Improving the Efficiency of a Public Health Service by Designing Its Innovation Management Structure Based on Data Envelopment Analysis

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ABSTRACT

This paper presents a proposal for Chile's health system innovation structure based on a formal service design approach, including management and process architecture definition. Such structure defines how to allocate innovation resources in the health system to increase its efficiency. It uses data envelopment analysis (DEA) to measure hospitals' efficiency, which also determines the variables that explain such efficiency. Thus, the architecture uses the knowledge about hospitals' efficiency and their determinants to define innovation projects and assign financial resources for them. It also assures their implementation to increase the efficiency of the hospitals. DEA measurements show great improvement potential since only six of 40 hospitals had an efficiency value of 1.0. Some of the projects with the best improvement potential were implemented with very good results, summarized in the paper. The main contribution of this work is to formalize and enlarge the scope of the structural design of health services to generate improved results for users at a lower cost.

KEYWORDS

Data Enveloped Analysis, Health Innovation Structure, Health Management Structure Design, Health System Service Efficiency, Service Efficiency and Design

1. INTRODUCTION

The research on design approaches to increase the efficiency of health service systems has many variants. Thus, in specific situations, the design centers on care pathways that are analyzed and improved with mostly qualitative methods, as in published cases on pathways for chronic and integrated care (Valentijn, Schepman & Opheij, 2013; Korner, Butof & Muller, 2016). The next level of complexity is to consider structural changes for a full health system, such as implementing new care models across primary care, community services, and hospitals in England (Starling, 2018). Further complexity occurs when doing a full redesign of a health system, changing its structure, as reported for some USA and European hospitals (Lee & Porter, 2013; Nolte et al., 2016; van Harten, 2018).

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For example, a functional health structure changed into integrated practice units with specialized care lines –e.g. low back pain– in a USA hospital, replacing teams and pathways (Lee & Porter, 2013) and the design of specialized services lines for an Emergency Service in Chile (Barros, 2019).

This work concentrates on the redesign of a full health system and uses a set of tools that have been useful in practice to generate and analyze service systems' alternative management structures (Barros, 2021; Trad, 2021; Mora et al., 2011). The specific case considered is the design of the structure that manages resources assigned to innovation initiatives for increasing the efficiency of the Chilean network of hospitals.

In Chile, resource allocation to public hospitals uses the idea of 'management commitments', which are goals measured by the number of medical interventions of different types a hospital promises to execute to receive a certain amount of resources in any given year. This method fails to set goals that consider the true capacity of the hospitals and provides no incentive to do more than the goal. Therefore, there is no guarantee that hospitals operate at the right efficiency level, according to the resources they have. Thus, the idea is to measure the efficiency of hospitals using Data Envelopment Analysis (DEA), a mathematical technique widely used in health (Hollingsworth, 2008; Sherman & Shu, 2006, 2013; Ozcan, 2014; Kohl et al.,2018). DEA identifies the least efficient hospitals that present the best opportunities to improve their performances, and efficiency measurements' results indicate how to improve them to get the best results. Subsequently, the proposal is to design an organizational structure that coordinates the assignment of innovation resources, based on DEA results, to define and implement improvement projects for inefficient hospitals. This design innovates the traditional use of DEA, which emphasizes analysis but does not consider specific improvement projects and a structure to manage them (Ozcan, 2014; Barpanda & Sreekumar, 2020). The methodology used for structure design concentrates on the Enterprise Architecture (EA), reviewed later, which defines the organization's units and the processes needed to manage the global improvement of the hospital network, a need also justified by Baporikar & Randa, 2020. This organization will redefine the assignments of funds to hospitals to generate innovation initiatives, with incentives to change their practices and increase efficiency. Modern Analytics, reviewed in the next section, is also present in the architecture to automate or give support to the architecture components defined later.

In summary, the proposal is to design a new organizational structure for the health service system to generate innovation projects, using DEA's ideas above, and to provide resources and local capabilities to the hospitals to execute such projects. A justification of such a structure is in the next section, where a review of the methods that support its design is included. This design idea is not only applicable to health, but other public services, such as education, social, and justice can use the proposed approach to increase efficiency.

2. METHODS USED AND THEIR INTEGRATION

To provide theoretical support for efficiency measurement and organizational structure design and evaluation, several disciplines provide methods, described subsequently. A design methodology that integrates such methods ensures the final objective of increasing the efficiency of the organization under analysis, which is the subject discussed in Section 2.5. This type of integration in the context of process improvements, which is part of the design problem subject of this paper, has also been recognized by other authors (Johannsen, Zellner & Griesberger, 2022).

