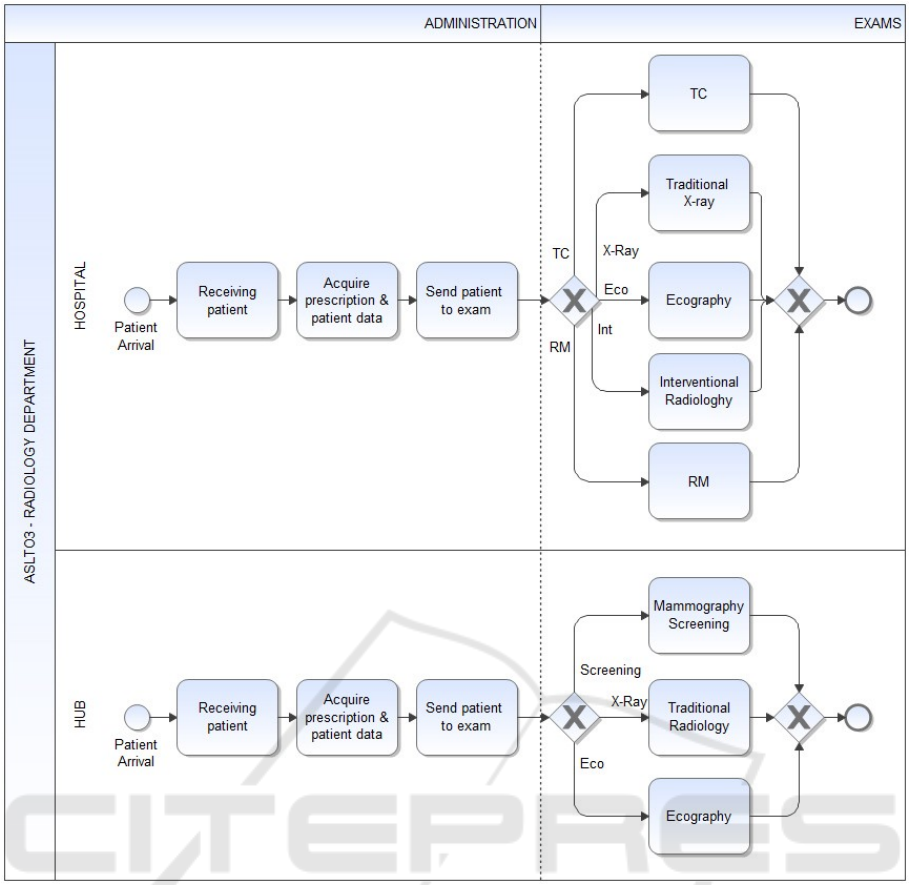

Figure 1: Digital process. To-Be process.

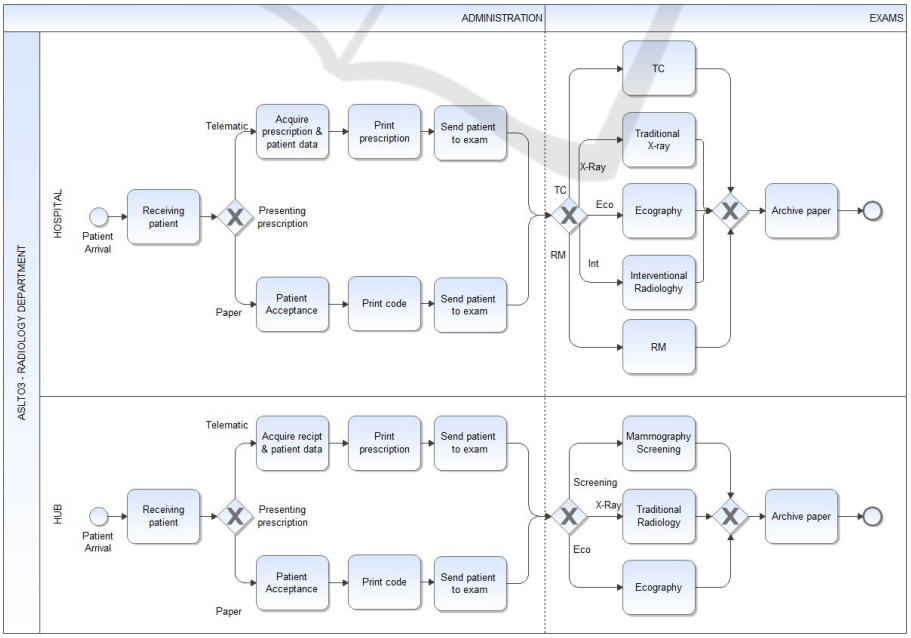

Figure 2: Paper process. As-Is process.

