Network-centric healthcare operations: data warehousing and the associated telecommunications platforms

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Abstract: With the rapidly escalating costs, the EU and the US make the adoption and application of Information, Computer and Communication Technologies (ICCT) in healthcare (e-health) an urgent priority, and the recent progress in ICCT facilitates transition from non-collaborative, platformcentric activities to fully federated, network-centric operations. The paper discusses the essential role of federated data warehouses in the novel concept of network-centric healthcare operations, and shows that the federated approach to data storage and management is the essential element for the improvement of access to coherent, relevant, and timely information required by governments and international organisations for better, more cost effective, and medically sound access, delivery, and administration of global healthcare.

Keywords: data warehouse; e-health; global healthcare; healthcare; healthcare doctrine; healthcare management; healthcare operations; healthcare policy; healthcare technology; IP multimedia subsystem; ICCT; network-centric healthcare; network-centric operations; OODA loop; services; standards.

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1 Introduction

During his State of the Union Address in January 2004, President George Bush affirmed the intention of the government to emphasise the role of technology in administration and delivery of healthcare in the US (President George Bush, 2004). Similar sentiments have been voiced by the European leaders (The Oslo Declaration on Health, 2003; Global Medical Forum Foundation, 2005), and the World health organisation (A Health Telematics Policy, 1997; e-health in eastern Mediterranean, 2005). Both European and US authorities define their initiatives primarily in terms of medical information technology centering on Computerised Patient Record (CPR), known also as Electronic Health Record (EHR) (see Brailer and Terasawa, 2003). WHO's platform statement (A Health Telematics Policy, 1997) speaks of 'health telematics policy', an all inclusive term that incorporates not only EHR but essentially all healthcare services provided at a distance and based on the use of Information Computer and Communications Technologies (ICCT).

In the context of the increasing divergence in the access to healthcare seen between the Developed and Less Developed Countries (LDCs), improvement and expansion of the existing ICCT infrastructure and operational efficiency may provide the best chance of reaching healthcare parity between 'haves' and 'haves-not'. (von Lubitz, Wickramasinghe and Yanovsky, 2005). With the predicted vast increase in future costs (National Coalition on Healthcare, 2006), it becomes apparent that vigorous application of information/computer/communications technologies may be probably the most suitable substitute for the financial burden of recreating in LDCs the traditional healthcare of the West, i.e. the network of 'brick-and-mortar' facilities together with their administration, high density of providers, multiple training sites, etc.) The costs associated with the *de-novo* establishment of what proves an extremely expensive and unworkable solution in the Developed World will be compounded by the collateral attempts to recreate ICCT support of the current Westernstyle healthcare operations (Winslow, 2006). Hence, superimposing e-health upon the already existing ICCT infrastructures and their maximum utilisation may offer a far more economical and operationally viable solution.

The complexity of global healthcare is magnified by the presence of multiple actors (agencies, governmental bodies, global organisations, etc.), who use a wide variety of independent and non-integrating platformcentric tools (von Lubitz and

Wickramasinghe, 2006a) to address, what they (often individually) perceive as the most essential tasks of, which some are extremely urgent, while other 'politically correct', and palliative. The consequent chaos impedes attainment of the declared healthcare goals and the quest for the development of the 'doctrine of global health' (Olutimayin, 2002; Banjeri, 2004; Onen, 2004) becomes a prominent trend aimed to substitute the highly fragmented programmes incapable of addressing the simplest (and, paradoxically, the most pressing) aspects of international healthcare.

2 Platformcentricity in healthcare operations

The use of networks in healthcare is not a new concept. The widespread use of Community Health Integrated Network (CHIN), Local Area Network (LAN) or Wide Area Network (WAN)-based electronic patient records, billing/reimbursement systems connecting several units within the same administrative entity, or even telemedical activities are among the best examples of this steadily increasing trend (Caarlile and Sefton, 1998; Overhage et al., 2002; Overhage, 2004; Kulkarni and Nathanson, 2005). However, despite frequently substantial geographical coverage, overall the existing networks represent distinctive and disconnected entities. Their operations are platformcentric, i.e. concentrate on exploitation of a single system (platform) with little or no regard to full integration with systems operated by other entities (von Lubitz and Wickramasinghe, 2005).

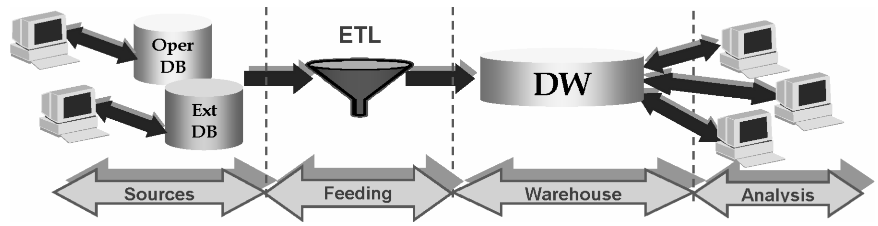
Platformcentricity of healthcare (or, for that matter any other) ICCT operations, with its concomitant fragmentation and broad incompatibility of individual efforts, has a major influence on the access range and sharing of high quality information that exists among or even within individual systems (Valdes et al., 2003). For these reasons, despite providing very significant advantages to the local users (Caarlile and Sefton, 1998; Overhage et al., 2002; Wickramasinghe and Mills, 2002; Overhage, 2004; McGowan et al., 2004; Kulkarni and Nathanson, 2005), the overall impact of the electronic information systems on either national or international healthcare operations continues to be relatively limited (Valdes et al., 2003; von Lubitz and Wickramasinghe, 2005).

3 Platformcentricity in data and information management in healthcare

The advent and rapid practical dissemination since mid-1990s of Data Warehousing (DW) combined with the already existing and used Data Base (DB) technology, provided relief to the rapidly accelerating accumulation of patient-related and administrative data (Griffin, 1996; Akhtar, Dunn and Smith, 2005), whose chaotic storage, retrieval and analysis not only reached daunting proportions but also contributed to often grave medical errors (Millar, 2001).

Conceptually, a data warehouse is nothing more but a new collector of information that integrates and synthesises elementary data stored in different and heterogeneous sources (databases, legacy systems, Internet, etc. e.g. Longman, 2004), organises them in an appropriate format and makes them available for analysis and evaluation purposes, finalised to evaluate trends, to discover meaningful correlations and, in conclusion, to acquire useful knowledge as a support to the decision process (Lechtenborger, 2001 and Figure 1).