2.1 Data Envelopment Analysis (DEA)

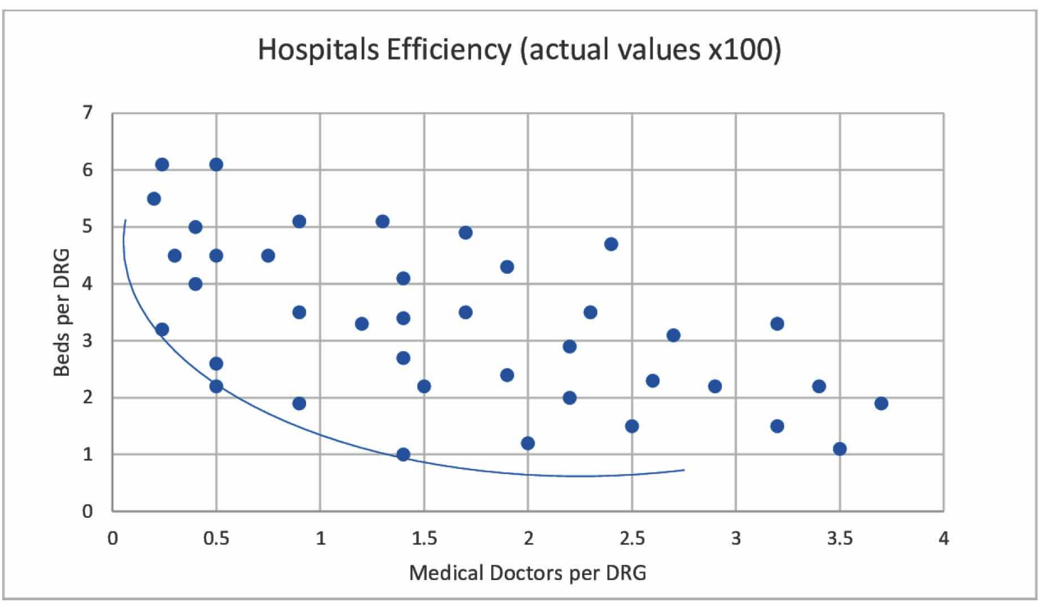
DEA makes it possible to measure and compare hospitals' efficiency by using the economic theory of the efficiency frontier (Farrel,1957). According to economic theory, a unit is efficient when it can produce, relatively to a comparable group, a greater amount of products for a given quantity of resources; alternatively, using a smaller amount of resources for a given amount of products is also efficient. For this reason, the definition of the levels of efficiency of the units is in relative terms, given the information available; the most efficient units are those that define the efficiency frontier in the way shown next.

To make clear the efficiency frontier concept, a situation close to the one defined in this work is considered. There are "n" comparable general hospitals, in the sense that they provide similar services. Each of these hospitals produces, in any given period, a variety of outputs. To standardize the production of multiple health outputs, a weighted measure called a Diagnosis-Related Group (DRG) exists (Fetter et al., 1980). In the literature, the use of DRG as a measure of a hospital's production is common, since it has been empirically observed that the relative weights of the DRG are correlated with the real cost of a hospital. The method introduces an indicator that identifies the potential relative consumption of the resources for a DRG (Farrel, 1957; Wynn & Scott, 2008). Most Chilean public hospitals have implemented DRGs to measure their production.

In producing the DRG output, a hospital uses many different resources: medical doctors (MD), nurses, supplies, installations, and others. Let us assume that the more significant inputs are MD and beads. Therefore, a simple way to compare hospitals' efficiency is to calculate the ratios of MD per DGR and beads per DGR and to plot the results, as Figure 1 shows for 40 hospitals in Chile.

It is clear from Figure 1 that the more efficient hospitals, in the sense that they use fewer resources per unit of output measured by DGR, are the ones in the lower boundary of the set of points shown in the figure. This is the efficiency frontier; those above this frontier are inefficient and further separated from it, more so. Several authors have considered the determination of the efficiency frontier for many inputs and outputs, developing various optimization models for its calculation (Sherman & Shu, 2006; Ozcan, 2014). Super efficiency calculation, which admits efficiencies greater than 1.0, is a new variant of DEA that allows better discrimination of the more efficient units (Xue & Harker, 2002); this work uses this variant. Such models run on available software, which processes the inputs and outputs historical data for calculating the comparative efficiencies. There are more complex DEA models –e.g., the ones considering stochastic data (El-Demerdash, Tharwat, & El-Khodary, 2021)– that can be incorporated into the methodology proposed later.

Figure 1. Efficiency frontier



The application of the DEA is common to compare the efficiency of health units; thus, Hollingsworth (2008) revised 317 international studies, where 75% of them used DEA to measure efficiency in health units. Additionally, Sherman & Zhu (2006, 2013), Ozcan (2014), and Kohl et al. (2018) present many DEA cases in several health organizations in different countries.

The DEA models give results in which input and output variables values explain a unit's inefficiency and determine what improvements for them can increase efficiency (Ozcan, 2014). The method has also a second stage that discovers other variables correlated with efficiency, not included in the calculations, which if improved for a unit, efficiency will increase (O' Neill, 1998; O' Neill & Dexter, 2004).

2.2 Enterprise Architecture (EA)

The design of the structure of the Chilean hospital network presented here uses a methodology proposed by Barros (2021) based on the ideas of EA "to discover and represent alternative structures –in terms of hierarchy levels, decentralization, modularity, innovation, and coordination– an enterprise may have". The objective is to have design guidelines, called patterns, to develop an EA, and avoid starting from cero. An EA pattern should synthesize the accumulated knowledge on how enterprises with certain characteristics should structure their processes, the people who execute them, and the Analytics and IS that support both of these, in such a way that they are aligned with given strategic guidelines. A complemented to EA patterns is an approach for EA characterization developed by Ross, Weil, & Robertson (2006) and Ross, Beath, & Mocker (2019), which links structure with strategy, providing four architecture types resulting from the analysis of the degree of integration of several business units and their processes' standardization observed in many cases in practice. They are the **Diversification** architecture that focuses on decentralized organizational designs with operating units having high local autonomy, as opposed to the **Unification** one, which pursues low costs and standardization of business processes through management's centralization. The **Coordination** architecture emphasizes integration without forcing specific process standards, whereas the **Replication** one pursues standardization with low integration among the different units. Thus, depending on the desired centralization and standardization, a corresponding architecture is the right one. The architecture used here is **Unification**, which is very popular and appropriate for an enterprise that has many similar operating units providing the same services, as hospitals do. In such cases, it is clear that the centralization of process innovation promotes standardization and avoids doing the same developments in all the units. This is clear in cases like Walmart and CEMEX, an international cement company, which centrally develops and standardizes all its processes and systems, using advanced Analytics, to assure a world-class supply chain with excellent service at a minimum cost (Ross, Weill, & Robertson, 2006; Davenport, 2006). Additionally, e-commerce leaders such as Amazon use the same approach (Ross, Beath, & Mocker, 2019). The main point here is that complex public service systems with many similar units, such as health, may learn from these experiences, particularly from the centralization of processes innovation, which favors standardization. Agency theory also supports this centralization, as presented in the next section.

