Predictive modeling of telehealth system deployment

Camille Jean, Marija Jankovic, Julie Stal-Le Cardinal, Jean-Claude Bocquet

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Healthcare systems are facing intense challenges to maintain and reinforce their value, such as cost efficiency, quality of care, accessibility, and safety. Telehealth is seen as a possible way to address these challenges. Recent studies have focused on telehealth organization, resources, and operations management. However, very few studies have focused on predicting impacts of telehealth integration in the current healthcare system. We propose a parametric simulation model that fills this gap in the literature. The model considers environmental factors (demographic changes, resources and economic context) affecting the healthcare system and predicts implications over a long time horizon. A scenario-based approach is used to investigate several research questions and possible developments. A case study of the Picardie region illustrates this approach by modeling current conditions over a 20-year period. We believe this approach can be used as a strong decision support tool in the deployment of telehealth systems in the future.

Keywords: Decision support, Simulation, Telehealth

1 INTRODUCTION

Healthcare systems are facing increasing demographic and economic challenges. Healthcare service demands are growing due to an aging population and a rise in the number of people afflicted with chronic diseases. According to the data of the National Institute of Statistics and Economic Studies (INSEE), the percentage of the population over 60 years of age in France will grow from 23.1% to 32.8% by 2035, a projected increase of 7 million people, bringing the total population in that age category to about 21 million (Brutel et al., 2003). This trend coincides with current global trends. The elderly often suffer from chronic polypathologies requiring long-term treatment. However this increase in the occurrence of chronic non-communicable diseases, such as heart disease, stroke, cancer, chronic respiratory disease and diabetes, is not only associated with an aging population. Other risk factors associated with contemporary urban life have been identified, such as poor diet, physical inactivity, tobacco use and alcohol or pollution (WHO, 2000). An immediate consequence of the increased prevalence of chronic disease is growth in healthcare service demand.

Despite this increased demand, France is facing a shortage of general practitioners and specialists. Moreover, medical "desertification" is a major problem in many country regions. Several factors explain this evolution: an inadequate practitioner replacement rate (the *numerus clausus* for determining the number of students that are allowed to proceed to the second year of medical studies is too low to compensate for retirement) (Doan et al., 2004), feminization of the profession, increased medical specialization, and the pursuit of a more comfortable life (i.e., more urban) by medical professionals. The combined impact of these factors is a decrease in physician density that will reach a minimum in 2020. Several policies have been put in place in order to bring physician density back to its current level by 2030 (DREES, 2009).

Despite interest in the potential opportunities and benefits of telehealth (Davalos et al., 2009), no studies to date have predicted the influence of large-scale integration of telehealth into the existing healthcare system. This remains a main challenge for decision makers who must allocate and manage resources in order to maximize the potential benefits and impact of integration. Given the inherent complexity of the telehealth system (i.e., many different actors, hidden system interfaces, technology management), predicting possible system utilizations, as well as possible impacts on existing healthcare services becomes quite difficult. In order to bridge this gap, we propose to develop an overall telehealth integration model with regard to its sustainability: economic aspect (different healthcare system related costs), social impact (medical time availability) and environmental impact (patient transport). The proposed parametric model is also scenario-based approach identifying several underlying hypothesis regarding telehealth system integration. The results underline the necessity to carefully plan telehealth system deployment in order to ensure healthcare system sustainability and efficiency.

Therefore, in the section 2 we address the utilization of simulation in healthcare modelling and current models related to telehealth. Section 3 gives details of the French telehealth model and in particular "Télégeria" project (Espinoza et al., 2011). Section 4 and 5 give an overview of the research design as well as different data gathered that are suited for telehealth system integration modelling presented in section 6. Different underlining scenarios as well as simulation results are detailed in section 9 and 10. In the end, we discuss general trends and conclusions.

2 LITERATURE REVIEW OF HEALTHCARE SIMULATION APPROACHES

Simulation is the process of developing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (Shannon, 1975). Simulation methods that are used to support decision making in other sectors, such as manufacturing or defense, have been used previously to help understand and solve healthcare problems. In their literature review, Brailsford and colleagues (2009) categorized more than 342 studies related to simulation and modeling methods used in healthcare engineering such as discrete event simulation, system dynamics, Monte Carlo simulation and Markov chains. Jun et al (Jun et al. 2009) have identified and categorized 8 methods they consider frequently used: agent based simulation, discrete event simulation (DES), gaming simulation, hybrid simulation, inverse simulation, Monte Carlo simulation, real time simulation and system dynamics (SD). Discrete event simulations and system dynamics have been found to be the two most simulation methods utilized in healthcare engineering (Brailsford et al. 2009).

DES models the operation of a system as a discrete sequence of events over time. Each event occurs at a particular point in time and represents a change in the state in the system (Zeigler et al., 2000). DES has been used for numerous studies in healthcare engineering. It has been used to track the spread and containment of hospital acquired infections (Hagtvedt et al., 2009), plan for disease outbreaks (Aaby et al., 2006), determine bed requirements (Griffiths et al., 2010), investigate emergency departments (Paul et al., 2010), and determine appropriate ordering policies in the blood supply chain (Katsaliaki and Brailsford, 2007). It is also used for planning, scheduling, reorganizing and managing healthcare and hospital services related to communicable diseases, bio-terrorism, screening, and costs of illness; comparing alternative healthcare interventions; evaluating policy and strategy (Fone et al., 2003; Katsaliaki and Mustafee, 2011); reducing risk, operating costs, lead time, and capital cost; facilitating faster plant changes; and improving customer service (Robinson et al., 2012).

System dynamics is an approach used to understand the behavior of complex systems over time. It was developed by Jay Forrester at MIT in the mid-1950s (Forrester, 1961). This approach addresses internal feedback loops and time delays that affect the behavior of the entire system. It is described as an analytical modeling tool based on a general systems theory approach (Bertalanffy, 1968; Le Moigne, 1985). The methodology uses computer simulation models to relate the structure of a system to its behavior over time. Using SD allows us to see not just events, but also behavior patterns representing time trends (Homer and Hirsch, 2006). Understanding patterns of behavior instead of focusing on day-to-day events can offer a radical change in perspective. The main objective is to show

how a system's own structure is related to its successes and failures. Several researchers (Erdil and Emerson, 2008) have used SD to examine the adoption of electronic health records and the impact of telehealth innovation on the overall system. Erdil and Emerson (2008) proposed a model for the adoption of electronic health records (EHR) in the United States. The challenge in EHR adoption is related to the one addressed in this research: addressing increasing patient demand while maintaining healthcare costs. SD was proposed as a way of understanding the complexity of EHR integration. The model captures the major variables that have been identified, such as the affected population, cultural barriers, industry pressure, market maturity and usage performance. These variables constituted a framework with the aim of identifying policies that would accelerate the process of EHR adoption.

