Preliminary Cost-Benefit Analysis of a Real-Time Telemedicine System

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***Abstract*—Information and communication technology in the medical field has witnessed great advances at research level but it is still largely unapplied in routine clinical practice. Technology-driven solutions, proved experimentally effective, are not always efficient in the complex health world. Each form of innovation needs to be sustainable, from an economic and organizational points of view, if it is to progress from the prototype phase to become a practical element of the healthcare system. A cost-benefit analysis can help establish if this is the case. Here, we apply a preliminary cost-benefit analysis to the real-time telemedicine platform we developed. It has proven successful from a diagnostic point of view, but how does it perform from an economic perspective? Our analysis compares the overall cost of the platform to the economic savings made from its operational use - where unnecessary patients' transfers are avoided. We estimate potential savings of about 66% of current costs.**

Keywords-real-time telemedicine; pediatric cardiology; cost-benefit analysis

I. INTRODUCTION

Tele-health, when supported by solid economic and organizational design, can promote new care models (like hub-and-spoke distribution or home monitoring), fostering a rational and effective use of investments [1] [2] [3] [4]. Standard telemedicine technology proves its validity in several contexts, but is generally unsuitable to situations involving operator-dependent diagnostic techniques – it is not sufficient simply to store and send images, it also needs the timely application of specific expertise in order to complete the examination. Only by providing real-time collaboration do the standard telemedicine technologies produce value. Pediatric Cardiology is one of those clinical discipline [5] requiring a specialized operator to obtain a reliable result: echocardiography is the focus of a congenital heart disease (CHD) evaluation, and it is only accurate when performed by an expert. In general, specialists in this fields are rare and their lack is particularly critical in some regions with high incidence of this kind of disease, like Sardinia - one of Italy's major islands (Fig. 1): in Sardinia CHD has a mean incidence of 20.25%, more than twice the typical incidence [6] and there is a unique specialized center (Pediatric Cardiology Structure in *Azienda Ospedaliera* "G. Brotzu", Cagliari [7]). As can be seen in TABLE I, the distances between the center and the eight main health districts (ASL-*Azienda Sanitaria Locale*), corresponding to the main cities (Sassari, Nuoro, Oristano, Lanusei, Carbonia, Olbia, Sanluri, Cagliari), are not extreme but the logistic infrastructure can cause critical travel time for patients' life. To mitigate the high risks deriving from this situation, CRS4 [8] and Brotzu hospital carried out a research project resulting in a real-time low cost telemedicine platform, able to support clinicians with the tele-presence of a specialist in real-time during echocardiographic evaluations [9]. The platform developed allows echocardiographic exams to be performed remotely, without physical interaction between the patient and the specialist. The ultrasound analysis is operated by a third doctor who physically visits the patient, while the specialist guides the operator directly, viewing the echographic output and the examination scene at the same time. The system has proven its diagnostic value [10] and the analysis presented below is a preliminary evaluation of its economic advantages, in anticipation of a regional scale trial.

Here, we test the hypothesis that the use of our real-time telemedicine platform is economically beneficial for both the Sardinian health service and patients by comparing the system's cost to that of savings to be made in patient transport - a very specific but substantial aspect. At this preliminary stage, we do not attempt an assessment in terms of quality of care – the necessary data are not yet available. Similarly, at this stage, a cost-utility or cost-effectiveness analysis, as recommended by literature [11][12][13], is not attempted. Nevertheless, this preliminary cost-benefit study gives some indicators for the future implementation of the system in real clinical life. The *Material and Methods* section describes the system workflow and the approach for cost evaluation analysis, which lead to the estimate summarized in the *Results* section and discussed in the *Discussion* and *Conclusions*.