Subsequently, a proposal for a general EA for health services is reviewed. This approach represents an EA as a process architecture, as proposed by Barros (2021) and modeled by following BPMN conventions (White and Miers, 2009).

Health services are part of a complex network, which includes a central management level, usually a high government office, and geographically defined sub-networks that have decentralized management and operating units, which may be hospitals or primary services that refer patients to them. The primary services may belong to the sub-networks or be decentralized and locally managed, for example, by counties. For this type of service, there is a proposal for a general process architecture pattern for multilevel structures that appear in complex organizations (Barros, 2021), such as government services, which, besides health, include education, social, and various others. The general pattern is specialized to the case of the public health system in Chile as shown subsequently.

The key structure design decision for this system is the degree of management decentralization since there are two main hierarchical levels —overall health system and sub-network management— above the hospitals that provide the health services. In principle, Chile has decentralized management of the system, since most of the hospitals are self-managed units; this is similar to the Diversification structure defined previously. But, many coordination issues need to be centralized, such as innovation initiatives; referrals among units within a sub-network and sub-networks; management of waiting lists; and sharing of scarce resources such as beds. The issue selected in this work is the coordination of innovations for hospitals to increase their efficiency.

The current solution to manage this decentralized network in Chile is "management by commitments", as explained in the Introduction. Nevertheless, this does not provide the necessary coordination to assure that hospitals are efficient, as justified previously. Thus, the general architecture in Figure 2, a specialization for the health system of the more general pattern (Barros, 2021), is used as a basis to design a structure for innovation in the hospital network.

The emphasis is on designing a structure that presents alternatives to distribute responsibilities to the innovation processes that exist at each level —network, subnetwork, and operating unit— such that efficiency is increased. The flows that connect processes and produce the required coordination, called interfaces, are also key design decisions, as explained subsequently:

1. The hospitals are represented by several "Health operating Unit j", each having three management levels –Operation, Innovation, and Planning- that are represented by a pool decomposed into lanes, following BPMN conventions.
2. The pools above the "Health operating Unit j" show the structure of the health system that has several 'Health Sub Network I', which exist to manage operations for a group of hospitals, geographically defined; they also define and make innovations on the service according to given strategic plans.
3. The upper level "Health System Network" represents the highest management level in charge to provide planning and coordination of the health system.

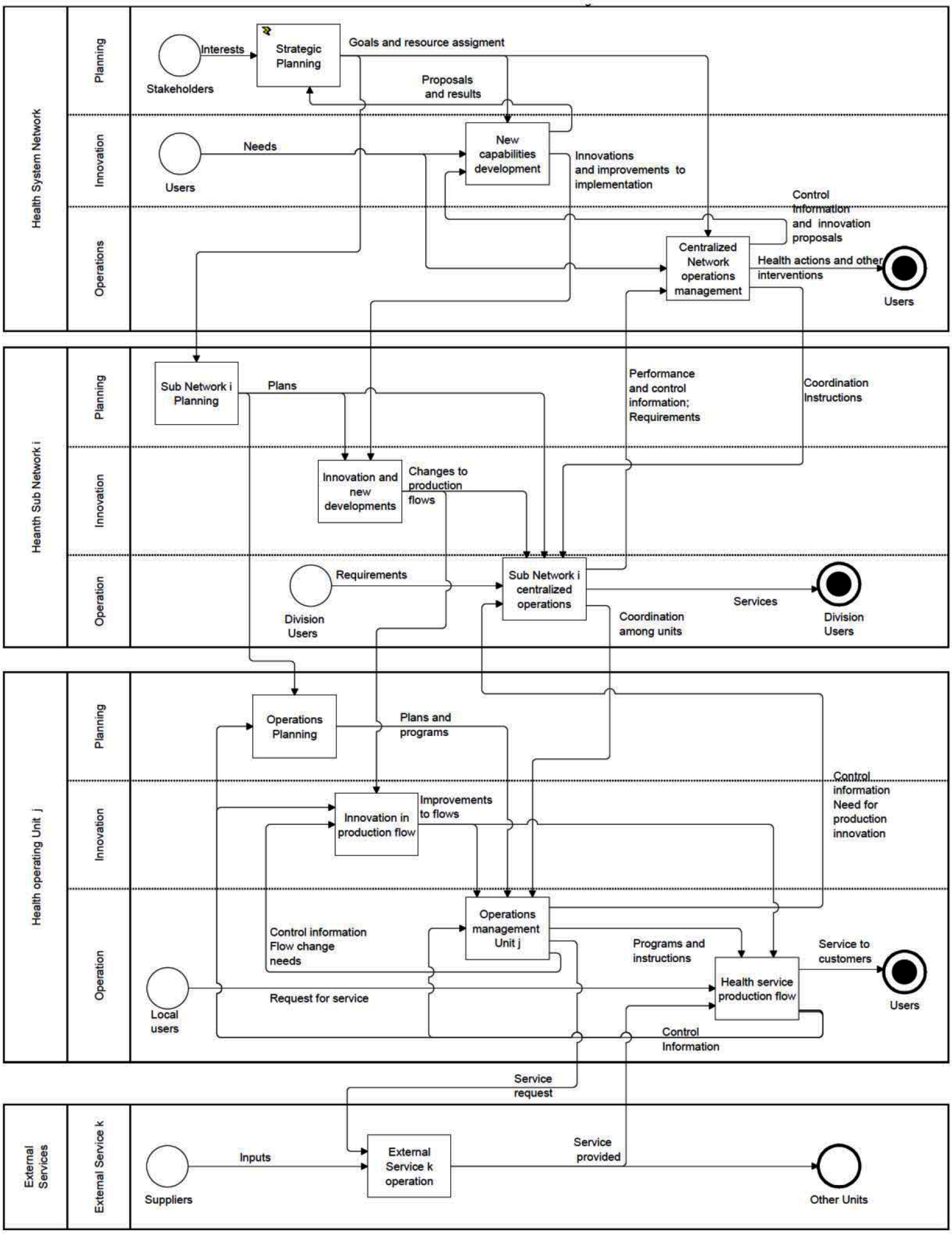
A more detailed description of the architecture follows, emphasizing the management of innovation.