Figure 1 Architecture and functionality of a typical DW fostered by operational DBs and other kind of external DBs



The Extraction, Transformation, Loading (ETL) functions of the warehouse serve as the essential precursor stage that precedes the process of data storage itself (Table 1). Under most circumstances, data extracted from the external and heterogeneous sources must be ‘polished’, to eliminate the inconsistencies and to fill lacking parts of records, integrated, to merge heterogeneous data sources according to a common scheme, etc. In turn, the DW (Harjinder and Prakash, 1996; Golfarelli and Rizzi, 2002) can be used as a source to build and support several Data Marts (DMs), i.e. partial replicas of the DW, each one addressing a specific area. Once loaded, individual DMs can be then queried by using reporting, On-Line Analysis Processing (OLAP) or Data Mining Methodologies (DMM) Compared to data warehouses, the use of a DMs is simpler and provides the user with faster, ‘just-in-time’ results (McKendrick, 2004), whose range is, however, lesser than that offered by the warehouse.

Table 1 ETL functions in a generalised data warehouse

Function	*Involved processes*
Extraction or capture	Data capture from real time operations, diverse operational systems, and other divergent legacy storage systems.
Transformation	Clean-up or cleansing or scrubbing (corrections and homogenisation of data e.g. redundancies, inconsistencies, wrong use of field, etc.) and Transformation (normalisation, conversion), Validation.
Loading	Refresh (complete rewrite) or Update (rewrite of modified data only based on a log file), Filtering.

When commercial ETL tools first appeared in the 1990s (Sunopsis, 2004) the most widely used Relational Data Base Management Systems (RDBMS) such as Oracle, DB2 and Sybase did not support a rich enough set of Structured Query Language (SQL) operators to handle the complex data transformation tasks required for data warehouse applications. Hence the dedicated ETL engine and proprietary transformation language emerged as the best alternative to laborious manual coding at the time. However, over the past decade the RDBMS vendors have increased the functionality of the SQL provided to programmers by an order of magnitude, while improving the performance and reliability of their engines at the same time. Complementing the richer language support, RDBMS vendors now provide a long list of out-of-the-box features and utilities that enable impressive performance, when executing ETL-type operations.

The operational profile of major healthcare organisations has a perfect fit with the theoretical characteristics of an organisation that would derive maximum benefit from a DW solution (McFadden and Watson, 1996; Table 2). Griffin (1996) estimated that, compared to an average financial transaction containing approximately 150 data elements, a complete patient profile may require up to 750 elements. Clearly, with an average healthcare system containing thousands of such profiles (e.g. Mead, 2005), warehousing of clinical data offers a very alluring solution (Akhtar et al., 2005).

Table 2 Data Warehousing suitability: a comparison between an ideal theoretical organisation and a major healthcare organisation

Organisational attribute	*Theoretical organisation*	*Major healthcare organisation*
Multiple users accessing large amounts of data	Yes	Yes
Data stored in multiple systems	Yes	Often
Information-based management style	Yes	Yes
Large/Diverse customer base	Yes	Yes
Different representation of same data in different systems	Yes	Often
Complex format of data storage patterns	Yes	Yes
Significant user computing present	Yes	Rarely as part of service delivery; often as part of ongoing operational performance analysis.

However, with the exception of a few large repositories such as the data banks of the Center for Disease Control (CDC) and other governmental or international organisations (e.g. World Health Organisation–WHO), most of the created warehouses remain predominantly if not entirely platformcentric. Created to serve the specific needs of specific electronic platforms used by specific systems of local rather than national/international range (e.g. Overhaage et al., 2002; Overhaage, 2004), and with access to- and/or dissemination of the warehouse contents often limited by the provisions of the Health Insurance Portability and Accountability Act (HIPAA) regulations, the data existing in a wide range of proprietary and commercial systems (e.g. Sinha, 2003) are accessible only to those within the organisation that owns the warehouse and the external users approved for such access.

Apart from needlessly increasing costs of overall expenditure on several largely similar yet non-integrated IT systems operating within the same and often constrained healthcare region, platformcentricity has little or no impact on the overall quality of delivered services at the limited intra-institutional/organisational level. Here, electronic systems *facilitate* operations and, in the vast majority of cases, increase their safety and quality. Essentially, in the realm of on-site/regional operations, it is not the philosophy of federated network-based systems that makes the difference in the attributes of the delivered services but the operational quality of the used systems themselves. The fact that such systems operate as 'stand-alone' entities is an immaterial consideration at the infra-organisational level and remain to be so as long the organisation does not need outside resources. Moreover, in the competitive atmosphere of US healthcare, platformcentricity may make superficial business sense by providing a natural barrier preventing competitors from accessing operationally sensitive data of other institutions. Internationally, the differences both in the conceptual approach to healthcare and in the attitude to as fundamental as privacy and security of data that separate the US and EU (Sinha, 2003) promote platformcentricity at an even greater scale. The essential need for the protection of data residing strictly within patient's privacy domain notwithstanding, from a purely technical and more general point of view, the needs of protection in the ICT world can be classified in the following categories (Zwicky, Cooper and Chapman, 2000; Russell and Cunningham, 2001; Becker, 2004; Choi, Seo and Blackburn, 2005): *reservation* (has the communication been intercepted?), *authentication* (is the user really who he claims to be?), *integrity* (are the received data really those sent?), no repudiation (can the sender retreat what he agreed on?), *availability* (is the communication medium always usable?) and *authorisation* (is every user able to access only their assigned resources?). These primary needs have been widely studied by the scientific community and nowadays a plenty of solutions are available to protect the hosts (intrusion detection and control tools, proxies, port/vulnerability scanner, etc.), the Network (firewall, screening routers, network intrusion detection, etc.), the communication (symmetrical/asymmetrical encryption algorithms, certificates and certification authorities, etc.) against common kind of attacks such as: eavesdropping, masquerade (IP spoofing), session hijacking or replaying, rerouting, smurfing, trojan horses/viruses/worms, etc.

Platformcentric philosophy becomes, however, a major impediment in situations, when catastrophic events arrest routine operations (as seen during and following Hurricane Katrina or Indian Ocean tsunami disaster) or, when multiplicity of recording and storing systems prevents rapid determination of sociogeographic patterns of disease, its prevalence, economic impact, etc. (as seen, for example, in the case of surprisingly wide distribution and severe impact of cardiovascular disease among the populations of LDCs, see Leeder et al., 2004). Thus, the lack of interoperability that characterises virtually all platformcentric systems may preclude critical, 'just-in-time' access to pertinent data and information contained within proprietary data warehouses by outside users (e.g. regional Emergency Medical Services (EMS), Federal Emergency Management Agency (FEMA), CDC, or, on international scale, WHO) and, in situations of sudden crisis, may directly contribute to the exacerbation of preventable injury and death.