Morecroft and Robinson (2005) compared these two approaches. They argued that DES is particularly suited to operational-level problems such as transactions, processing, and the flow of individual entities. In contrast, SD is often used to assess aggregated high level implications, especially when considering the impact of policy and strategic decisions. The choice between these two approaches can be based on the level of detail needed in problem solving: a close-up resolution in DES yielding individual entities, attributes, decisions and events, versus a distant resolution in SD capturing homogenized entities and continuous policy pressures. In their study on the use of SD in healthcare between 1965 and 2004, Koelling and Schwandt (2005) found that SD is used mostly to study international, national and regional strategy and policy implications (76% of the articles). Like Jones and Homer (2006), we agree that SD is an adapted approach that is well-suited to supporting healthcare professionals in their reasoning and decision making. In fact, SD and its visual nature encourage debate among involved stakeholders on the impact of the underlying structure on overall system behavior, which leads to the creation of new policies (Taylor and Lane, 1998; Zare Mehrjerdi, 2012).

As discussed previously, simulation has been widely used in healthcare engineering. In this research study, the focus is on telehealth system integration. We have found very few studies related to this subject. The work of Bayer et al. (2007) is one of them. The authors present an interesting study about the implementation of home telecare in the UK. They highlighted the fact that most studies about telehealth services consider either clinical or economic impacts, thus failing to evaluate the overall system. In order to help decision makers gain a greater understanding of telehealth implementation, the authors proposed a model that would consider delays between different patient categories. The authors concluded that it may be more beneficial to focus on somewhat frail patients rather than the very frail. This is mainly due to the fact that a system evolves gradually, and investments in new home telecare technology should be made accordingly because people have a limited ability to cope with radical changes in the way they receive care. However, our work is not related to telecare (home healthcare) but telehealth (access to a medical expert in healthcare establishments) and does not concern the same material, human resources and perimeter.

The research studies discussed in this section illustrate some of the approaches used in healthcare modeling and impact investigation. However, in the case of telehealth, we found no research tackling related issues associated with long-term telehealth integration, with regard to its sustainability (economic aspect, environmental aspect and social aspect). Therefore, in order to support decision makers, we propose a parametric scenario-based model integrating long-term exogenous factors such as demographic patient information and the availability of specialist practitioners with the aim of predicting possible impacts over the next 20 years. The objective of this study is also to create a shared vision of the telehealth system amongst different stakeholders in order to ensure its deployment.

3 TELEMEDICINE MODEL IN FRANCE: TÉLÉGERIA CASE STUDY

Previously discussed challenges in healthcare system, combined with reduced allocations of public funding to the healthcare system due to the global economic crisis, have fostered a sense of urgency around innovation in medical system organizations. One of them is telehealth which consists in the use of information and communication technology to deliver health and social care (Barlow et al., 2006). The main idea is to provide remote access to healthcare services, thus bridging physical distance between patients and healthcare professionals. Telehealth is based on inter-professional collaboration and necessitates establishing collaboration rules and best practices. In France, two main applications of telehealth are defined by law (Legifrance, 2010): (1) teleconsultation is the framework for consulting a non-local doctor (a healthcare professional may be present with the patient to assist the doctor during the teleconsultation) and (2) teleexpertise involves soliciting the opinion of one or more colleagues for knowledge acquisition or training purposes.

Télégéria project (Figure 1) is one of the experimental projects with aim of testing telehealth approaches; and mainly consists of teleconsultation and teleexpertise. This model has been chosen as one of the references in the French healthcare system. It has been deployed in 3 hospitals (Geogres Pompidou Hostpital, Vaugirard Hospital and Julie Siegfried EHPAD). It is the largest telehealth implementation in France. Over 36 months, more than 1,500 telemedicine sessions integrating 21 medical specialities were conducted. Telehealth stations may consist of a main screen and two related screens: one connected to radiology and medical records, and another one connected to biomedical equipment for exchanging medical information (i.e., hand camera electrocardiograph, spirometer, dermatoscope, otoscope, or ultrasound). Secure networks are mandatory in order to protect transmitted data (Espinoza et al., 2011).

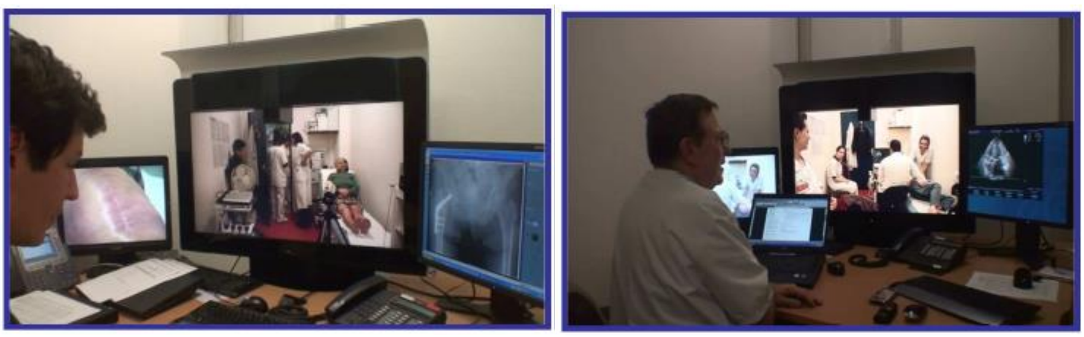

Figure 1: Télégeria project and mock-up

Based upon this experimentation and observations related to this project, the aim of this research is to investigate potential large-scale deployment involving 200 healthcare establishments that are identified as future constituents of the telehealth network of the Picardie region. This network should decrease the number of laborious inter-healthcare establishments transports, reduce waiting time with a better coordination between health professionals, strengthen prevention, and improve access to health services in rural areas.