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Figure 1 – *Sardinian Health District locations.*

TABLE I. DISTANCES

Distance of each Health Districts from the main hospital		
Health District (ASL)	***Distance (km)***	***Time (hours)***
ASL 1 - Sassari	216	02:19
ASL 2 - Olbia	276	02:57
ASL 3 – Nuoro	207	02:18
ASL 4 – Lanusei	125	01:52
ASL 5 - Oristano	96.9	01:08
ASL 6 – Sanluri	47.9	00:39
ASL 7 – Carbonia	71	00:56
ASL 8 – Cagliari	4.8	00:11
AO – Cagliari	4.8	00:11

II. MATERIAL AND METHODS

To evaluate the cost-benefit of our telemedicine system, we consider the route from the unique centre of specialization in Cagliari to nine secondary hospitals - one per Sardinian health district (ASL), plus another hospital in Cagliari (AO). Below we outline the method of evaluation.

A. Cost-benefit analysis: approach

We take a societal perspective, highlighting cost and benefits deriving from the use of the system both for health system and for patients – but only in terms of travel savings, since our system is not currently operational so we are yet to measure benefits in terms of effectiveness. The analysis is based on a cost comparison during the year 2012 considered with and without the system.

Currently, patients suspected of CHD are sent to Cagliari (Brotzu Hospital), by their General Practitioner (GP) or, in emergencies, sent directly by other hospitals, often by ambulance. A specialized visit then occurs to confirm CHD, or not. Visits that do not confirm CHD are indicated as unnecessary below. TABLE II details the consultations claimed by health structures or by GP (for outpatients). We enumerate the former category into both necessary and unnecessary visits – but lack the data to do the same for outpatients consultations.

With the presence of the telemedicine system, the main costs are those related exclusively to the system set-up and maintenance, while the main economic benefits consist in the savings due to avoiding patient transfers to Cagliari: the patients could be first visited in their health district and then only urgent cases sent to the main center. Therefore, the economic benefits are:

- for the patient, in saving the cost of all transfers required for outpatient consultations;
- for the health structures, in saving the cost of transfers at first considered to be urgent but revealed as unnecessary.

These costs may be evaluated by this equation:

$$C = Cv + Ct = \left[\left(\frac{Cf}{Mf} + Cu\right) * D\right] + T * \sum_{n} Mn \quad (1)$$

where:

Cv = vehicle cost (ambulance, or standard car)
Ct = team cost (only in case of ambulance)
Cf = fuel cost
Mf = medium fuel usage
Cu = fixed cost of usage
D = distance
T = time
Mn= nth member of ambulance team

When transfer is by ambulance, both the terms Cv and Ct are present, since both vehicle and the team have associated costs - which vary according to the specific conditions.

D and T are the values of distance and time, respectively, taken from TABLE I.

The term Cf is calculated as the average fuel (diesel and gasoline) costs in Italy in 2012, published by Italian Economic Development Ministry [15][16].

TABLE II. 2012 CONSULTATIONS

Face-to-face Consultations Performed in 2012		
Health District (ASL)	***Consultations by Health Structures Required (Necessary)***	***Outpatient Consultations***
ASL 1 - Sassari	1 (1)	82
ASL 2 - Olbia	0 (0)	71
ASL 3 – Nuoro	4 (2)	164
ASL 4 – Lanusei	0 (0)	41
ASL 5 - Oristano	1 (1)	210
ASL 6 – Sanluri	2 (0)	378
ASL 7 – Carbonia	23 (5)	348
ASL 8 - Cagliari	57 (4)	1839
AO - Cagliari	18 (5)	-

B. The Platform: Description and cost evaluation

A suspected CHD case may be detected either by a GP or a health structure: with our telemedicine system in use, the patient is to be sent to the closest secondary center with a teleconsultation station. The workflow has three main parts, depicted in Fig. 2:

1. **scheduling**: the secondary center, according to the tertiary/specialist center availability, requires the teleconsultation (step 1 and 2 in Fig.2);
2. **teleconsultation**: the specialist accepts the request and starts the remote visit, interacting in real-time with the operator at the secondary center (step 3 and 4 in Fig.2);
3. **reporting**: the specialist saves the digital diagnosis in a structured report which becomes immediately available to the doctor who performed the test and to the patient (step 5 in Fig.2).