The "Health operating Unit j" pool in Figure 2 is just one typical unit, but there may be several. All the components of a unit are a partition of the pool into lanes of Operation, Innovation, and Planning, which perform the following functions:

1. "Operations" includes "Operations management Unit j", which performs operations scheduling, resource provision, performance control, corrective instructions, and detecting the need for production changes. It generates coordinating flows such as "Programs and instructions" to "Health service production flow", which is the other component of this lane.
2. "Innovation" executes "Innovation in production flow"; e.g., for managing improvements originated in production´s observations as continuous innovation or changes determined by a higher level. This generates "Improvements to flows" to "Health service production flow" and "Operations management Unit j".
3. "Planning" that performs "Operating Planning" based on instructions coming from higher levels or local control information, which generates "Plans and programs" to direct "Operations management Unit j".

Typical "Health System Network" and "Health Sub Network I" levels are modeled to provide the management necessary to assure that the service is provided according to strategic guidelines and that the right innovations are executed to generate the capabilities necessary for a changing environment.

Figure 2. A general process architecture for the health system



Additionally, they provide the necessary coordination among subnetworks and different Operating Units. For this, basic processes of "Planning", "Innovation" and "Operation" are replicated and instantiated according to the level needs. This structure generates information flows that direct and control lower levels; examples of such flows are "Innovation and improvements to implementation", "Changes to production flows", and "Coordination among units". These levels will be included in the case presented later to show how their tasks relate to the design performed over the production components to increase efficiency. "External services", at the bottom of the model, give services to all "Operations management Unit j" components, e.g., supplies and IT, including intelligent support, and there may be many of these. Outsourcing of some of these components to external suppliers is possible and the same representation with a separate pool is adequate in such a case; the coordination with them utilizing interfaces uses information flows for its representation.

The centralization design issue, analyzed at the beginning of this section, is present in Figure 2 in the information flows or interfaces between structure levels or pools. Such flows may go from very precise and detailed plans, programs, and instructions, in the centralized option, to general policies and guidelines in the decentralized alternative. Thus, some of the key design issues considered in applying this model are as follows:

1. How to distribute "Operations", "Planning" and "Innovation" among levels of Figure 2 is an important design decision, which, according to the previous discussion, may be the responsibility of the 'Enterprise' level in some situations; but in some cases, where the Diversification model applies, they can be decentralized. Economic analysis, as presented in the next section, is a way to decide on this issue. Centralized management in the line of Unification of some operations is a possibility, since there may be coordination and share of experience issues among "Divisions" and "Operating Units" that well managed, with appropriate Analytics, can generate large benefits, with moderate costs of developing processes and systems needed.
2. The design of interfaces is the key to assure that coordination works. There are two alternatives to this. First, the arrow "Improvement to flows" allows including very detailed service specifications that define the "Health service production flow" in Figure 2, such as physical predefined flows and protocols to evaluate needs that determine the flow. These instructions, supported by an IS, mean that the service provider in the "Health service production flow" can route the flow in a decentralized way. The other possibility is that "Operations management Unit j" performs explicit coordination and decides about the flow; this may include the use of tools to support such decisions, as in the decentralized case, but also explicit analysis of the state of the customers and service provided may be included. These alternatives are not mutually exclusive and both may be part of a particular design, as shown in the case presented in a later section.
3. The design in the previous item requires continuous innovation, due to the formalization of relationships and coordination contained in the interfaces that determine the flow. Thus, performance must be evaluated and necessary changes discovered to correct flow behavior when necessary. The model considers this in the "Innovation" lanes at several levels; for example, at the "Health operating unit j" pool, in the "Innovation" lane, there is the process "Innovation in production flow" that performs continuous observation of the flow and corrections in its design. However, at higher levels, there are also "Innovation" lanes that participate according to the dynamics of the service. If the service is very stable, necessary changes are minor and managed in a decentralized way, but in highly dynamic services –due to frequent demand changes or the need to innovate the service to stay competitive– all the levels should be involved in innovation. The roles and processes dedicated to such innovations are present in the case given subsequently.
4. Share of services is another design decision since there are usually several services possible to centralize in the proposed structure. Supply management is an obvious example since there are many benefits in its centralization in enterprises with divisions that consume similar items. Logistic services are another possibility, including outsourcing. Another obvious candidate for centralization and outsourcing is consulting and IT services, an option taken by many enterprises all over the world.