In addition to platformcentricity, the non-volatile nature of data stored in traditional warehouses (Gray and Watson, 1998) may pose further difficulties in healthcare operations conducted on a major continental or global scale. The data stored in a DW are essentially historical rather than real time. They are updated periodically or, when some particular event occurs through trigger-driven procedures (McAllister, 2005). Yet, in situations of disaster relief healthcare operations, bioterrorism, or natural outbreaks of rapidly spreading infectious diseases (e.g. SARS), the breadth of data and information produced by the composite set of the involved macro- and micro-environments within, which the event itself takes place, the rapid pace of change, and the broad range of information existing within such set, has a tendency not only to rapidly overwhelm the ETL capacity of the system, but the subsequent data dissemination, analysis and conversion into meaningful information that is critically needed to determine and implement the relevant actions (Boyd and Col, 1987; Richards, 2004, 2006). There is also the risk of losing some of the data/informational elements that may have a profoundly adverse impact on the decision-making process (von Lubitz and Wickramasinghe, 2006b). The difficulty of accessing timely, relevant, and up-to-date information in heterogeneously unstable environments is compounded even further by the fact that, despite attempts to address this problem (e.g. Kerkri et al., 2001; Sinha, 2003; Longman, 2004), the existing data warehousing systems have predominantly *domain-oriented* *nature*. (e.g. Mercer, 2001; Shams and Farishta, 2001). It is because of the operational failures following the recent major disasters (Indian Ocean Tsunami, Hurricane Katrina, Kashmir Earthquake) that the national and international policymakers and the high level administrators realised that large scale healthcare operations involve a vast range of subcomponents many of, which reside outside the obvious boundaries of the healthcare domain (e.g. hangar capacity and warehousing throughput at the area airports or the suitability/availability of beaches for the discharge of critical supplies) but yet may play an essential role in both in the determination of intervention strategies and implementation of appropriate actions (Dyson, 2006; von Lubitz and Wickramasinghe, 2006b).

The existing difficulties notwithstanding, it is necessary to remember that prior to large-scale implementation of ICCT, many of the cross-domain data management and manipulation activities were virtually impossible due to the sheer magnitude of the analytical task. Nonetheless, although the technologies for cross-domain operations exist, the continuing insistence on domain-defined characteristics of useful and pertinent information may push the neutral balance of the potential outcome in large scale (national/international level activities) towards its negative conclusion. Consequently, successful interaction with complex sets of macro-environments (macro-environment galaxies) such as global healthcare (which comprises a vast array of independently identifiable macro-environments) presents a major managerial and operational challenge. Extraction and management of pertinent cross-domain information, critical thinking unencumbered by dogma, and the capability of real time interaction with rapidly changing environments may be among the most important needed for the resolution.

4 The nature and definition of the doctrine of network-centric healthcare

The doctrine of Network-Centric Healthcare Operations (NCHO), (see von Lubitz and Wickramasinghe, 2006a) has been defined as

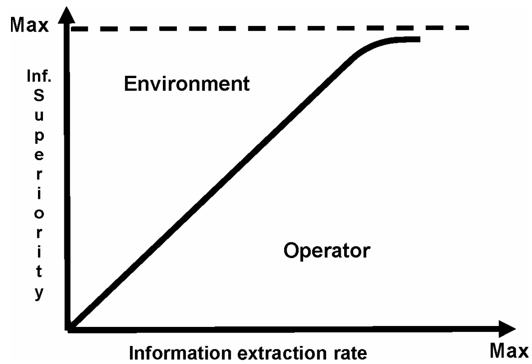
> "unhindered networking operations within and among the physical, information, and cognitive domains that govern all activities conducted in healthcare space based on free, multidirectional flow and exchange of information without regard to the involved platforms or platform-systems, and utilising all available means of ICCTs to facilitate such operations".

The essential physical and information platform for network-centric operations constitutes of a highly sophisticated, multilayered network of ICCT incorporating a full range of integrated and interoperable telecommunication platforms, sensors, data storage elements, analytical nodes, and dispersed access points, the operation of, which provides flexible command and control and rapid response capabilities. In other words, networkcentricity is the antithesis of the platformcentric philosophy.

In strict scientific terms, the doctrine of network-centric healthcare has its roots in network-centric computing (Alberts, Garstka and Stein, 2000; Alberts and Heyes, 2003), whose practical development has been greatly facilitated by the rapid progress of various areas of ICCTs (e.g. Markup Languages, Internet and Web technology, JAVA, etc.). Conceptually, however, networkcentricity is the consequence of two major trends: the change in the post-Cold War warfighting doctrines (Richards, 2006) and the adoption by the EU of networks as the major forces of societal transformation and operations

(Rifkin, 2004). The principal goal of all operations based on the network-centric concept is the development of the information superiority state (von Lubitz and Wickramasinghe, 2006a) that can be obtained through fast, highly streamlined extraction of information from the operational space (Figure 2).

Figure 2 Information extraction



Dependence of information superiority depends on the rate of information extraction from the environment. The higher the rate, the more is known about the operational environment, i.e. the higher level of superiority. Note however, that even at the maximum extraction rate, the superiority does not reach maximum. There will always be unknown elements, the extracted information may be inadequate, imprecise, or even incorrect. Collectively, the unknown information contents of the environment constitute the 'fog of war' ('friction of war' – see Carl von Clausewitz 'On War', Everyman's Library, Knopf 1993, pp.138–140).

Every environment contains definitive amount of information that characterises this environment. While novel environments may contain familiar elements, the bulk of information they contain is unknown – the environment is informationally 'superior' to the actor interacting with that environment, Gradual extraction of information contained within the novel environment by the actor operating within that environment shifts the superiority from the environment (containing less and less hidden information) to the actor (who acquires increasingly more information about the environment). Ultimately, the collective amount and quality of the acquired (extracted) information will be adequate to allow purposeful and focused interaction with the novel environment that will allow the actor to influence it in a coordinated, decisive and pre-planned manner. The actor will attain the state of 'information superiority' which, in turn, presents the actor(s) with the critical *operational advantage.* It is the latter, that is essential in determination and enforcement of the direction and tempo of all activities in a highly coordinated, and if needed – collaborative, manner. In other words, information superiority allows the actor to transform the initial state of chaos into a sequence of events under increasingly tighter operational control that will lead to the reduction of time, effort and cost required to reach the preset objectives. Information superiority is thus among the essential elements of attaining operational goals in the most effective and economical manner. The point is best illustrated by actions during and after Hurricane Katrina with many reports showing that the absence of the state of information superiority was one of the principal culprits in the resultant leadership failures, absence of coordination, and a number of avoidable post-hurricane fatalities (e.g. CNN News, 2a–c 2005; Dyson, 2006)