4 RESEARCH PROTOCOL

The goal of this model is to help healthcare managers understand the hidden impacts of several strategies of telehealth integration and to investigate their potential performance. The main difficulty associated with system modeling and investigating possible behaviors is building a model that is reliable and easy to understand. Therefore, our research protocol is divided in 5 phases:

(1) Problem definition: We organized a working group comprised of doctors, medical staff and healthcare managers in order to define the direct impacts of telehealth integration, healthcare performance indicators, the time span and the geographic area;

(2) System modeling: Based on their feedback, a telehealth system integration model was proposed and discussed within the working group. The underlying hypothesis and related variables were defined in this phase;

(3) **Quantitative data collection:** Only parameters with data from reliable sources were included in the model. Data were collected from French administration reports and on the most significant telehealth experiment in France at the time, Télégéria;

(4) **Scenarios making:** Once the system structure was validated and the variables were defined, different telehealth implementation scenarios and their potential impacts over time were discussed and defined with the working group;

(5) **Results and analysis:** Scenarios were investigated in order to predict the future behavior of the system with respect to the impacts defined in step 1.

Even though this process seems to be sequential, in reality several feedback loops occurred when the working group expressed the need to integrate or remove telehealth impacts, change variables and even to clarify or change the research questions.

5 PROBLEM DEFINITION

5.1 The working group

The aim of this work was to investigate the possibility of telehealth integration on a national level. In order to identify system limits and potential integration problems, a group of stakeholders were identified to work on this issue. Our group was comprised of medical professionals associated with the leading telehealth experiment in France, *Télégéria* (Espinoza et al., 2011), and healthcare managers from the Picardie region. Moreover, government policy makers were identified and contacted for specific needs during the design work. In the restricted working group 12 stakeholders were involved, including 5 practitioners and 2 medical staff associated with telehealth, and 5 healthcare managers.

5.2 Group brainstorming

During this first phase, the working group highlighted many quantitative and qualitative impacts of telehealth. The objective was to organize the proposition and to set the probable impacts and system parameters for the model.

For example, the members of the working group highlighted the fact that institutions and their practitioners are in considerable need of telehealth services. Indeed, it can help their patients avoid long transports and associated risks, as well as provide easier connections with medical experts. Moreover, the group mentioned that for specialized practitioners, telehealth might be a way to save medical time by delegating activities and creating a more effective patient triage through increased use of teleexpertise. They also emphasized that telehealth might be a way to save costly patient transportations and to reduce bottlenecks in emergency departments. They also identified a potential medical development activity due to easier access to medical specialists.

5.3 Direct impacts retained

In view to possible telehealth integration, the working group identified five major impacts: the number of admissions to emergency departments, the number of transports, the number of specialized consultations due to better patient triage, the number of specialized consultations due to better territorial access, and the average duration of consultation. All other qualitative or quantitative impacts related to medical quality (such as the average length of stay (ALOS) of a hospitalization) were withdrawn due to a lack of consensus. These impacts are considered to be inputs in the proposed system:

1) Impact on the *number of admissions to the emergency department*: The working group posited that telehealth may help reduce visits to the emergency department by anticipating medical problems, especially for older people. In fact, sometimes, the risks associated with moving a patient are considered to be higher than the potential benefits. Therefore, older patients are rarely transported to see a specialist practitioner for prevention. This results in visits to the emergency department when problems become serious. A decrease in the number of admissions to the emergency department will help solve problems such as overcrowding and cost challenges;

2) Impact on the *number of transports*: The group highlighted the fact that using telehealth instead of moving patients or healthcare professionals would help to save costs associated with transports;

3) Impact on the *number of specialized consultations due to better patient triage*: The members of the group emphasized that the use of teleexpertise will help prioritize high-risk patients for earlier access. For example, sending skin images for dermatology consideration will help prioritize patients who are more at risk, and avoid inadequate or unnecessary consultations. They also noted the fact that teleexpertise takes less time than face-to-face consultation;

4) Impact on the *number of specialized consultations due to better territorial access*: The group emphasized the fact that putting telehealth stations in the territory may increase the number of medical consultations by facilitating access to medical specialists;

5) Impact on the *average duration of consultation*: The group noticed that teleconsultations are shorter than regular consultations with specialized practitioners because specific tasks are delegated to medical staff. This will increase the amount of medical time available.

5.4 Performance indicators retained

Several aspects of system performances have been discussed as important for telehealth system integration:

1) Economic aspect, whether telehealth implementation increases or decreases the cost of the healthcare system. The related indicator is the *total healthcare cost*
2) Environmental aspect, whether telehealth implementation increases or decreases the CO2 equivalent rejected. The related indicator is the *Carbon Dioxide Equivalent emitted*
3) Social aspect, whether telehealth implementation increases or decreases medical time available making medical expertise available without delay. The related indicator is the *total medical time available*

Telehealth will also have an impact on medical quality (differences between the medical outcomes of telehealth consultations and normal consultations). Although some of the issues have been discussed, it has been decided not to integrate them at this stage as further medical investigation is needed with this regard.

Therefore, in this model, we assume that a face-to-face doctor-patient consultation is equivalent to a teleconsultation in terms of quality of medical care.

5.5 Time span and geographic perimeter

The French government has decided to focus on several strategic regions. One of them is the Picardie region and this study has been in particular considering this region with its specificities. The time span that has been chosen is 20 years, as it is the maximum time span in the literature for demographic projection.

6 SYSTEM MODELING

In order to investigate telehealth system integration, a parametric scenario-based model has been proposed (see Figure 2). This model integrates possible telehealth deployment hypothesis that are represented at the very top of the model, and three system performance aspects (economic, social and environmental). Due to the number of variables in this model, we propose to discuss in detail different causal relationships that have been taken into account.

