Weakness of Modern Hospitals

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INTRODUCTION

Until some decades ago, health care services were primarily supplied inside hospitals. The patient had to move from his or her home to the hospital, where various diagnostic and therapeutic treatments were provided. Moreover, inside the same hospital, the various tools and processes were insulated and autonomous. Patients and doctors had to move from one tool to another, often placed in different areas, to acquire the different resources. Information provided by these tools was generally collected via paper records. These records were then physically moved (generally in a very inefficient way) from one place to another in order to exchange information. In many situations, these records represented the most critical element in the health system due to misunderstanding, errors, and loss of information caused by their use. Nevertheless, its main drawback was the difficulty, or even the impossibility, to retrieve information from paper records when there were needs in the future and/or outside the hospital.

This situation was largely inefficient, especially from the patient's point of view. Indeed, he or she had to spend a lot of time moving to and from the hospital and supporting a great deal of stress to supply time and again the same information (often in an incomplete, vague, or erroneous manner), and eventually suffering for errors and/or unavailability of information previously stored in other records.

To overcome this drawback, in the past few years, the health care systems has largely changed the way in which their services are produced and supplied. In order to improve the quality (e.g., better diagnosis and treatments), guarantee more comfort to the patients, increase the efficiency of the systems (e.g., reducing time in hospital and, more generally, any type of side-effects), and have a more rational use of the money, ICT (information and communication technologies) has spread throughout fields of health care. Indeed, due to the power of ICT to make interoperable the different elements and actors, useful synergies have been exploited to better use any resource.

This contributes to improve the quality of the services (qualified and specialized services may be provided in spite of geographical location) and, at the same time, to improve efficiency (because it is possible to better distribute loads and to exploit synergy and scale economy).

To achieve this result, the various apparatuses, components, and systems (once autonomous entities) are no longer insulated but rather are grouped into networks to allow sharing information, to support co-operation, to exploit complementary, and to implement supplementary strategies.

In this framework, from the patient's point of view, any single element of the system is less and less important owing to the network as a whole providing the services. This is obtained by integrating multichannels delivery strategies into the front-ends and making interoperable the various back-end elements.

Implicitly in this change of paradigm is the increased rule played by technological infrastructures in the health care systems. These infrastructures that, until few years ago, were not strictly related with the core business (i.e., supply care) but rather confined to complementary activities, today are becoming the backbone of any health care system.

Unfortunately, this introduces many *dependency* and *interdependency* links among the various components. This represents the real weakness of this scenario. Indeed, even if a network-based health care system is more robust than a model composed by single "asset" with respect to a component's failure, it appears more fragile to "catastrophic" events. The presence of these interdependencies (many of them not designed or considered at implementation time and actually poorly known or even completely hidden) exposes the system to a huge variety of threats. Moreover, it makes the system susceptible, due to domino and cascade effects, to simultaneous failures of many services, as dramatically emphasized in health care and other sectors by the blackouts of 2003 (Italian Government Working Group, 2004).

Then, moving from a traditional health care scenario to a network-centered framework, we improve our capabilities to provide efficient, effective, and economic services, but at the same time, we also need to consider the side-effects so introduced. This chapter is devoted specifically to pinning down some of them and to stimulating great attention to this topic.

BACKGROUND

To analyze the amplification of negative consequences of a failure owing to the presence of interdependencies among the various infrastructures used inside a modern hospital, we have used the Input-output Inoperability Model (IIM). IIM is a simple tool, proposed by Haimes and Jiang (2001), to emphasize how the presence of dependencies and interdependencies among the various components of a complex system may facilitate the spreading of degradation.

Haimes and Jiang (2001) set up this model, building on the well-known theory on market equilibrium by Nobel Prize winner Wassily Leontief. The IIM uses the same framework proposed by Leontief but instead considers how the production of goods or services of a firm influences the level of production of the other firms; it focuses its attention on the spreading of "degradation" into a networked system. To this end, the authors introduce the concept of *inoperability*, defined as the inability of a system to perform its intended functions and analyze how a given amount of inoperability inside one element influences the other components of the network.

Haimes, Horowotz, Lambert, Santos, Lian, and Crowther (2005) use this approach to analyze how inoperability induced by a High Altitude Electromagnetic Pulse (HEMP) affects the various sectors of the U.S. economy and to estimate the recovery time under various hypotheses. In Reed, Chang, and McDaniels (2006), this approach has been used to provide a tool for resource allocation for postevent recovery considering the Katrina hurricane scenario, while in Panzieri and Setola (2008), the approach is modified to also explicitly consider the spreading of failures.

The great interest in this approach is related to its simplicity, even if the results that it provides are, for many aspects, largely qualitatively and oversimplified.

The idea at the base of IIM is that an event (e.g., a failure) that reduces the capability of the i-th infrastructure to correctly operate induces degradation also in other infrastructures that use services or goods produced by the i-th one. This degradation may further propagate involving other infrastructures (cascade phenomena) or even exacerbate the negative consequences into the i-th one (feedback effect).

Mathematically, IIM describes these phenomena on the basis of the level of inoperability associated with the various infrastructures. Specifically, the inoperability of the i-th infrastructure is coded via the variable x_i defined in the range [0, 1], where $x_i = 0$ means that the infrastructure is fully operative, while $x_i = 1$ means that the infrastructure is completely inoperable.

The inoperability induced on the system due to persistent external causes u_i is calculated via the following dynamic equation:

$$\mathbf{X}(k+1) = \max\left\{\mathbf{A}\,\mathbf{X}(k) + \mathbf{U}, \mathbf{1}\right\} \tag{1}$$

where $\mathbf{X} \in \mathbb{R}^n$ and $\mathbf{U} \in \mathbb{R}^n$ are vectors composed, respectively, by the level of inoperability and external failure associated with each one of the n infrastructures considered in the scenario. $\mathbf{A} \in \mathbb{R}^{n \times n}$ is the Leontief matrix, which entry a_{ij} represents the level of influence that the inoperability of the j-th infrastructure has on the i-th one.

We impose that $a_{ii} = 0 \;\; \forall i$ because we do not consider any recovery phenomena. Notice that in the model, $a_{ij} = 1$ means that the i-th infrastructure is completely dependent on the j-th one, because a given amount of failure in the latter will directly induce an equal level of degradation into the i-th infrastructure.

In order to evaluate the level of dependencies of an infrastructure, we introduce the *dependency index,* defined as the sum of the Leontief coefficient along a single row:

$$\delta_i = \sum_j a_{ij} \quad \text{(row summation)} \tag{2}$$

This index represents a measurement of the robustness of the corresponding infrastructure with respect to the inoperability of the others. If this quantity is less than 1, then the i-th infrastructure preserves some working capabilities (e.g., thanks to the presence of

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