From the software point of view, the system is open-source and composed of a portable application for the sonographer, a desktop application for the specialist and a web application for managing scheduling and patient information (clinical data and reports). As for hardware, the platform requires a central server, a laptop for the specialist and, for each center requiring teleconsultation, a network camera (to record the examination scene), an encoder (directly connected to the echograph) and a mobile device like an Apple *iPod* touch (to enable the communication between the clinicians through a VOIP audio chat). So, from the hardware point of view, the system costs are the sum of these items.

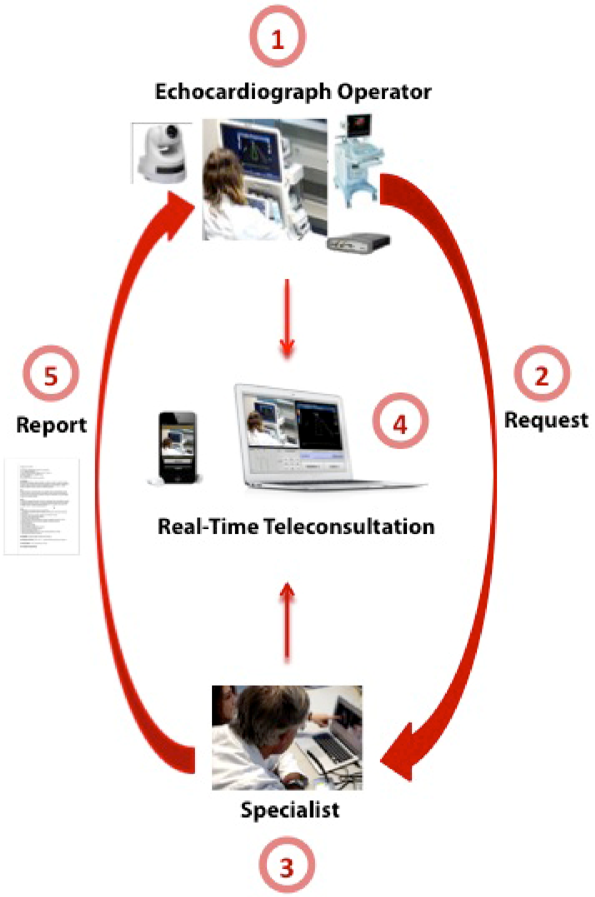

Figure 2 – ***System basic workflow.***

The costs are based on market prices: the estimate for the server is based on the idea of using a clustered virtual machine [14]. There are no additional costs for the network infrastructure: the system is designed to take advantage of preexisting networks and it doesn't need dedicated connections, requiring only 2.5MBps bandwidth. Each center has its own existing general purpose communication infrastructure so no additional costs are incurred during the development of the telemedicine intervention system due to such communication.

Moreover, each center has an IT department and the maintenance of the system can be easily incorporated in the routine maintenance of the other systems already running in each center. The platform does not require specific knowledge to be used by the clinicians once they have had a few hours training experience. TABLE III summarizes the costs for the telemedicine system.

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TABLE III. PLATFORM COSTS

Platform costs		
Type of unit	***Component***	***Price (€)***
Center Requiring Consultation	Encoder video Axis Q7401	400
	Apple iPod touch	250
	Network Camera Axis PTZ 214	1300
TOTAL FOR THE UNIT		**1950**
Center Offering Consultation	McBookAir	1000
	Central server	2000
TOTAL FOR THE UNIT		**3000**

C. Transfer costs analysis: healthcare system perspective

Adopting our telemedicine system ought to enable the specialist in Cagliari to see the patient nearer the onset of suspected CHD, allowing the patient to be transferred for therapy at an earlier stage.