The models presented emphasize the design of the process flows, but it is possible to include details about the logic that guides each process component, using formal models based on the Analytics given later and other models proposed recently (Hashmi, 2022)

The specific use of these ideas for the management of innovations in Chile's health network will illustrate how these design decisions lead to the proposed structure.

2.3 Evaluation Theory

In evaluating the designs generated as explained in the previous section, economic theory provides the tools, as presented subsequently.

The economic evaluation approach that is relevant for this work is **agency theory**, which considers the executive of an organization as the principal and subordinates as agents (Arrow, 1985; Schneider & Mathios, 2006). In this theory, an organization is a set of related contracts among individuals with their interests, instead of the usual assumption that they maximize the productivity of the firm. Therefore, a set of agency contracts allows the principal to hire agents (employees) to perform tasks. According to this theory, costs depend on the degree of decisions´ centralization. There is an information-processing cost, which includes the information necessary for the principal to make decisions about agents' behavior, which increases when centralized. Additionally, opportunity costs arise due to a lack of, or erroneous information for decision-makers. However, decentralization increases the agents' monitoring cost to assure a behavior according to the principal´s interest; but this does not assure expected results, so there is a residual loss. Therefore, the degree of centralization is a design variable in any complex service. Modern tools, including Analytics, favors centralization since they allow the development of intelligent routines and IS that advise and, in some cases, automate service processes. These centrally designed innovations take care of the principal's interest. For example, Walmart centrally designs intelligent IS to process online data from all the sales points and feed predictive models that forecast demand for each of such points. These forecasts are the inputs to optimization models that determine actions over the supply chain logistics to assure product availability at a minimum distribution cost (Davenport, 2006). Currently, they are also using social media big data to predict shoppers' purchases and act on that basis to plan logistics (Davenport, Dalle Mulle & Lucker, 2011).

2.4 Analytics

Advanced Analytics supports and makes feasible the architectures presented in previous sections. This discipline complements the previous ones by incorporating predictive and prescriptive models in routine service production and management process components. Here, true Intelligence advises, recommends, and in some cases automates decisions and actions using the full range of analytical tools: Data Mining, Optimization, Machine Learning, and the like. The example of Walmart given before is a good instance of this idea. Another real case example is to use diabetes patients' data, available in the whole health system, to develop predictive models to allow detecting probable crisis for a specific patient, before it occurs, to prevent serious health problems and high emergency treatment costs (Paschalidis, 2017; Barros, 2017).

The use of Analytics in the design proposal of the next section provides a logic that supports intelligent decision-making and operations. The central idea is that, in executing health services delivery and related processes, intelligent logic is necessary to formalize certain routines using models to assure attaining certain objectives. In some cases, this logic is fully automated as Amazon does for the logic that makes recommendations for clients, or the logic that Walmart uses to optimize its logistics. In others, the logic will make recommendations to whom operates the process and a person will have the authority to follow them or not. Cases that use this idea are included in the "Findings" section when designing processes' improvements to increase hospitals' efficiency, motivated by DEA measurements.

2.5 A Research Method to Integrate Previous Disciplines

The general research opportunities this paper considers are the ones discovered by Frost & Lyon (2017), particularly "applying service science theories and methods to specific domains" in the line of learning from real-life cases, which is a key idea of this paper. Additionally, they found the need "to create a service system framework which offers descriptive, prescriptive and evaluative analysis methods". In this line, this paper presents a framework, based on process patterns, which provides such methods.

Thus, this paper aims to contribute to the comprehensive structure design need with a theoretical background that uses "artifacts" (Gregor & Hevner, 2013), based on supporting disciplines and a methodology. For this, there is the need to discover and represent alternative structure configurations –in terms of hierarchy levels, decentralization, modularity, innovation, and coordination– an enterprise may have and then be able to evaluate such alternatives for choosing the right one for a particular case. As explained in a previous section, the objective is to provide general design options by using process architecture patterns, based on experience or previous knowledge, to develop a structure specialized for a case. The pattern proposed here incorporates processes, the people who execute them, the Analytics and IS that support both, and the IT layer on which such systems operate.

To show the practical value of the proposal, the modeling and redesign of the structure for innovation for the Chilean hospital use the network architecture pattern.

2.6 Methodology for Discipline Integration

One of the main objectives of this research is to integrate all the methods presented in the previous sections into a methodology that assures the objective stated before of assuring efficiency of the health system, which steps are as follows:

1. Use DEA to define inefficient hospitals and the determinants that have to improve to increase their efficiency, e.g. better use of operating rooms.
2. Using the innovation EA designed with the method presented before to define innovation projects to increase efficiency, e.g. mechanisms to decrease the operation room time at inefficient hospitals and execute their implementation, given as a case in a later section.
3. Evaluate projects to calculate the resulting efficiency improvements.
4. Implement cost-effective projects: efficiency improvements greater than costs.