5 The worldwide healthcare network: interfacing telecommunications, information storage and retrieval systems, and operational support entities

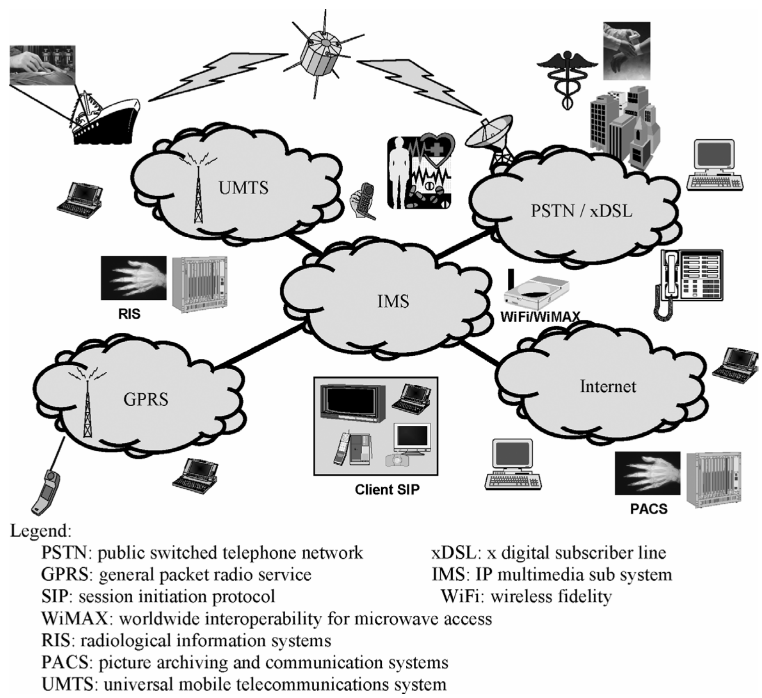
Worldwide Healthcare Information Grid (WHIG) is the essential physical component of network-centric operations that allows hindrance-free sharing of information among individual domains, their constituents, and among constituents within and across the domains. Hence, WHIG must consist of an interconnected matrix of ICCT systems and capabilities (including communication platforms, data collection, storage, manipulation/dissemination and sharing), associated processes (such as information and knowledge storage and retrieval, management and their dissemination/sharing), people (e.g. healthcare providers/investigators, administrators, economists, politicians, lawyers, ICCT personnel), and agencies (governmental and – Non-Governmental Organisations – (NGOs) at local/national/international level). Steps towards the development of comprehensive networks of such capability are now made by the European Union (Rifkin 2004**)** and also by the defence establishments of several countries (Ibrűgger, 1998.)

Providing interoperability is introduced through the development of sufficiently potent and flexible bridging platforms (Patricelli 1998a,b), the already existing platformcentric DWs can act as the building blocks that, interconnected with the Computerised Patient Record (CPR) stored in local and heterogeneous Medical Information Systems (MIS), Radiological Information Systems (RISs), Picture Archiving and Communication Systems (PACSs), etc. will allow to build the worldwide 'Super-System' (Figure 3). The latter would constitute the cardinal medical information pillar of WHIG. The backbone connecting all the involved local entities can be provided using Next Generation Networks (NGNs)/IP Multimedia Subsystem (IMS) that will provide multimedia, multi-access, secure and reliable services based on the IPv6 protocol. The most diffused version of IP (IPv4), even if not considered obsolete yet, has already aged (IPv4 was standardised in September 1981), and is gradually substitued by its successive version (IPv6) standardised by the Internet Engineering Task Force (IETF) in December 1995. Among the most important functionalities introduced by IPv6 are its extremely simple and rational conception allowing to elegantly overcome the limits of IPv4, a practically boundless addressing space, the possibility to self-configure the hosts, an effective support for security and mobility, a mostly fitted structure for transport of real-time traffic and the possibility to realise a gradual and painless transition from IPv4 to IPv6. The impetus for the development of NGNs, and a rapid and widespread adoption of the IPv6 standard is provided by the awareness of companies like Telecommunications Operators (Telcos) that healthcare is one of the most important applications/services that will need to be addressed during the forthcoming decade simply as a matter of being competitive in the volatile telecommunications market (Patricelli et al., 1997; O'Sullivan, 2004; Lavoro and Rasi, 2005).

The forthcoming NGNs with their distributed architecture will fully exploit state-of-the-art technologies permitting more efficient continuation of the existing services and footing a wide range of new, highly sophisticated ones (Koong, Liu and Mok, 2004; Choi, Teer and Metha, 2006; von Lubitz and Levine, 2006**)**. The important aspect of NGNs relates to the expected increase of revenues combined with substantially reduced investment and operational costs (von Lubitz and Levine, 2006**)**.

The IMS (De Nitto, Ferrero and Marino, 2004; Znaty and Dauphin, 2005) supports, on a fully IP network, real-time services (voice, video, conference, etc.) and non-real-time services (Push-To-Talk, Presence, instantaneous messaging, etc.). Moreover, a critical aspect of IMS that promotes a network-centric operations is the concept of convergence of services supported indifferently by different kind of networks (fixed, mobile or Internet). IMS is not an unique network but comprises of different interoperating networks interlocked by IMS roaming agreements (fixed-fixed, fixed-mobile and mobile-mobile). IMS provides a normalised interface based on the Session Initiation Protocol (SIP) to access the services; the user handles therefore an IP multimedia terminal that is identified by an IP (IPv6) address. This protocol that allows also accessing to the platforms of services, is very useful because of its capacity to interface the mobile networks at minimal costs.

Figure 3 Proposed general architecture for the WHIG 'super-system.' For the sake of clarity only healthcare domain inputs are depicted



Since many of these services have not been in existence at the time of the inception of the current networks, even the most sophisticated DWs lag significantly behind in their ability to exploit the full advantages the current and forthcoming telecommunications platforms. We believe that one of the reasons for the prevailing platformcentricity of the existing DWs is the divergence between telecommunications as a major revenue-gathering, global business and DWs, which continue to exist as *service* elements either within or for other revenue generating entities. Also, domain orientation of DWs does not promote the utilisation of the full spectrum of capabilities offered by advanced telecommunications systems. In healthcare, because the need for cross-domain data exchange is perceived only at the time of major, wide area crisis (von Lubitz and Levine, 2006; von Lubitz and Wickramasinghe, 2006b), the level of utilisation of the advanced telecommunications platforms is virtually nil.