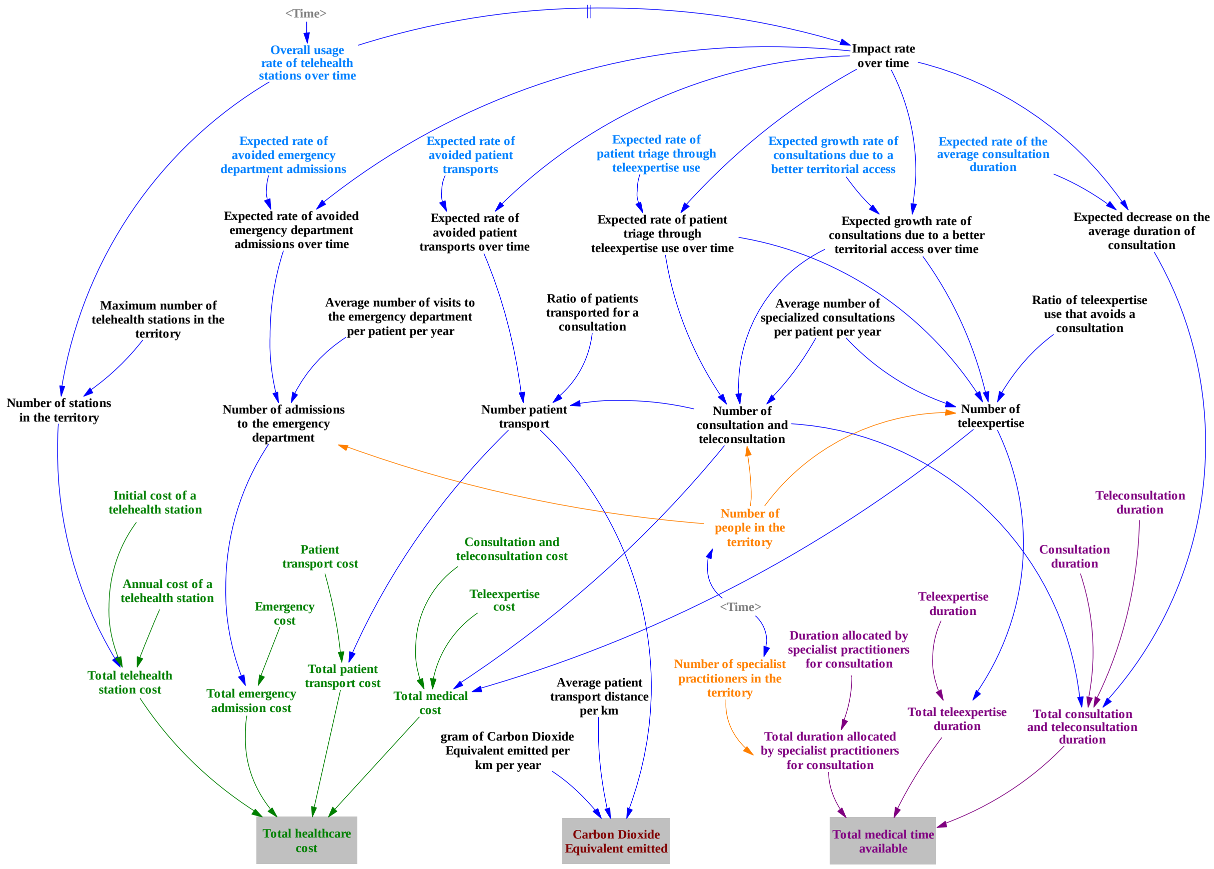

Figure 2. Telehealth system integration model.

6.1 Calculation of the five impact rates over time

The scenarios presented in section 7 provide the maximum rate of each direct impact retained. This maximum is reached when all the medico-social establishments of the region have telehealth stations. As telehealth implementation is made gradually, the direct impact rates need to be calculated over time (top of Figure 2). In order to do so, the maximum rate of each direct impact is multiplied by the *impact rate over time*.

This *impact rate over time* is delayed 18 months from the *overall usage rate of telehealth stations over time* to take into account the phenomenon of inertia of the healthcare system. This value was quantified by the group members based on their experiences with change management.

The *overall usage rate of telehealth stations over time* represents the speed of telehealth implementation in the region. It starts at “0” (no telehealth stations) and ends at “1” (all medico-social establishments have stations).

6.2 Calculation of the total medical time available

The bottom right of Figure 2 represents the *total medical time available* calculation. This indicator represents the capacity to offer specialized care to patients. Its value is calculated by taking the difference between the total number of hours offered by medical specialists and the total number of hours needed by patients (sum of teleexpertise, teleconsultation and consultation time).

Parameters, such as *teleconsultation duration*, *consultation duration*, *teleexpertise duration*, and *duration allocated by the specialist practitioners for consultations* are quantified in section 7.

6.3 Calculation of the Carbon Dioxide Equivalent emitted

The bottom middle of Figure 2 represents the *Carbon Dioxide Equivalent emitted* calculation. This indicator is directly correlated to the number of patient transports.

Parameters, as the *average patient transport distance per km*, and the *gram of Carbon Dioxide Equivalent emitted per km per year* are quantified in section 7.

6.4 Calculation of the total healthcare cost

The bottom left of Figure 2 represents the *total healthcare cost* calculation. This indicator verifies whether telehealth implementation will increase or decrease the total healthcare cost of the healthcare system. Its value corresponds to the sum of the telehealth station cost (material, implementation, maintenance and work force), emergency cost, transport cost and medical cost.

Parameters such as the *initial cost of a telehealth station*, the *annual cost of a telehealth station*, *emergency admission cost*, *transport cost* and *consultation cost* are quantified in section 7.

6.5 Overall model

Figure 2 represents our final model to predict the impacts of telehealth integration and help decision makers. It includes the two exogenous variables that change over time: the *number of people in the territory* and the *number of practitioners in the territory*.

The *number of stations in the territory over time*, the *number of admissions to the emergency department*, the *total number of transports*, the *total number of consultations and teleconsultations* and the *total number of teleexpertise sessions*, and their respective costs and durations, are calculated by multiplying the terms that influence each of them (Figure 2).

As telehealth is a complex system, the variables are interrelated. For example, the *average number of specialized consultations* per patient per year has an influence on *total medical costs*, but also on *total patient transport costs* and on the *total medical time available* and on the *Carbon Dioxide Equivalent emitted* .

7 QUANTITATIVE DATA COLLECTION

Rigorous data collection provided the quantitative parameters of the model. Most of the data were extracted from official reports of French Agencies. The other values are based on the existing telehealth experiment at Georges Pompidou Hospital. It is the largest telehealth implementation in France; over the past 36 months, more than 1,500 telemedicine sessions in 21 medical specialities were conducted. Even with this high number, the data available were limited and not as high quality as would be desirable because of the small scale of the project compared to a territory implementation. However, this is the most reliable data in France.

Cost inflation over the 20-year time horizon was not taken into account. In fact, the simulations were run *ceteris paribus* (all other things being equal). This enabled fair comparison of scenarios to ensure valid results and proper recommendations. Tables 1 and 2 quantify the exogenous variables and model parameters with their data sources.

Exogenous variable	Value	Sources
Number of specialist practitioners in the territory	2,000 in 2010, then a decrease to 1,800 in 2020 and an increase to 2,100 in 2030. Figure 2 shows these values.	Data are based on the predicted number of specialist practitioners at the national level between 2006 and 2030 (DREES 2009) and the predicted number of specialist practitioners in the Picardie region in 2008 (CNOM 2009). The same ratio was maintained to predict the number of specialists over the 20-year time horizon in Picardie.
Number of people in the territory	In the Picardie region, there were 1,950,000 people in 2010 and a linear projection predicted the population would reach 2,050,000 people in 2030. Figure 3 shows this increase over time.	(INSEE 2010)

Table 1: Dynamic exogenous variables changing all along the 20 time year's span

The trends related to these exogenous variables are given in Figure 3 and 4.