will be digitalized the process will appear exactly as Figure 1, else the activity "*Archive paper*" will still appear.

3.2 The Simulations Setup

The ASLTO3 is made by 3 hospitals and 4 territorial hub. For reasons of space, we decided to take into consideration the data of the radiology department related to one of the hospitals and one of the territorial hubs.

The generators of simulations are set up with an average of 29,694 incoming patients for the hospital and an average of 14,080 patients for the territorial hub in one year. Finally, in Table 1 there is the percentage of each type of exam conducted in a year in the hospital, while territorial hub percentages are shown in Table 2.

Table 1: Percentage of each type of exam made in Hospital.

Exams type	Percentage
X-Rey	45.6%
TC	28.8%
Eco	20%
RM	4%
Interventional	1.6%

Table 2: Percentage of each type of exam made in territorial hub.

Exams type	Percentage
X-Rey	92.2%
Eco	7.3%
Screening	0.5%

The considered paper cost is related to the prescriptions and the informed consent.

The prescriptions are needed for most of the exams, but not all the exams. The same goes for informed consent, it is not always needed as it is related to the level of risk of the medical exam. The informed consent does not always have the same format, it can change in relation to the exam.

3.3 Comparisons and Results

In the healthcare sector, in our case in the radiology department, there are many interconnected factors that impact and depend on each other, such as activities, time, costs, number of papers, and archive space. Below we will analyze them individually and then follow with final observations.

3.3.1 Activities and Time in the Processes

Activities. Comparing Figure 2 and Figure 1 is visible that if the prescriptions can be just digital, the paper branch will disappear and, in the digital branch, of course, will disappear also the activity "*Print prescription*".

Finally, at the end of the To-Be process, the activity "*Archive paper*" will disappear. This, however, will only come as a consequence of several adjustments.

To make such activity disappear both the digitalization of the prescriptions and the digitalization of the informed consents are needed. In case only prescriptions are digitalized the archive activity would remain. Also, this scenario is only possible if there were legal interventions at the national level to harmonize the digitalization of informed consents, which would as well make them visible in the electronic health record of each patient. Only in this scenario it would be possible to delete the storage task.

Time. With the change of the activities, the working time will be affected. In this case, the simulation is related to the working time of the administrative staff and not to the working time of exams themselves. The working time of exams can only be affected by clinical variables.

Excluding first-aid patients, the radiology exams considered in this paper, exclusively cover booked patients and hospital patients. Patients tend to have an order of arrival staggered according to the established time of the clinical exams. Therefore, those waiting times are not so representative. They are mostly related to delays in the arrival of external patients or delays in the transport of patients from the hospital wards.

What is affected is the time in the sequence of the activities of acceptance:

1. "*Receiving patient*" + "*Acquire prescription & patient data*" + "*Print prescription*" + "*Send patient to exam*"
2. "*Receiving patient*" + "*Patient Acceptance*" + "*Print code*" + "*Send patient to exam*"
3. "*Receiving patient*" + "*Acquire prescription & patient data*" + "*Send patient to exam*"

The first two are related to the current paper process (As-Is) branches and the last one is related to the digital process (To-Be).

Table 3 shows a comparison between the current process (As-Is) and the digital process (To-Be). The simulation results of both processes is expressed in the administratives' working time (in minutes) per patient.

Table 3: Comparison between the current process (As-Is) and the digital process (To-Be) simulations results of the administrative working time (in minutes) per patient.