It is hard to quantify a priori the advantage of such prompt intervention, but we can evaluate the savings in transfer cost. We have no hard data whether transport cost are incurred by health service (ambulance transfer) or by patient (own car) so we consider the costs in each case, supposing either transfer via ambulance or via a "standard" car. As the costs for medical and private vehicle transfer are not directly available, we estimate them using equation (1), taking into account both the cost of the vehicle and the cost of the team.

For the evaluation of the medical vehicle costs we consider a series of 10 vehicles on the market [18], obtaining for each of them an estimate of our term Cu [17] and term Mf.

For the evaluation of the team costs, we consider five kinds of team, composed by:

- A1 – driver and nurse on duty;
- A2 - driver and nurse on call;
- B1 – driver, nurse and doctor on duty;
- B2 - driver, nurse on call and doctor on duty;
- B2 - driver, nurse on duty and doctor on call;
- B3 - driver, nurse on call and doctor on call.

The hourly costs for the personnel are in TABLE IV.

TABLE IV. AMBULANCE TEAM COSTS

Ambulance team costs (€/hour)	
Team Member	***Cost***
Driver	14.80
Nurse (on duty)	16.38
Nurse (on call)	27.00
Doctor (on duty)	36.34
Doctor (on call)	60.00

Combining all these factors with data from 2012 about transfers from health structures (TABLE II), it is possible to evaluate the total costs for (necessary/unnecessary) transfer by ambulance. The methodology used to evaluate term Cv in case of private cars is described in the next section.

D. Transfer costs analysis: patient perspective

In case of non-urgent suspected CHD, patient families use their own car for all outpatient consultations. To evaluate these costs, we considered only the term Cv in (1), calculating it for a "standard" car, i.e. the best-selling car in Italy in 2012 [19], FIAT Panda "1.3 MJT 16V 95 CV". Term Mf was obtained from the manufacturer website, term Cu from ACI databases [17] and term D from TABLE I. After estimating the cost for car, we multiplied it by the number of transfers in TABLE II. We did not include transfers from within the Cagliari District since patients would already be in the hospital of destination (Brotzu Hospital) so there was no need to move.

III. RESULTS

A. Transfer costs analysis results: healthcare system perspective

The estimate of the transfer costs to Brotzu Hospital for the consultations required by other structures are presented in TABLE V, for both vehicle-types: ambulance and private car. Since for consultations by health structures we have the data for whether a request was necessary or not we also list the unnecessary costs in the table.

B. Transfer costs analysis results: patient perspective

The costs for patient transfers to Cagliari center related to outpatient consultations are depicted in TABLE VI.

C. Transfer costs analysis results: societal perspective

Considering all the results for the transfer costs analysis from health system and patients perspective, we obtained the overall cost-benefit results of TABLE VII.

In the table, the column "expenditure nature" clarifies if, for society, the amount must be considered a cost or a benefit. The costs for transfers from other structures by ambulance are marked with (A), while the costs by private cars are marked with (C).

TABLE V. 2012 TRANSFER COSTS RELATED TO CONSULTATIONS REQUIRED BY HEALTH STRUCTURES (AMBULANCE AND PRIVATE CAR)

Costs for Consultations Required By Health Structures (Ambulance)			
Health District (ASL)	***Consultations Required (of which Necessary)***	***Ambulance Costs Due to Unnecessary Consultations Costs €***	***Private Car Costs Due to Unnecessary Consultations Costs €***
ASL 1 - Sassari	1 (1)	0	0
ASL 2 - Olbia	0	0	0
ASL 3 – Nuoro	4 (2)	572	190
ASL 4 – Lanusei	0	0	0
ASL 5 - Oristano	1 (1)	0	0
ASL 6 – Sanluri	2 (0)	149	86
ASL 7 – Carbonia	23 (5)	2481	602
ASL 8 - Cagliari	57 (4)	824	876
AO - Cagliari	18 (5)	202	319
TOTAL	**106 (18)**	**4228**	**208**