The key element in the development of operations utilising IMS is the creation of value, and number of important telecommunication services will be required to interface with the already existing IT applications, Customer Relationship Management (CRM) and Enterprise Resource Planning (ERP) systems. If networkcentricity is to be used as an operational doctrine, similar principles should be adopted, while interfacing global healthcare information systems with the telecommunication networks. IMS will then serve as the telecommunications backbone connecting through a worldwide, end-to-end, fully IP network the broadest variety of currently platformcentric components such as DWs, Decision Support Systems (DSS), Expert Systems (ES), Executive Decision Support (EDS), Information and Education/Training services (Patricelli and von Lubitz, 2005), etc. It will also mallow inclusion of systems serving domains that superficially have no role in healthcare operations but, under specific circumstances, may play the essential role that determines between success and failure (e.g. von Lubitz and Levine, 2005). In practical terms, IMS is probably the most flexible platform in existence that permits rapid development of a WHIG umbrella serving a network-centric 'Super-System' of multi-service, multi-access, secure and reliable worldwide network (Figure 3). Telcos need to create and implement new services on the NGNs they are deploying and healthcare Network-centric applications are for sure among the most interesting and profitable.

6 Network-centric healthcare operations and data warehousing

Data warehousing has recently reached a new level of maturity, both as a discipline and a technology market. Demand for Business Intelligence (DBI) and DW is stronger than ever (Knightsbridge White Paper, 2005). However, in the typical world of corporations, each of their departments has created its own solutions for data analysis. This approach resulted in duplication of efforts, inefficiency and increased expense. Standardising and consolidating DW infrastructure is therefore an important even if not an easy task; it involves political and organisational issues that are just as challenging as the technology itself.

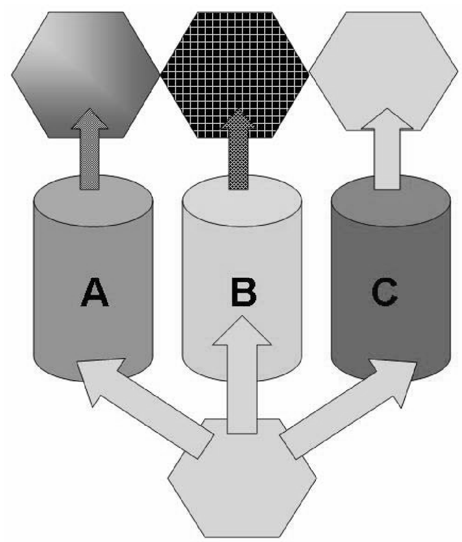
The growth of the DW market has not gone unnoticed among vendors in other technology areas. New entrants include vendors with US$ revenues from one million to several billions, from niche or single product suppliers to companies with frameworks and multiple products, and from start-ups to the well-established giants the most powerful of, whom are ERP and CRM vendors like SAP, Oracle and Siebel. Yet, although all of these companies help their clients get the data they need on a short-term basis, and although they are succeeding in penetrating the market, a broader view of the field is less alluring. Rapidly progressing globalisation of world's markets and the rapid growth of interdependencies among previously disconnected regional economies (Barnett, 2004) revealed not only new opportunities (ibid) but also entirely new challenges that either already affect or are about to affect the world (Brown, 2006). Hence, in the world of new and rapidly changing realities, before they will achieve widespread acceptance as core DW solutions, both the old and the forthcoming generation of vendors must prove their ability to handle data that come from outside their traditional enterprise applications. With operationally pertinent data and information residing in countless, often disparate systems, and the ever increasing demand for 'just-in-time' access to the multiplicity of ever more divergent sources, whose combined output is the only means of obtaining the *true* picture of the dynamically changing operational space (von Lubitz and Wickramasinghe, 2006b), the development and implementation of *global range* Enterprise Information Integration (EII) became an imperative operational need rather than an insignificant technicality. The solutions must centre on meta and master data management, and on the creation of interconnected meta data repositories with well defined rules specifying how stored data and information relate to each other, how to access them, and, at the same time, provide the *means* of accessing the repositories either individually or as a network.

Paradoxically, the newly discovered complexity of the new operational space *imposes* networkcentricity as the only viable means of instantaneous access to multi-spectral, multi-source information required for instantaneous positioning and response to the pressures imposed by the rapidly, and often unpredictably, changing pressures of global markets (Barnett, 2004; Rifkin, 2004; DvL and Wickramasinghe, 2006c). Subject to such pressures, both governments and the corporate world need to abandon the principles of their individuality and independence and put, instead, a layer on top of their chosen integration technologies that connects the tools and adds value in a manner that only a network can do (Rifkin, 2004). The need for such network is emphasised by the fact that no single vendor has the complete breadth of products to meet the full complement of the 'global enterprise needs'. Thus, in the environment as complex as that of global operations, selection of prospective solutions must be not only careful but based on thorough understanding of DW and ICCT but also on vendors' investments and commitment to networked, global-range DW solutions that will assure emergence of new data/information repository infrastructure in which disparate sources will appear as one. The need for such approach is clearly demonstrated by the aggressive promotion of metadata management concepts taken by the international Object Management Group (OMG) (see OMG RFP IMM 2006; and also http://www.tdan.com/i013hy02.htm)

In the current, predominantly platformcentric world of healthcare, the problems of interoperability are not centered on individual systems but rather on the incompatibility of data within these system (Mead, 2005). Typically, even within one organisation, the exchange of often critical data among the involved systems requires development of bridging interfaces. In the absence of uniform standards for data exchange, the cost of developing, maintaining, and operating such interfaces in the US alone reaches almost US$ 80 billion. Clearly, with the EU and other developed countries of the world experiencing identical problems, the involved expenditure is staggering. More importantly, the development of internationally accepted standards for healthcare data storage and exchange the resultant savings could be transferred into the development of comparably high quality of healthcare in underserved and underdeveloped regions of the globe.

Interoperability of systems engaged in data exchange can be either syntactic, semantic or be based on consistent and unambiguous exchange of meaning among the platforms participating in such exchange (Jones and Mead, 2005). In the first case, although the structure of the data will be interpreted correctly by all participants of the exchange, the meaning may vary at the level of transfer to each individual platform and reconciliation of the differences depends on human involvement (Figure 4). While humans are experts at semantic interoperability, i.e. exchange of *meaning*, machine-based systems continue to be highly deficient in such exchanges *unless* every aspect of the exchanged data is clearly and precisely defined (Jones and Mead, 2005). The final case represents that of Computable Semantic Interoperability (CSI, Mead, 2005), where clear, precisely defined meaning is exchanged. Importantly, in the latter case it is not the uniformity in the process of handling the data themselves that is essential, but the fact that each involved machine extracts identical meaning from the received data block. Ideally, both in a fast-paced environments of complex healthcare operations seen, for example, immediately after major disasters or in ultra-complex setting of international healthcare, CSI would be the most desirable approach to the development of multi-domain based, automated decision support. However, due to often loose definitions, the proponents of e.g. eXtended Markup Language (XML)–rooted Web portals (see von Lubitz and Wickramasinghe, 2006d) discuss the latter as using CSI rather than interactions based on human-mediated semantic interoperability.