	Average Working Time per patient
As-Is	2.37 minutes
To-Be	1.66 minutes

3.3.2 Number of Paper Prints and Costs

Number of Paper Print. To understand this point we need to make two premises:

- **Prescriptions** are required for each exam except for preventive screenings, where patients receive invitations at home. If a patient arrives with a digital prescription, administrative staff must print it for archiving purposes. If the patient has a paper receipt, a code must be printed and stapled to the prescription, counting as a second sheet. Legal compliance for prescriptions can be managed with internal adjustments.
- **Informed Consents** are not required for all exams, and for those that do, the format and number of pages vary. Informed consent forms must be printed in duplicate: one copy for the patient and one for the healthcare facility. Table 4 provides a summary of this information.

Table 4: Paper pages needed for the informed consent for type of exam.

Exams type	Printed pages for informed consent
TC	2 (X2)
Interventional	2 (X2)
Eco	2 (not for all exams) (X2)
Screening	1 (X2)
RM	5 (X2)

In this case, the simulation helps us to understand the extent of the potential savings and present an argument in support of the legislative harmonization for digitalization of informed consent and prescription. If the harmonization becomes effective, the simulated savings will become effective.

The simulation results reported in Figure 3 show the number of papers that are printed on average in one year for the prescription, and the same for informed consent. They both are presented in relation to the hospital and to the territorial hub.

The digitalization of the prescriptions and of the informed consent are two different procedures. Thus, there will likely be an intermediate situation (i.e. the "*Partially Digital*" scenario) in which all the prescriptions are digital but not the informed consent. The informed consent could be sent online to the patient, while it should be archived in a paper format. This means that there is still a paper copy to be taken into consideration for the informed consent. However, there would be a relevant reduction in paper which is evident in Figure 3.

Of course, in case of fully digitalization the amount of paper would be zero.

	HOSPITAL		HUB	
	Paper	Partially Digital	Paper	Partially Digital
Prescriprion				
Print prescription	14847		7040	
Print code	14847		6012	
Informed Consent				
TC	34208	17104		
RM	11880	5940		
Interventionnal Rdiology	1900	950		
Ecography	6000		142	71
Screening			1028	
Tot Numper of Paper	**83682**	**23994**	**14222**	**71**

Figure 3: Number of paper used in the hospital and in the hub in the AS-IS ("*Paper*") situation and in the To-Be ("*Partially Digital*") situation. Related to the prescriptions and to the informed consents.

Table 5: Paper pages saved using the partial digitalization and the full digitalization, expressed in number of pages and in percentage concerning the current situation.

	Saving N. of paper Partially Digital	in%	Saving N. of paper Fully Digital
Tot Hospital	59,688	71.3%	83,682
Tot hub	14,151	99.5%	14,222

In conclusion, starting from Figure 3, Table 5 shows that just with partial digitalization, i.e. digitalize the prescriptions and the informed consents for the hospital, printing just the copy for the hospital archive, "*Partially Digital*") almost 60,000 paper sheets will be saved in the hospital and almost 1,500 in the hub. With a full digital system, almost 85,000 paper sheets will be saved in the hospital and almost 14,000 in the hub.

Costs. Figure 4 reports the results of the simulation on costs for the hospitals and the hub. These are related to the cost of the paper and the printing costs in proportion to hard copies. The Figure also shows a comparison between the As-Is and the To-Be "*Partially Digital*" scenario.

Also in this case, if all informed consents can be filled out, signed, and kept totally in digital, the cost of printing and paper would be zero.

In conclusion, starting from Figure 4, Table 6 shows that just with partial digitalization, i.e. digitalize the prescriptions and the informed consents for

	HOSPITAL		HUB	
	Paper	Partially Digital	Paper	Partially Digital
Prescriprion				
Print prescription	296,94 €		140,80 €	
Print code	296,64 €		120,24 €	
Informed Consent				
TC	684,16 €	342,08 €		
RM	237,60 €	118,80 €		
Interventionnal Rdiology	38,00 €	19,00 €		
Ecography	120,00 €		2,84 €	1,42 €
Screening			20,56 €	
Tot Cost	**1.673,34 €**	**479,88 €**	**284,44 €**	**1,42 €**

Figure 4: Cost of paper consuming and printing costs related to the AS-IS ("*Paper*") situation and in the To-Be ("*Partially Digital*") situation, divided for prescriptions and informed consents.