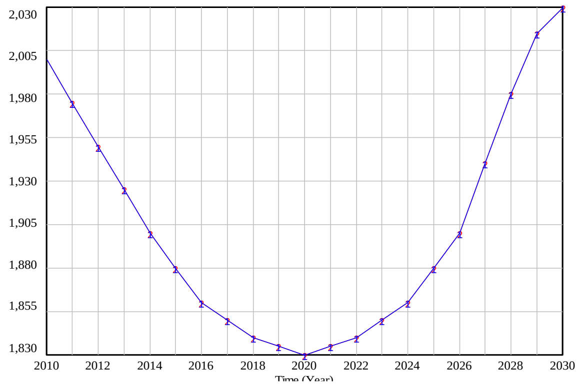

Figure 3: Number of specialists in the Picardie region, calculated from (DREES 2009) and (CNOM 2009)

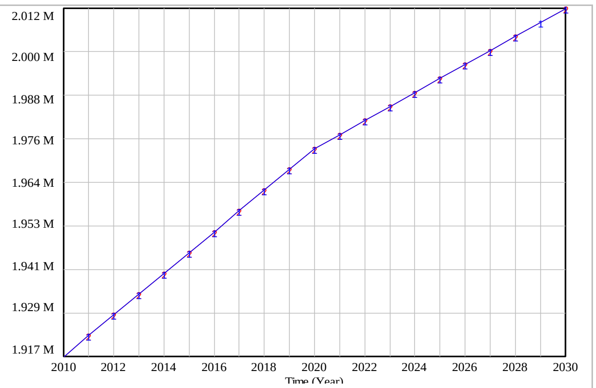

Figure 4: Number of people in the Picardie region (INSEE 2010)

Other parameters considered in this model are given in Table 2. For each of them, a quantification is given as well as the source of information.

Variables	Value	Sources
Maximum number of telehealth stations in the territory	200	(ARS Picardie 2010)
Average number of visits to the emergency department	0.2 per patient per year	(DREES 2003)
Ratio of patients transported for a consultation	5%	Working group hypothesis based on their experiences
Average number of specialized consultations per year per patient	2 per year per patient	Working group hypothesis based on their experiences
Ratio of teleexpertise use that avoids a consultation	33%	Télégéria Project Data
Initial cost of a telehealth station	10200€ (material cost of the station) + 1000€ (implementation cost)	Télégéria Project Data
Annual cost of a telehealth station	1100€ (maintenance cost) + 10000€ (200h per year of medical staff and 200h per year of administrative staff)	Télégéria Project Data
Emergency admission cost	191€	(Cours des Comptes 2009)
Transport cost	186€	(Eyssartier 2010)
Consultation cost	25€	(Legifrance 2011)
Teleconsultation cost	25€	Working group hypothesis
Teleexpertise	6€	Working group hypothesis
Teleconsultation duration	0.3h	Télégéria Project Data
Consultation duration	0.4h	Télégéria Project Data
Teleexpertise duration	0.1h	Télégéria Project Data

Time allocated by specialist practitioners for consultation	855h per year (19h x 45 weeks)	Working group hypothesis based on their experiences
Average patient transport distance per km	40 km	Working group hypothesis based on their experiences
Number of gram of carbon dioxide equivalent per km per year	401g/km	(Boget and Portugal 2010)

Table 2: Parameters for the 20-year time horizon

8 SENSIBILITY ANALYSIS

In order to investigate the robustness of the model, a sensitivity analysis has been conducted with regard to five variables defining proposed scenarios. The change has been defined as uniform distribution with the variation of 10% depending on the case on each of the variables. The effects have been observed on the specialized medical time available, CO2 emissions equivalent and total system cost. Results are given in Table 3

	Imput sensitivity range (uniform law)	**Impact on the total healthcare cost**	**Impact on the total Carbon Dioxide Equivalent emitted**	**Impact on the total medical time available**
Number of admissions to the emergency department	0% to -10%	0% to -3,5%	0%	0%
Number of patient transports	0% to -10%	0% to -1.9%	0% to -10%	0%
Number of specialized consultations due to better patient triage	0% to -10%	0% to -3.3%	0% to -10%	0% to 37,3%
Number of specialized consultations due to better territorial access	0% to +10%	0% to 7.1%	0% to +10%	0% to >100%
Average duration of consultation	0% to -10%	0%	0%	0% to 23,5%

Table 3: Sensitivity analysis

We can note that the variables that have the greatest influence on the cost of the system are in descending order: (1) number of specialized consultations due to better territorial access, (2) number of admissions to the emergency department, (3) number of specialized consultations due to better patient triage, (4) number of patient transports. The impact on the average duration of consultation has no influence on the cost indicator.

Concerning the Carbon Dioxide Equivalent emitted, we can note that the number of patient transports, number of specialized consultations due to better patient triage and number of specialized consultations due to better territorial access are linearly correlated.

Concerning, the number of specialized consultations due to better territorial access have been found to have a large influence on the total medical time available indicator. However, whatever the change in input variables, the overall relative comparison of scenarios stay the same.

9 TELHEALTH DEPLOYMENT SCENARIOS

The research objective of this model is to support policy makers understand different impacts of telehealth implementation strategies and to identify those that can contribute greatly to system performance represented as indicators (section 4.4). Four scenarios were proposed by the working group based on their past experiences and possible degree of telehealth system integration (Table 4):

(1) A statu quo scenario : telehealth system is not deployed at all;

(2) Teleconsultation scenario: Teleconsultation are implemented between different institutions in the region. Teleconsultation may cause a reduction of transport and of the average duration of consultations. However, an increase in the number of consultations is expected due to a better territorial access ;

(3) Teleexpertise scenario: Teleexpertises concerns having an expert opinion between medical institutions. Wanted impact can be a reduction of the number of emergency admissions and the number of specialist consultations through better triage ;

(4) Teleconsultation and teleexpertise scenario: Teleconsultation and teleexpertise between different institutions in the region are implemented. It is hoped that a reduction of the transport, of the average duration of consultations, of the number of emergency admissions and of the number of specialist consultations through better triage. However, this reduction will be offset by a rise in the number of consultations due to a better territorial access.