Figure 4 The same data segment is fed into three different automated data analysis and interpretation systems (A, B, C)



Although the structure (hexagon) is interpreted correctly by all systems, there is a subtle difference in the interpretation of the meaning. Only system C perceives the true nature of the segment, i.e. uniformly filled hexagon, while systems A and B do not detect uniformity and perceive the data either as skewed (one sided shading) or incomplete (dot pattern). Definitive interpretation must be performed by a human operator whose determination may be affected by subjective factors (knowledge, experience, emotional status, etc.).

The development of CSI among domain-unrelated systems is complicated by the existence of divergent standards defining data management in healthcare and non-healthcare environments. In the former, Health Level 7 (HL7) emerges as the predominant standard, particularly with the advent of its Version 3 that, compared to the preceding versions, provides a much greater cross-enterprise scalability and flexibility needed for the development of an information system that is sufficiently powerful to serve as a reliable healthcare decision support system (Jones and Mead, 2005) The practical (and fiscal) significance of implementation of HL7 standards emerged following Huricane Katrina, when immunisation of refugees was greatly facilitated by HL7–mediated compatibility of records in Louisiana and Texas (Advance Editorial at http://www.health-care-it.advanceweb.com/common/editorial/editorial.aspx?CC=61662). The overall robustness of the newly emerged Version 3 of HL7 is supported by the willingness of HL7 Inc. to harmonise with standards of other organisations (Mead, 2005); the recent agreement between American Society for Testing and Materials (ASTM International) and HL7 represents one of the steps towards interoperability of clinical and administrative data governed by these two major standards that is necessary for the development of national Electronic Health Record (EHR)

The US National Health Information Initiative (NHII) and similar EU efforts aim at the development of highly complex healthcare data network, whose goal is to improve delivery of healthcare to individuals, improvement of population health, and improve administrative cost efficiency of the associated processes. As already discussed, national and international initiatives of this magnitude require an unprecedented degree of collaboration if the rigid boundaries separating individual vendors and vendors from governmental/political bodies are to be eliminated. For this reason, major technology companies (e.g. IBM, Oracle and Microsoft) created an Interoperability Consortium (IC), whose goal is to address the highly complex issues involved in the implementation of Health Information Initiative (HII) Importantly, the same companies are also members of Object Management Group (OMG) involved in the development of standards governing operation, management, and coordination of heterogeneous data repositories. Involvement of the same corporate entities in the creation of interoperability standards governing business on the one hand and healthcare on the other may be instrumental in facilitating cross-mapping allowing seamless integration of data exchange among all domains relevant as much to global business as global healthcare (Table 3).

Table 3 Essential aspects of semantic attributes within a cross domain meta-data relationship system

Functionality	*Extent*
Entity	All elements of the physical and information domains* (e.g. places, structures, persons, systems, etc.)
Significance	Capability or capacity, competence, impact (time/space related)
Involvement	Role and impact in the context of activity
Activity	Nature of involvement (e.g. clinical, administrative, economical, political, geographical, etc.)
Links	Links between or among activities

*See von Lubitz and Wickramasinghe, 2006a.

Although operational interdependencies of both domains have been demonstrated on several occasions (e.g. Barnett 2004; Rice 2004; Sachs, 2005), the means for the readily available, practical access to the relevant cross-domain data do not exist. Whenever such data are required, particularly on an emergent ('just-in-time' basis, as during post-disaster recovery operations), relevant information is sought using human rather than machine interfaces. As a result, decisions that lead to catastrophic consequences are made not because of incompetence or inefficiency but simply because they are made on the basis of information that is bypassed, subjectively ignored as irrelevant, or remaining entirely undiscovered (von Lubitz and Wickramasinghe, 2006b). The severity of such consequences can stretch from a relatively minor clinical error to massive and entirely unnecessary casualties resulting from mismanagement of a major disaster.

7 The network-centric data, information, and knowledge systems for global healthcare

Typically, situations as the one depicted above have taken place in the absence of an universally accepted standard for both inter- and cross domain DW and/or in the presence of a multitude of proprietary systems and solutions offered by either single or a group of vendors. The crowd of forums, normative bodies and groups of interest, together with the presence of proprietary solutions and de facto standards, has made the activity of standardisation of DWs complex and fragmented (Knightsbridge, 2005). Precise definition of a standard and a rigorous enforcement of interoperability requirement (such as, for example, HL7 in DoD's simulation activities) seems therefore to be the only way to oblige the vendors to leave their proprietary solutions and be compliant with the need for commons architecture, interfaces, etc., necessary for easier integration of the platformcentric and heterogeneous systems into a network-centric Super-System (System of Systems).

Far reaching, the establishment of the proposed Super-System does not represent a Utopian endeavour demanding *de-novo* creation of its subcomponents, but can be accomplished by combining the already existing platforms. Spanning all healthcare domains, HL7 Version 3 and its potent 'toolkit' represents arguably the most flexible data manipulation standard that is not only accepted by essentially all US governmental organisations involved in healthcare, but also gains a rapid international recognition. In addition, HL7 is also one of the cornerstones of the US NHII, whose development is, in turn, facilitated by leading data management companies also involved in the OMG. The latter represents a commonality of particular significance for the development of healthcare and non-healthcare metadata management interfaces, the implementation of, which is critical for the operation of machine-mediated access to- and manipulation of data and information existing in a wide range of currently incompatible repositories. Moreover, by promoting creation of DW networks, operation of such interfaces will impose (almost automatically) the materiel conditions necessary for the conduct of large scale, complex national and international network-centric healthcare operations. The telecommunication backbone of such operations will be rooted in the extensive implementation of both the IP and SIP (already existing and off the shelf) protocols. Governed by the already known and well-established standards, they will allow the platformcentric equipment that is already compliant with these standards to communicate automatically with its peers and/or upper layers of other equipment/systems to which they are connected through the NGN/IMS that are under current deployment by Telcos (Figure 3).