Table 6: Costs saved using the partial digitalization and the full digitalization, expressed in Euro and in percentage concerning the current situation.

	Saving Cost in euro in Partially Digital	in%	Saving Cost in euro in Fully Digital
Tot Hospital	1,193.46€	71.3%	1,673.34€
Tot hub	283.02€	99.5%	284.44€

the patient, so printing just the copy for the hospital archive ("*Partially digital*") almost 1193.46€ will be saved in the hospital and almost 283.02€ in the hub. While with a full digital system almost 1600€ will be saved in the hospital and almost 300€ in the hub.

3.3.3 Archive

Removing physical storage in healthcare facilities has several benefits. It eliminates the need for file placement and manual searching, which can be time-consuming and require multiple staff members. Digital databases allow for quick retrieval of files within seconds. Physical storage demands large spaces in healthcare buildings and poses risks such as document loss, damage from fires or flooding, and the need for regular disposal to make room for new documents. With the increasing number of required documents due to technological advancements, the need for larger storage spaces is growing

3.3.4 Final Remarks

All the simulations shown until now are related to one hospital and one hub of the radiology department.

As remarked before, the ASLTO3 involves 3 hospitals and 4 hubs, which implies that both the cost center and the archive are centralized for all the radiology departments. Our aim is to show the impact of the digitalization of just these two documents of one department on the cost center and the archive of the ASLTO3. Table 7 and Table 8 show respectively the possible number of saving sheets paper and the possible saving costs for the ASLTO3.

Table 7: Paper pages saved using the partial digitalization and the full digitalization, expressed in number of pages and in percentage concerning the current situation.

	Saving N. of paper Partially Digital	Saving N. of paper Fully Digital
Tot ASL Hospitals	179,064	251,046
Tot ALS hubs	56,604	56,888
Tot ASL	**235,668**	**307,934**

Table 8: Costs saved using the partial digitalization and the full digitalization, expressed in euro concerning the whole ASLTO3.

	Saving Cost in euro in Partially Digital	Saving Cost in euro in Fully Digital
Tot ASL Hospitals	3,580.38€	5,020.02€
Tot ALS hubs	1,132.08€	1,137.76€
Tot ASL	**4,712.46€**	**6,157.78€**

Although the single results shown may not be impressive, the impact of all these interconnected factors is relevant. We only took into consideration two administrative documents among all administrative documents, we excluded medical documents, and our scope got as far as only one hub and one hospital among all the ASLTO3. Also, these administrative documents only came from the radiology department of the chosen hospital and hub. This means that what is saved in terms of time and costs in this scenario exponentially grows if adopted in the whole ASL TO3. This is shown in Table 7 and Table 8. Table 7 refers to savings in number of hard copies, wheres Table 8 refers to saving in costs. Using paper not only creates a physical and printing cost but also creates a storage space problem.

Saving time in healthcare facilities leads to a cascading effect by freeing up staff to handle other tasks, address bottlenecks, and increase available human resources. Cost savings can be redirected to invest in medical equipment or additional staff, improving both care quality and work conditions by reducing overtime and balancing workloads. This results in better patient care, fewer errors, and higher patient satisfaction, which can reduce legal complaints.

With technological advancements come new legal standards, particularly for health data, requiring more

administrative documents and storage space. Switching to digital databases eliminates the need for additional storage, repurposing current storage areas for medical use and cutting costs. Additionally, new documents require more storage space, increasing the costs of renting adequate places. Digital databases cut these costs, eliminating the need for new storage spaces and allowing current storage areas to be repurposed for medical rooms or storage.

In Italy, the healthcare system is public, which means it is publicly funded. If optimizing document management in just one department can have a significant positive impact on public services and funds, it also has the potential to bring massive benefits on a national scale. This optimization currently involves only 1 ASL out of 12. Considering that Italy has 20 Regions, and Piedmont is just one region, this type of optimization could bring to the whole public service and public funds a great impact in scale.