	Number of admissions to the emergency department	**Number of patient transports**	**number of specialized consultations due to better patient triage**	**number of specialized consultations due to better territorial access**	**average duration of consultation**
Scenario 1 : Statu quo	0%	0%	0%	0%	0%
Scenario 2 : Teleconsultation	0%	-15%	0%	1%	-2%
Scenario 3 : Teleexpertise	-2%	0%	-5%	0%	0%

Scenario 4 : Teleconsultation and teleexpertise	-2%	-15%	-5%	1%	-2%

Table 4: Scenario quantification

As possible deployment hypothesis, a 4 year period of telehealth stations deployment has been considered, i.e. time necessary to equip all 200 hospitals needed has been considered to be 4 years (Figure 5). Figure 5 represents the *overall usage rate of telehealth stations over time* and the *impact rate over time* delayed with an average of 18-month.

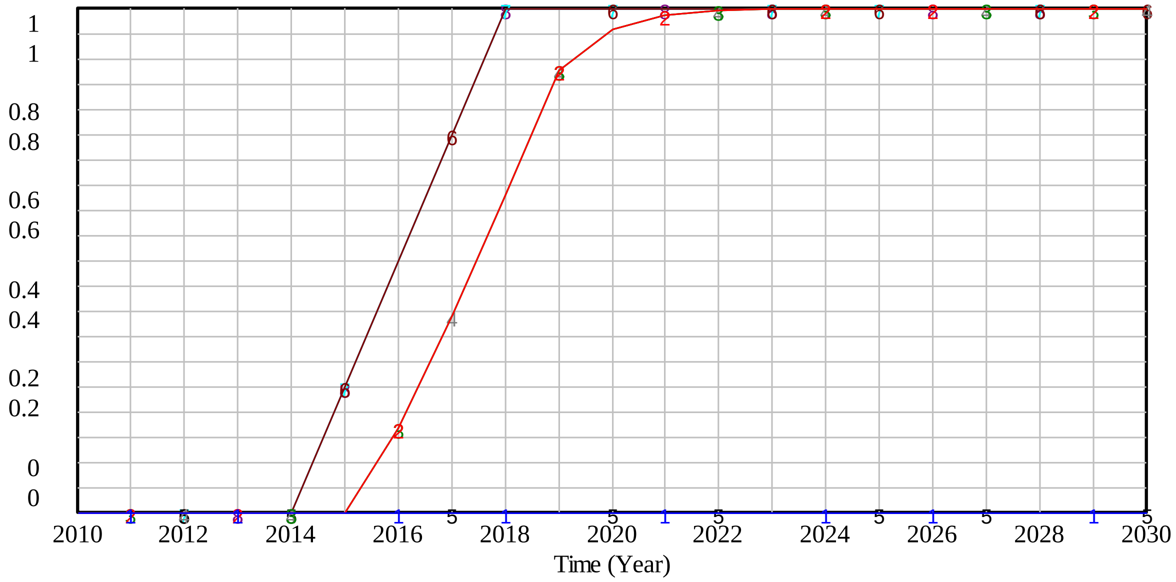

Figure 5: Overall usage rate of telehealth stations over time (left) and impact rate over time (right)

10 RESULTS AND ANALYSIS

Each of the 4 strategies for telehealth integration was investigated over 20 year period. Figure 6 shows the evolution of the *total healthcare cost*, Figure 7 shows the change on the *Carbon Dioxide Equivalent emitted* and Figure 8 shows the change of *total medical time available* for specialists. In each figure, there are 4 functions representing each of the scenarios previously discussed.

Concerning the economic aspect, one can observe in Figure 6 that in the statu quo scenario the *total healthcare cost* increase continuously. In all other scenarios, in which telehealth stations are implemented in the region, the value of this indicator is less than the reference status quo scenario where telehealth is not deployed. The general tendency is overall cost increase in time in all scenarios as the population is increasing. One can observe that overall healthcare cost increase in period between 2014 and 2018. This is due to the costs related to the acquisition of the telehealth stations and not being able to use their maximum capacities. However, all scenarios show a decrease of overall costs after that period. It can be observed that, from 2020 Scenario 2 (teleconsultation) saves 1% per year, Scenarios 3 (teleexpertise) saves 1.2% per year and scenario 4 (teleconsultation and teleexpertise) saves 3.1% per year compared to the statu quo scenario. It seems that the most interesting scenario is scenario 4 where both teleconsultation and teleexpertise are deployed.