3. FINDINGS

The results of the DEA efficiency calculations and analyses are included in this section. Additionally, an architecture design to manage innovations of the health network, using DEA results to increase efficiency, follows.

3.1 Efficiency Measurement

In using DEA for the Chilean health system, high complexity hospitals that provide the same services in regions of the whole country were selected; they are 40 and their outputs and inputs were determined using a full year of digitally available data. For the output measurement, Chilean hospitals currently use an international version of the DRG developed by the 3M Company, called I-DRG, which defines 1077 different types from groups of related diagnoses differentiated by severity levels, discounting the cases with ambulatory medical services. All high-complexity hospitals use the DRG measure. Thus, the output data is discharged patients adjusted by clinical complexity (DRG weighted discharges) for the 40 hospitals.

For the inputs, the variables are the number of MDs working at the hospital and the number of beads. This was justified by regressing the total DRG production of the 40 hospitals on the number of doctors and beads, which has a very good fit with an R^2 of 0.886. The basic statistics for these variables are:

- The number of doctors has a range of 65 to 566, with an average of 198 and a standard deviation of 107.49.
- The number of registered beds has a range of 130 to 870, with an average of 384 and a standard deviation of 183.32.

The DEA model and the associated data of inputs and output just presented were run using the software GAMS (2021), considering normal Constant Returns to Scale (CRC) efficiency and super efficiency (AP), also with CRS, which admits values greater than one that allows a better differentiation of the more efficient hospitals (Xue and Harker, 2002; Chitnis & Mishra, 2019). Table 1 presents a summary of the efficiencies calculated for the 40 hospitals considered.

For the second phase, to find factors that explain efficiency, 240 hospitals´ variables were considered; for example, social indexes and characteristics of the population attended, the complexity of medical services offered, and the percentage of patients coming from primary services. Data for such variables are routinely collected and digitally available. A statistical procedure was applied to them, which is a variation of the two-stage Tobit proposal (Ozcam, 2014) to look for variables related to efficiency, as O'Neill and Dexter (2004) proposed for hospitals' perioperative services. Such a procedure detects outliers, correlated, and non-significant variables; it allowed determining the variables that explain efficiency, which are the ones potentially manageable to increase such efficiency in a hospital.

The results of the analyses of the variables that may explain efficiency are in Table 2, which shows the ones that have the largest correlations with the efficiency measured by the model. These variables are some of the 240 considered in this analysis. One that has a high correlation with efficiency is "social-delinquency vulnerability", which has a significant negative correlation since patients have health problems that are more complex in poor neighborhoods than in wealthy ones. In the same way, all the other variables in Table 2 have factors explaining the correlation that if managed can increase efficiency as explained next.

Thus, with the selected variables showing greater improvement impact, projects to produce improvements for the inefficient hospitals follow. For example, 'variable 2' of Table 2, 'Percent of programmed patients', has a significant positive correlation with efficiency. Thus, the opportunity for defining projects for inefficient hospitals that introduce processes implementing programming. A sample of typical projects derived from this analysis implemented in Chile follows; they consider programming using Analytics that advises or automates management or flow execution activities, as explained in Section 2.4.

Table 1. Efficiency results with DEA and AP

	Efficiency (CRS) calculated with DEA model	Efficiency (CRS) calculated with AP model
Minimum	0.634	0.661
Maximum	1	1.511
Average	0.8212	0.913
Standard Deviation	0.1092	0.191
Hospitals in the efficiency frontier	6	7

Table 2. Main explanatory variables

No	Name	Category	Correlation	p-value for significance
1	Social-delinquency vulnerability index	Social factors	–0.40	0.012
2	Percent of programmed patients	Patient management	0.44	0.005
3	Patients coming from a lower level in health network	Network integration	0.35	0.026
4	Meeting payment deadlines with suppliers	Supply and financial management	0.40	0.013
5	Patients coming from an emergency service	Demand behavior	–0.39	0.012
6	Hospital with breast surgery	Hospital structure	–0.36	0.021
7	Hospital with maxilla-facial surgery	Hospital structure	–0.40	0.011
8	Hospital with neurosurgery	Hospital structure	–0.45	0.003
9	Percent of adult patients	Demand behavior	–0.38	0.016
10	Percent of child births	Complex variable	–0.47	0.002
11	Date hospital started with self-management	Complex variable	–0.49	0.002
12	Children hospital	Demand characteristics	0.38	0.015
13	Rotation index	Complex variable	0.34	0.033