4 CONCLUSIONS AND IMPLICATIONS

This work shows the interconnection, the analysis, and the impact of multiple factors in the complex territorial health system.

It has been demonstrated that in the medical field, digitalizing just two administrative documents (non-clinical) of just one department would have a considerable impact on activities, time, costs, number of paper files, and storage spaces throughout the territory. The successful optimization of administrative healthcare activities is fundamental as it can be expanded proportionally and exponentially throughout the entire national territory. The interconnection of factors brings a cascading optimization effect, bettering the entire health service on multiple fronts. Last but not least, these kinds of optimizations are indispensable to align with the digitization and eco-friendliness required by the European Union. In the next future, we will continue this collaboration with ASLTO3 to try to implement the digitalization of the prescriptions.

REFERENCES

Amantea, I. A., Di Leva, A., and Sulis, E. (2020a). A simulation-driven approach to decision support in process reorganization: A case study in healthcare. In *Exploring Digital Ecosystems*, pages 223–235. Springer.

Amantea, I. A., Quaranta, M., Molinari, M., Peduto, C., and Demarchi, F. (2023). The e-dossier as a tool to optimize civil courts: The cuneo case. In *In Proceedings of the 13th International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, pages 425–431.

Amantea, I. A., Robaldo, L., Sulis, E., Boella, G., and Governatori, G. (2021). Semi-automated checking for regulatory compliance in e-health. In *2021 ieee 25th international enterprise distributed object computing workshop (edocw)*, pages 318–325. IEEE.

Amantea, I. A., Robaldo, L., Sulis, E., Governatori, G., and Boella, G. (2022a). Business process modelling in healthcare and compliance management: a logical framework. *Journal of Applied Logics—IfCoLog Journal of Logics and their Applications*, 9(4).

Amantea, I. A., Sulis, E., Boella, G., De Marchi, F., Mazzini, L., Alloatti, F., and Bolioli, A. (2020b). Adopting assistive technologies in healthcare processes: a chatbot for patients with amyotrophic lateral sclerosis. In *Italian forum of ambient assisted living*, pages 163–174. Springer.

Amantea, I. A., Sulis, E., Boella, G., Marinello, R., Grosso, M., and Crespo, A. (2022b). A modeling framework for an innovative e-health service: the hospital at home. In *Simulation and Modeling Methodologies, Technologies and Applications: 10th International Conference, SIMULTECH 2020 Lieusaint-Paris, France, July 8-10, 2020 Revised Selected Papers 10*, pages 111–132. Springer.

Dumas, M., La Rosa, M., Mendling, J., and Reijers, H. (2018). *Fundamentals of business process management*, volume 1. Springer, 2nd edition.

Dumas, M., van der Aalst, W. M., and ter Hofstede, A. H. (2005). *Process-aware Information Systems: Bridging People and Software Through Process Technology*. John Wiley & Sons, Inc., New York, NY, USA.

Ladyman, J., Lambert, J., and Wiesner, K. (2013). What is a complex system? *European Journal for Philosophy of Science*, 3:33–67.

Martinho, R., Domingos, D., and Respício, A. (2016). Evaluating the reliability of ambient-assisted living business processes. In *ICEIS (2)*, pages 528–536.

Motter, A. E. (2004). Cascade control and defense in complex networks. *Physical Review Letters*, 93(9):098701.

Sulis, E., Amantea, I. A., Boella, G., Marinello, R., Bianca, D., Brunetti, E., Bo, M., Bianco, A., Cattel, F., Cena, C., et al. (2019). Monitoring patients with fragilities in the context of de-hospitalization services: an ambient assisted living healthcare framework for e-health applications. In *2019 IEEE 23rd International Symposium on Consumer Technologies (ISCT)*, pages 216–219. IEEE.

Sulis, E. and Di Leva, A. (2017). An agent-based model of a business process: The use case of a hospital emergency department. In *International Conference on Business Process Management*, pages 124–132. Springer.

Van Looy, A. and Shafagatova, A. (2016). Business process performance measurement: a structured literature review of indicators, measures and metrics. *SpringerPlus*, 5(1):1797.