8 Discussion

One of the key ingredients of succeeding in today's healthcare environment is the ability of making better decisions faster. Wide range of business operations in healthcare-unrelated fields have shown that a data warehouse can provide accurate and timely information together with suitable business analysis tools that may offer key competitive advantage. The complexity of modern healthcare, the fluidity of its global field affected by the political and population changes, natural and man-made disasters, and the emergence of new threats, indicates that the traditional conduct of healthcare operations may soon prove inadequate to address that wide range of problems. Moreover, the need for real time data, for timely and accurate information based on such data, and for the pertinent knowledge whose scope, may vastly exceed the boundaries of conventionally conceived healthcare. There is thus the eminent and imminent need for the creation of a 'super-system' of data warehouses interconnected within the structure of the WHIG. The warehouses, operating on the principles of networkcentricity and accessible through dedicated portals (see von Lubitz and Wickramasinghe, 2006d), will provide an invaluable asset for decision support, particularly in situations, when time is of the essence, and the need for the rapid modification of the existing, often flexible or simply inadequate, procedures is critical (e.g. pandemics, disasters and large scale preventive operations).

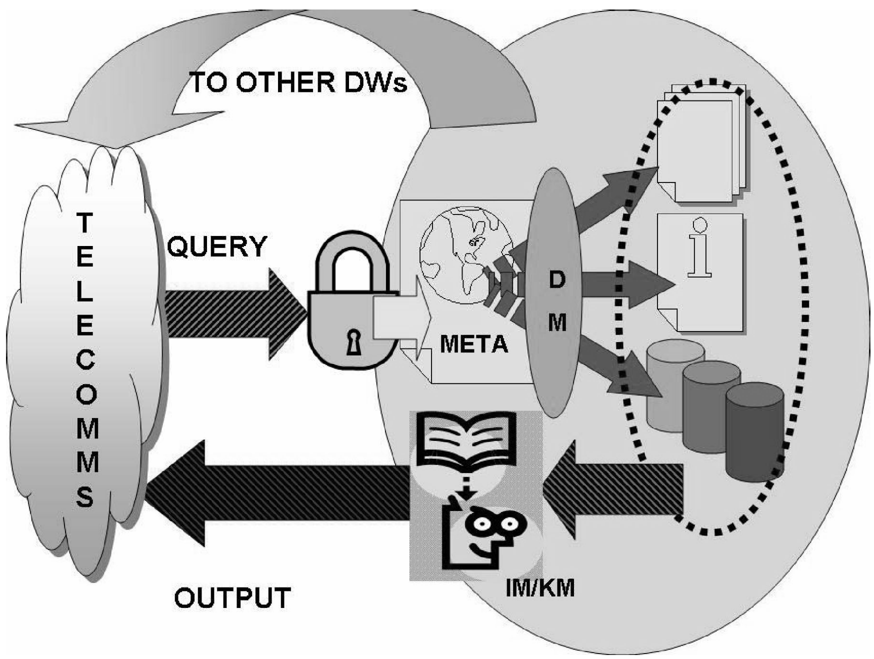
Networked operations, in order to be meaningful, require openness that is counterintuitive to the competitive 'market wars' (Rifkin, 2004). Nonetheless, the powerful drive of the EU towards the 'networked society' is based on interoperability of different systems, mutually agreed operational standards, and the development of high-speed information grids linking the entire continent. Moreover, the attitudes of the Europeans that support 'togetherness' rather than the rugged individualism of their US counterparts may, in conjunction with the significant infrastructure changes taking place within EU provide further impetus for the acceptance of networkcentricity in EU healthcare before its arrival in the US. The delay will, most likely be compounded by the significant differences in philosophy and policies driving the respective healthcare systems of EU and US.

The legislative and executive branches of the European Union strive towards legal and administrative unification of their members that will assure full integration and interoperability of the activities conducted within the Union. Within the US, healthcare operations are, on the other hand, subject to divergent federal/state/local legislatures, conflicting executive processes, corporate interests, and demands that are often grounded more in political expediency than true societal needs. Yet, both US and EU are subject to the escalation of healthcare costs so rapid that within foreseeable future it will attain economically crippling level.

Networkcentricity may relieve many of the emerging problems by facilitating access to healthcare expertise that is independent of fixed ('brick and mortar') delivery sites, by improvement in allocation of dispersed resources, and by better administrative management that is relevant to the needs of the patient rather than administrative convenience or the rules of traditionally accepted practices. Networkcentricity will also promote a much higher global efficiency of health monitoring and disease prevention by the simple expedient of facilitating real time collection, analysis, and dissemination of relevant albeit multi-spectral data (e.g. Frost and Sullivan, 2004). The latter is of particular significance in enhancing sensitivity of detecting the emerging major healthcare problems such as, for example, the newly recognised and alarming prevalence of cardiovascular mortality and morbidity in the LDCs (Leeder et al., 2004).

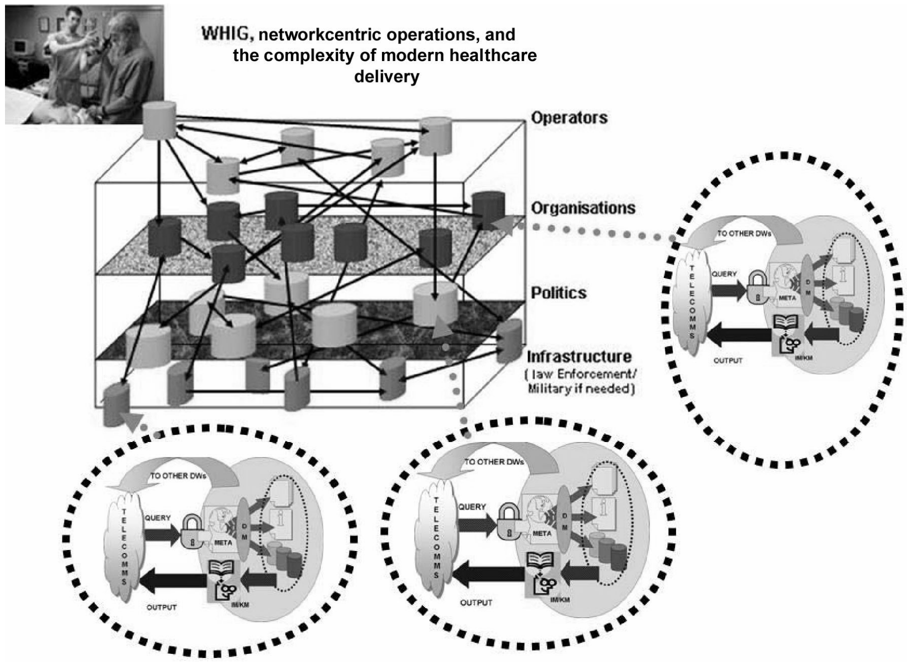
Recent history of catastrophic events continuously shows that healthcare operations in post-disaster environments depends on information and knowledge input from domains that traditionally are not affiliated with healthcare. Yet, time and time again the relief operations have been hampered by the suddenly evident lack of elementary knowledge of logistic capacity in the affected area, inability to coordinate weather patterns with delivery of medical assistance, fundamental lack of awareness of political/social realities displayed by the relief agencies, etc. The prime example of such deficiencies is provided by the response to the devastation caused by Hurricane Katrina, where the cumulative cost of disaster management errors reached billions of dollars in addition to the associated political and racial tensions whose combined effect will be felt for a long time (Dyson, 2006). Many of the errors could have been avoided providing relevant information existing within a wide range of entirely disconnected data warehousing systems flowed freely within the network-centric 'super-system' prior to the disaster. The existence of such system would facilitate the development of appropriate knowledge-based solutions to the potential problems, allow their simulation-testing and dissemination among all agencies involved in disaster response operations (Figure 5a,b; see also von Lubitz and Levine, 2006). Consequently, flexible 'joint' operational plans could be implemented and tested, and substitute individual and incompatible 'agency-owned' procedures all of which failed under the 'real life' test (ibid.).