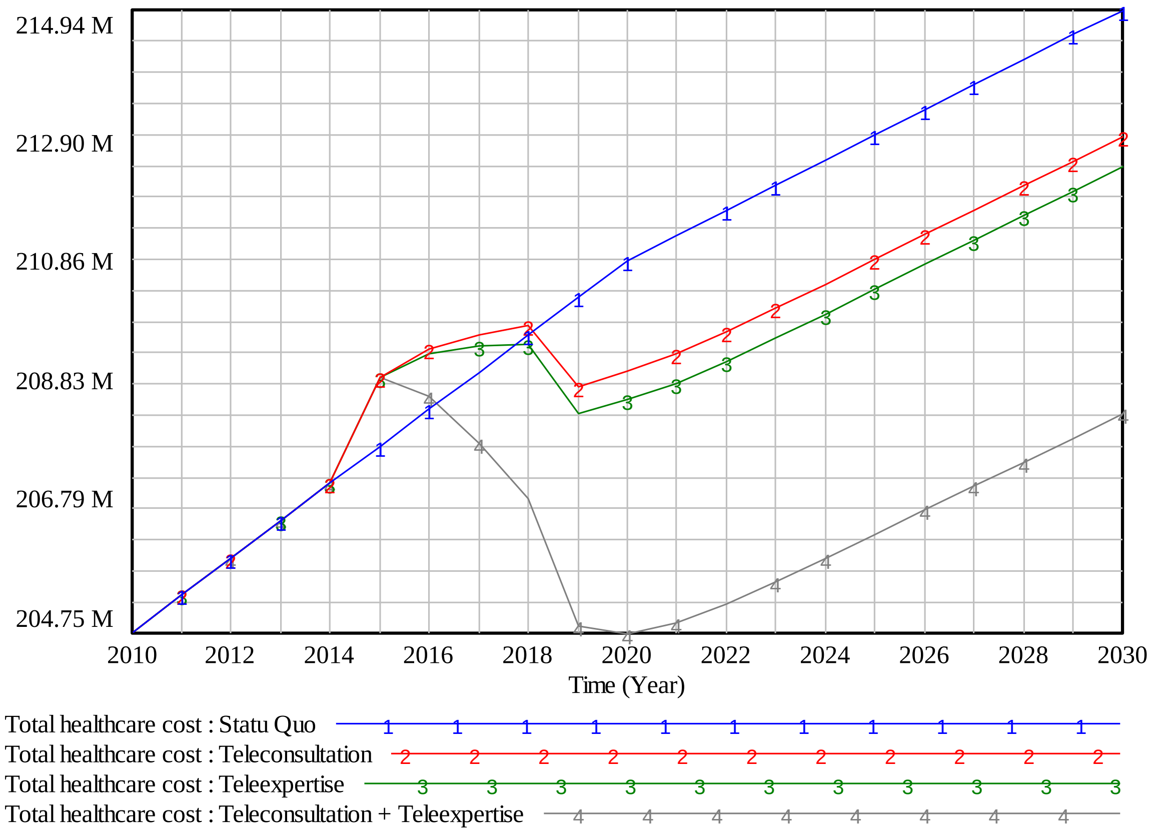

Figure 6: Total healthcare cost evolution over 20 years (in euros)

Concerning the environmental aspect, the impact of these four scenarios has been investigated in relation to the Carbon Dioxide Equivalent emitted (Figure 7). In Figure 7 one can notice that in the statu quo scenario the total Carbon Dioxide Equivalent emitted grows continuously over the 20-year time horizon. In all other scenarios, in which telehealth stations are implemented in the region, the value of this indicator is less than the status quo reference scenario. From 2020, in the case of teleconsultation deployment, the *Carbon Dioxide Equivalent emitted* is reduced by 14.1% per year, in the case of teleexpertise deployment, it is reduced by 5% per year and in the case of scenario 4 (teleconsultation and teleexpertise) it is reduced by 18.4% per year compared to the statu quo scenario. The decrease of *Carbon Dioxide Equivalent emitted* in scenarios 2 is due to the reduction of patient transport, the decrease in scenario 3 is due to a better prevention with a higher triage of patient and the decrease in scenario 4 is due to both reduction of patient transport and better prevention with a higher triage of patient.

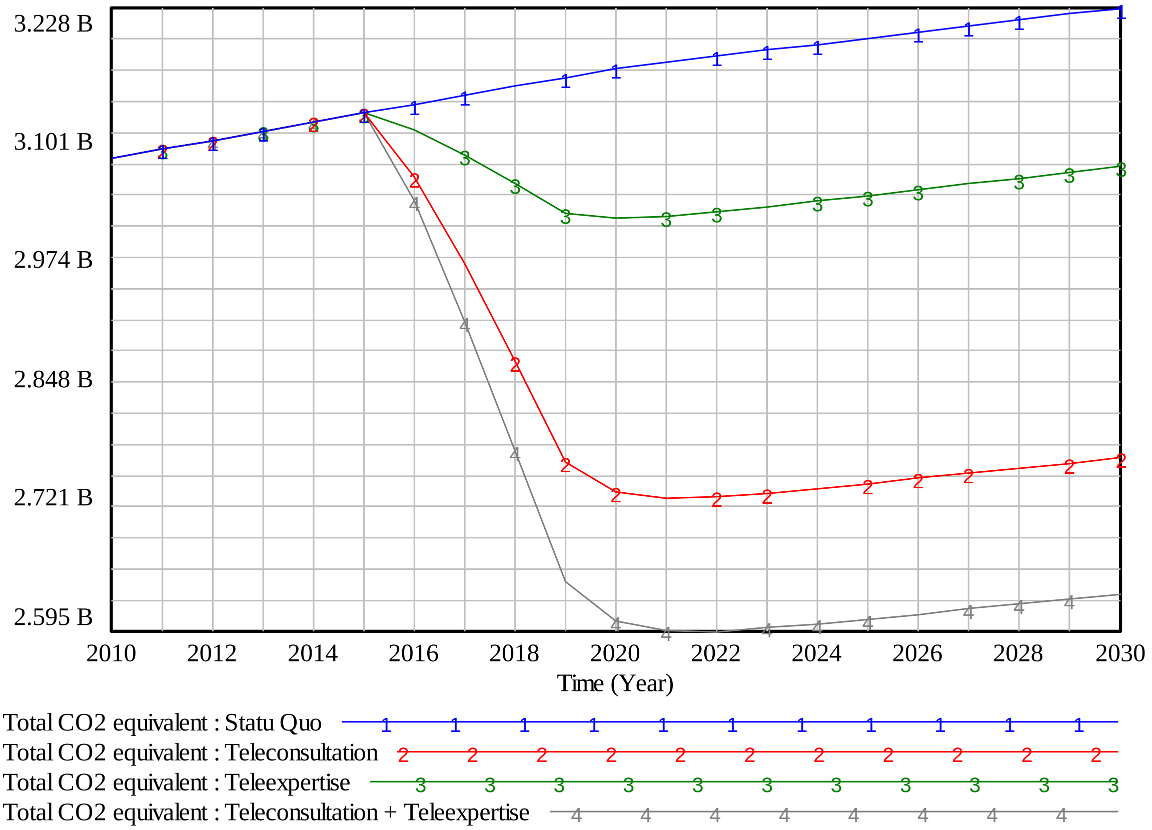

Figure 7: Carbon Dioxide Equivalent emitted over 20 year period (in gram of CO2e)

Concerning the social aspect, the total medical time indicator is estimated by calculating the difference between the total number of medical specialists hours available (supply) and the total number of needed hours with regard to the population (demand) (section 6.2). There are several causes for negative values in this analysis (Figure 8). One is due to the replacement rate for medical specialists. This shortage of medical specialists is something that has been discussed by the French government and is related to the decision about the *numerous clausus*. In this case, what is observed also in real situation is an increasing delay for specialist examinations due to this shortage. As this number has been rectified we can observe a general increasing tendency after 2024. In Figure 8, as in previous figures, the statu quo scenario is presented by the first function. We can see that Scenario 2 (teleconsultation) reinforce the problem of supply demand. Only Scenario 3 (teleexpertise) and Scenario 4 (teleconsultation and teleexpertise) are better, with the first one the best.