TABLE VI. 2012 TRANSFER COSTS RELATED TO OUTPATIENT CONSULTATIONS

Consultations required by GPs		
Health District (ASL)	***Consultations Required***	***Consultations Costs €***
ASL 1 - Sassari	82	6113
ASL 2 - Olbia	71	6763
ASL 3 – Nuoro	164	11717
ASL 4 – Lanusei	41	1769
ASL 5 - Oristano	210	7023
ASL 6 – Sanluri	378	6249
ASL 7 – Carbonia	348	8527
ASL 8 - Cagliari	~~1839~~	NOT CONSIDERED
TOTAL	**1294**	**48163**

The cost-benefit analyses are summarized in TABLE VIII, which shows that our telemedicine platform could help save between 33586 € and 35740 € within one year, reducing the costs of the system to 66% of the total expenditure. Moreover, in the future hardware costs should decrease, while the same is not expected for transport costs.

TABLE VII. COMPARISON OF 2012 COSTS WITH AND WITHOUT THE TELEMEDICINE SYSTEM

Comparison Of Costs With And Without The Telemedicine System			
Expenditure Cause	***Expenditure Type***	***Costs With Telemedicine €***	***Costs Without Telemedicine €***
Regional Telemedicine System	Cost	16650	0
Necessary Transport From Health Structures	Present in all cases	1832 (A) 692 (C)	1832 (A) 692 (C)
Unnecessary Transport From Health Structures	Benefit	0	4228 (A) 2074 (C)
Transport For Consultation Required By GPs	Benefit	0	48163
TOTAL		**18482 (A)** **17342 (C)**	**54223 (A)** **50929 (C)**

TABLE VIII. COST-BENEFIT ANALYSIS RESULTS

Expenditure Cause	***Min €***	***Max €***
Costs	16650	16650
Benefits	50263	52391
TOTAL SAVINGS	**33586**	**35740**

IV. DISCUSSION

Although the result of our analysis appear good we should emphasize some limitations of this study:

- the precise number of consultation requiring ambulance transfer are unavailable for some health structures;
- the ambulance costs are an estimate since the precise cost are unavailable;
- for outpatient consultation we used average estimates of distance rather than precise mileages;
- for the patient perspective costs, we excluded data from the Cagliari district.

These limitations probably do not undermine the value of our preliminary analysis, but they do suggest themes for future studies: cost-effectiveness analysis and sensitivity analysis should be designed to enhance the quality of the system evaluation.

Another question left open is that of the relative performance of telemedicine systems: our solution is open and low cost, but about commercial systems? We have yet to compile a similar table of costs for existing commercial telemedicine applications (their prices are not publicly available). Instead, we tabulate some teleconference systems (not necessarily dedicated to CHD), that might be used in similar way. TABLE IX summarizes the systems we studied.

TABLE IX. SIMILAR TELEMEDICINE SOLUTIONS

System	*Price*
VSEE [20]	$299/kit/month $49/user/month
Lifesize Communications conference streaming system [21][22]	$2000 to $15000 hw $49/month sw
Cisco TelePresence [23][24]	$ 9900 hw
Tanderberg video communication (Cisco company) [25][26][27]	~$10000 to $30000 for clinical presence system
VIDYO [28][29]	starting at $17000

None of the solutions we list here appear to guarantee the performance offered by our platform, in terms of teleconsultation support and setup/maintenance cost savings.

V. CONCLUSIONS

The preliminary cost-benefit analysis presented in this paper shows that the adoption of the real-time telemedicine solution we developed is potentially useful from a societal perspective. This analysis is local and is focused on a specific situation, but the design principles that guided its development enable it to be applied in other clinical contexts that require operator-dependent diagnostic techniques. At the moment, the telemedicine system is under trial in emergency structures for the FAST (Focused Assessment with Sonography for Trauma) examination. Another added value of the system derives from its adaptability to support learning sessions. In conclusion, the benefits of our telemedicine system confirm the original hypothesis from which we started and encourage us to trial the system on a regional scale, once the an organizational model has been completely defined.

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