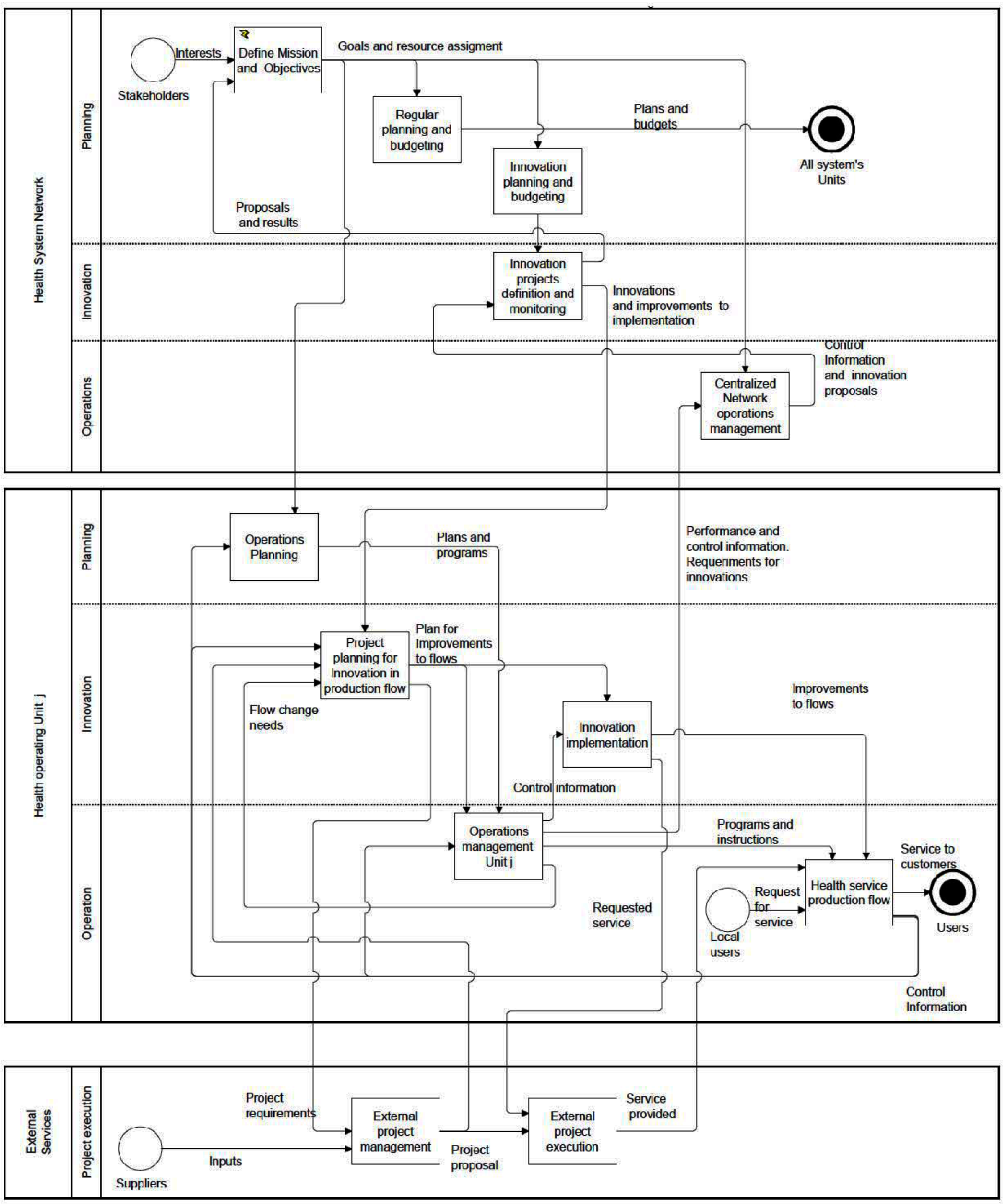
1. Predictive models for chronic patients to detect critical situations in advance, avoiding crises and expensive treatments. This was implemented in a public hospital for children with chronic respiratory problems that may be treated at home, for which a Machine Learning predictive model was developed that, based on remote online monitoring, advises doctors when there is any risk for such patients (Rios, Garcia, & Jimenez-Molina, 2014). The goal was to encourage home treatment programmed according to the needs of the chronic disease to improve fairness and efficiency. This resulted in avoiding the use of most of the up to hundred hospital beds available for these children.
2. Operating room management, including patients' prioritization, operation scheduling using optimization models, and intervention monitoring. There are projects of this type in several hospitals, which show increased use of resources, such as 20% of more use of operating rooms, and a reduction in waiting lists, especially for priority patients (Duran, Rey, & Wolff, 2017).
3. Design of service lines in an Emergency Department organized by Triage severity levels, with specialized care lines, which allow a well-programmed sequence of activities. Lines implementation resulted in a 30% reduction of service time and savings of about US$ 250.000 annually (Barros, 2019).

Thus, the processes and IT support designs developed for these cases can be transferred to other low-efficiency hospitals as innovation projects to improve their performance using the architecture presented subsequently.

3.2 Service Process Architecture

The architecture in Figure 3 is an instantiation or specialization of the general pattern in Figure 2 for managing innovations in the hospital network. 'Health Sub Network' of the such figure is not included, since this level lacks personnel with innovation capabilities and responsibilities in Chile, which is difficult to change; therefore, it is not relevant for the innovations' definition and implementation. At the "Planning" of the "Health System Network" level, "Regular planning and budgeting" is oriented to traditional operation and a new process of "Innovation planning and budgeting" appear. The latter process executes the DEA-based logic, explained in the previous section, to determine the innovation projects in less efficient hospitals that maximize the value associated with the objective stated earlier of efficiency increase; for example, patient programming projects, as exemplified

Figure 3. A process architecture design for innovation resource management in the public-hospital network



previously in this section. This innovation definition exists to develop new capabilities for hospitals, which is a centralized planning approach for the whole health system. Then the projects are defined by "Innovation projects definition and monitoring", including a detailed project plan and the possible use of external services suppliers that can help in its execution. This process generates the flow "Innovation and improvements to implementation" that goes to "Project planning for innovation in production flow" of the "Health Operating Unit j" (hospital). Thus, this process and "External Services", which are specialized consulting services, generate the "Plan for improvements to flows" that guides the process of "Innovation implementation" to put projects into practice. The idea behind this proposal is that hospitals do not have health innovation and project management specialists, so the projects should be executed with the help of externalized services, as has been the case in many historical projects dealing with IT support or process design.