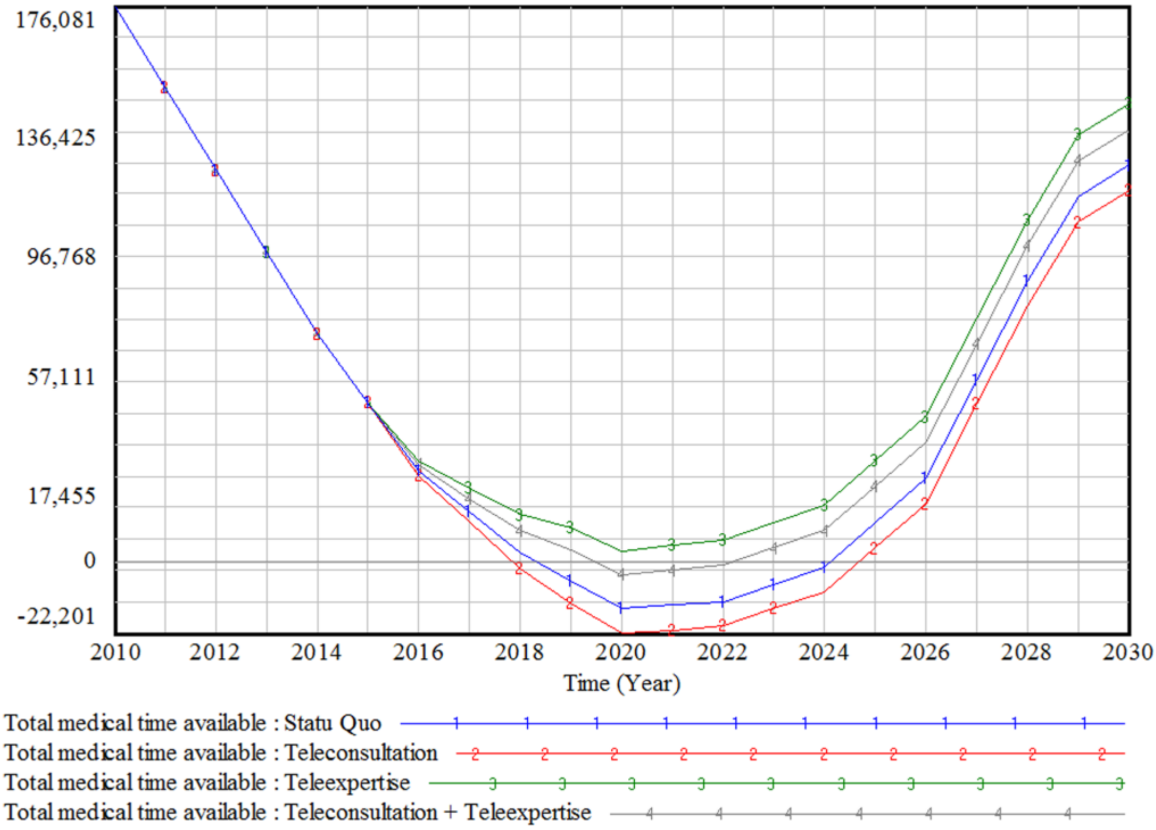

Figure 8: Total medical time available over 20 year period (in hours)

10.1 Discussion

In this work, we investigated the effects of several potential telehealth implementation scenarios defined based on discussions with healthcare managers. With regard to the simulations presented in sections 10, Scenario 3 (teleexpertise) will yield the best outcomes related to the *total medical time available* and scenario 4 (teleconsultation and teleexpertise) will yield the best outcomes with regard to *total healthcare cost* and *Carbon Dioxide Equivalent emitted*.

Saving medical time of specialist practitioners is judged as a priority by the French Ministry of Health (Ministère des affaires sociales et de la santé 2012). Therefore it seems that the most promising possibility is to put the priority in teleexpertise development. Nevertheless, deploying teleconsultation and teleexpertise is also a possibility. It will be less influential on saving time, but more concerning the economic and environmental aspects.

11 CONCLUSIONS, GENERALIZATION AND FUTURE WORKS

Healthcare systems are facing intense challenges to maintain quality and fairness. In the face of severe budget restrictions, solutions must be found to solve the supply-demand problem of healthcare as exemplified by some regions in France, where the number of specialized practitioners is decreasing while the population continues to grow. Telehealth is seen as a possible way to address these challenges. It provides remote access to healthcare services, thus bridging the physical distance between patients and the healthcare professionals best suited to helping them.

Different strategies of implementation can be applied. Our study simulated 4 different implementation scenarios (statu quo, teleconsultation, teleexpertise and both) in order to understand which one will yield the best outcomes as defined by experts in the field. We organized work sessions with a group of practitioners, medical staff and healthcare managers in order to identify the direct impacts that telehealth implementation will have on the system. Five potential impacts were retained in the model: the number of admissions to the emergency department, the number of transports, the number of specialized consultations due to better patient triage, the number of specialized consultations due to better territorial access, and the average duration of consultation. To identify the influence of an implementation strategy on the healthcare system, three indicators were selected: economic aspect (*total healthcare cost*), environmental impact (*Carbon Dioxide Equivalent emitted*) and social impact (*total medical time available*). The perimeter of this study was the Picardie region and a 20-year time horizon.

We chose to use a parametric scenario-based model based on design principles that enables formal computer simulations of complex systems to be built and used in the design of policies aimed at increasing the effectiveness of organizations. Furthermore, we chose it because its visual nature facilitated understanding of the model in discussions with the expert group.

The results of these simulations compare strategic telehealth implementation scenarios. They take into account the number of telehealth stations and their effective use over time, and provide decision support in order to reduce healthcare costs, reduce Carbon Dioxide Equivalent and save valuable medical time in this region. Based on the results presented, teleexpertise scenario will yield the best outcomes to save medical time available and teleconsultation and teleexpertise scenario will yield the best outcomes to save healthcare cost and Carbon Dioxide Equivalent emitted. As the French Ministry of Health gives priority to save medical time of specialist practitioners, our recommendation is to make a priority of developing teleexpertise. Nevertheless, deploying teleconsultation and teleexpertise is also a possibility. It will be less influential on saving time, but more concerning the economic and environmental aspects.

We believe that this approach can be seen as a strong decision support tool in the development of telehealth systems in the future. Further work might be done to incorporate more qualitative impacts in the overall system and to expand the parameters to other regions and countries.

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LIST OF ACRONYMS

CO2e	Carbon dioxide equivalent
DES	Discrete Event Simulation
DREES	Office of Research, Evaluation, and Statistics
EHR	Electronic Health Records
INSEE	National Institute of Statistics and Economic Studies
SD	System Dynamics
WHO	World Health Organization