Figure 5a Schematic diagram of functionalities within a complex data warehousing WHIG node



The legitimacy of a WHIG-based data query or data input is determined by the entry portal security systems then forwarded to the site mapping (meta data) system. The incoming data segment or query is subjected to further ETL procedures (DM – Data Management stage) until finally directed to the appropriate storage subsystem (stippled oval). A query initiates search for relevant data contained within interconnected multidomain storage subsystems of the directly queried warehouse as well as other sites connected to the WHIG indicated by a large arrow at the top of the figure). The extracted, pertinent data are analysed and, eventually, compiled into pertinent information. The latter is associated with appropriate pertinent knowledge elements, and then transmitted to the querying entity. If the analysis of pertinent data leads to the formulation of new forms of germane knowledge, the latter is disseminated within WHIG and becomes part of its permanent contents (Based on von Lubitz and Wickramasinghe, 2006d).

Figure 5b WHIG networking operations



The ‘operators’ (in this case an emergency medical site) can be both the source of new data as well as the recipient of data and information required for its activities and constitute one type of the networks’ ‘sensor sites’. The wide variety of input/output traffic sensor sites (von Lubitz and Wickramasinghe, 2006a,d) are distributed within the entire multilevel network whose nodes (networked cylinders) comprise of complex data warehousing/management and information/knowledge management sites and the associated access portals (exemplified by systems within stippled ovals, see also Figure 5a) Note that WHIG contains not only the sites belonging exclusively to healthcare domain (‘operators’) but also supporting warehouses containing information that characterises other domains (e.g. infrastructure, politics, business organisations, etc.), which may exert critical influence on the conduct of healthcare activities *per se*. Despite significant complexity of the depicted ‘Super System’, technology and adequate standards already exist that allow development of WHIG and network-centric healthcare operations

Interoperability of currently dissociated data warehousing systems and implementation of networkcentricity in healthcare operations are of particular significance in the context of national and international healthcare delivery and administration. Like many other ‘e-based’ activities, they promise higher efficiency, better throughput, and sustained quality of output at a lesser cost to the consumer be it individual patient or the entire society as such. They also promise enhanced responsiveness to new trends, providing a measure of ‘anticipatory’ rather than ‘consequence’ management approach. In times, when industrial giants (e.g. General Motors) are brought to their knees due to the escalating healthcare costs, improved efficiency of service, administration, and expenditure provide a strong motivation for the implementation of the network-centric healthcare concept. Some components (e.g. increasing access to broadband and mobile telecommunications, improved automated data extraction/management/dissemination techniques/development of standards) necessary for such implementation already exist. Others, such as WHIG, will need to be developed. On the other hand, many existing platforms and systems of platforms will need to be converted to assure the required level of global interoperability. Moreover, new security approaches will need to be devised, and entirely novel legal and ethical issues will have to be addressed.

The existing evidence (deriving from both civilian e-business and military operations) indicates the soundness of the proposed network-centric DW philosophy in healthcare. There are, however, problems that need to be addressed before deployment of routinely based network-centric healthcare operations. E-health involves new forms of patient-physician interaction and poses new challenges and threats to ethical issues such as online professional practice, informed consent, privacy and security issues (Rippen and Risk, 2006). Ethical concerns are, therefore, intimately linked to network-centricity in healthcare and the concerns are evidenced by the vigorous debate of the possibility of potential access to personal healthcare information and 'health profiling' by a wide range of governmental and private organisations. The threat of healthcare data abuse is enhanced by the rapid development of methodologies allowing early detection of long term, often debilitating diseases, and the indubitable inclusion of the results of such data in the electronic health records. The fear of clandestine stratification into 'health risk' classes is therefore real, particularly that misuse of genetical data opens the doors to their use as one of the determining factors in offers of employment, health insurance, and even acquisition of credit. Most Western countries legislated against such discrimination, but the enforcement of these laws is not simple and arbitrary decisions based on subjective evaluation of the rights of personal privacy *vs.* rights of employer to reduce financial risk are quite likely. In the 'network-centric world,' whose informational complexity is vastly greater than that of the presently used platformcentric entities, security is, therefore, of primary concern, and measures at a level, whose stringency is substantially superior to those currently adapted by, for example, financial institutions (e.g. Sullivan 2004; Evans, 2005), will need to be rapidly developed. Ultimately, transparency, international synergism, and adherence to the highest ethical standards of operations will be among the most instrumental factors to convince the users (i.e. both deliverers and recipients of healthcare) that networkcentricity in healthcare offers tangible benefits that have been unattainable prior to the implementation of the concept.

The critical issue that needs to be addressed while contemplating introduction of highly advanced healthcare technologies both among the developed (G8) countries and into the world of LDCs is the benefit they provide against the funding required to implement these technologies. The staggering costs of global healthcare and continuing deficiencies of its delivery indicate the real possibility of the collapse of worldwide healthcare. Hence, substitution of the currently disparate and ill-coordinated efforts with a well- defined operational doctrine centred on an integrated global system of data, information, and knowledge management and network-centric operations (Smarr, 1999) is now an operational imperative rather than the subject of academic debates. The dynamic drive of the EU toward practical use of large scale computing networks in daily operations of the constituent nations (Markoff and Schenker, 2003) portend the direction in which healthcare operations of G8 countries will rapidly evolve. However, of even greater importance are the majority of LDCs, where population explosion, growing disparity in economic status, the prevalence of preventable disease, and poor or non-existent public health induce political tensions and economical instability. Presently, the major thrust needs to be centered on LDCs, and it is our belief that, rather than creating redundancies and small-scale e-health projects, the effort needs to concentrate on the development of healthcare-relevant network-centric infrastructure supported by the backbone of the ongoing major international efforts aimed at the improvement of the regional economies.

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