The architecture in Figure 3 centralizes the decision of funds assignments and definition of innovations projects that maximize hospitals' efficiency improvements; it is justified by agency theory —summarized in Section 2.3— since this option takes better care of the principal (government) interests for this efficiency improvement decision. This is so because there is an overall comparison of investment opportunities for a given budget, considering jointly all the possibilities, which leads to a global optimum for results; DEA makes feasible such a comparison. But the execution of projects is decentralized since the same theory states that this is preferable because operating people (agents) know more about these implementation issues, and if the principal tries to manage them, he would incur severe opportunity costs due to lack of information or high information processing costs. The idea of centralization of innovation is also present in organizations with many replicated units and is justified by the Unification structure, used by Walmart and CEMEX among others, as presented previously.

4. CONCLUSION

First, an evaluation of the last section's findings concerning its compliance with the service research opportunities defined by Frost & Lyon (2017), described in Section 2.5, who discovered a "lack of empirical evidence for design proposals", follows. The proposal of this work uses this opportunity because architecture patterns, successfully used, come from real-life case experiences. Another research opportunity they found is to "create a service system framework which offers descriptive, prescriptive and evaluative analysis methods". The method applied to the case offers a descriptive proposal for a general architecture pattern for complex services, such as health, a prescriptive proposal of how to generate designs for such systems using the pattern, and a method to evaluate design alternatives and chose the one that offers the best value for public health and its users. Additionally, they recognized the need that service design includes innovation. The architecture model and cases explicitly recognize the role of innovation and provide ways that allow the design of mechanisms to make such innovation work.

Gregor and Hevner (2013) have also proposed factors to evaluate research, summarized in Section 5; the ones relevant for this work are the following.

First, a "solution to problem or contributions toward a solution that improves substantially upon previous work" should be present. Thus, learning from real-life cases, an architecture pattern based on their common features allowed providing a comprehensive structure design approach for complex health systems with multiple levels. Such a pattern integrates enterprise architecture and process architecture modeling, evaluation methods, and Analytics. Thus, applied to the design of the innovation structure of Chile's health system, formal modeling of the situation under design proved feasible. Clear design guidelines allowed the discovery of several important issues not considered in the current structure by other methods. In particular, the design of mechanisms for the interactions of the different structure levels to coordinate innovation's management levels is particular to this design method. This includes a design of the degree of management decentralization, for which specific guidelines, based on economic theory, are available. An important management factor discovered is that a good innovation design, with clear responsibilities at different management levels, assures that the service is continuously adapted to new situations. The formal design of all these coordination issues allows for the explicit design of Analytics and IT support. Therefore, the value of the proposed approach is the design of solutions that consider explicitly and formally several issues, not included in other methods, which favors giving a better service and eliminating inefficiencies.

The second contribution of this work, proposed by Gregor and Hevner, is to “advance knowledge of theory, methods or applications”. Thus, the development of design patterns using real-cases experience has proved feasible for a complex services comprehensive structure. This opens the way to use such patterns for other complex services and eventually makes improvements that make it more general.

Finally, this work advances in another contribution, which is the “understanding of the area of research and application” of complex services, by proposing a new challenge: the design of their comprehensive structure not covered by current methods. The problem definition and formal design approach presented in this paper open the way to improved definitions and alternative or complementary design methods.

Thus, it is clear that the proposed approach for complex service systems design makes a significant contribution and meets criteria as the ones proposed by Gregor and Hevner (2013).

From the results of this research, the conclusion is that it is possible to measure and compare hospitals’ efficiencies and, from them, define medical and management innovation projects to increase such efficiencies. To make the projects feasible, a new health system’s EA is proposed, which defines the different roles and processes that should exist to define and manage the projects’ implementation. Therefore, in centrally managed health systems, the design proposed provides a general solution to assure hospitals’ efficiency improvements. This is the case for the health system in Chile, where several innovation projects based on the results of this work have been implemented, as exemplified in a previous section.

The proposed approach includes the possibility of learning from hospitals that are more efficient and sharing with the less efficient ones the medical and management solutions that have proved successful for them. This can generate a virtuous circle due to the centralized assignment of resources for innovation oriented to improve efficiency, taking into account quality of service, which will move lower-performing hospitals to the efficiency frontier. This opens the way for further research on designing and testing the proper structure for health innovation coordination in health networks. Thus, very significant efficiency improvements are possible which means better service at a lower cost.

This work also shows the importance of integrating several methodologies to generate better-founded designs. Starting with a system approach, several disciplines —such as DEA efficiency measurements, economics, enterprise architecture formalization, organization processes management, and Analytics— support the formal design approach for health organizations used in the case reported. This integration is lacking in health-service design research, particularly in connection with EA, processes, and organizational structure; this paper shows that this is a promising line of application.

A closing conclusion of this paper is the value of having a frame of reference that can be instantiated for a particular case, like the one proposed here, for producing results in much shorter times than the ones usually experienced in projects of this type and the possibility to evaluate designs based on economic theory.

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