Systems Engineering and Healthcare

In U.S. military lingo, a "force multiplier" is any capability or advantage that, when added to and employed by an enterprise, significantly increases the potential of an individual or organization, and thus enhances the probability of successful mission accomplishment"[1]. American military strategy calls for achieving battlefield dominance over any regional power with which U.S. forces might be engaged in conflict and accomplishing this through leadership in systems technology.

In this paper, "system" is defined as an "organized collection of diverse elements (people, equipment, software, facilities, policies, etc.) required to produce results not obtainable by the individual elements alone. The 'value added' by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts"[2]. Military systems typically include both physical hardware/software systems technologies (e.g. weapons, sensors, communications/networks, information technology systems) as well as human user/warfighter dimensions (e.g. maintaining situational awareness, training, education, experience, teamwork, ingenuity, organizational/leadership culture).

The scale and scope of military operations has led the military community to formalize the concepts of organized "system of systems" (SoS) and the processes of "system of systems engineering" (SoSE) as an extrapolation of traditional systems engineering thinking. This extrapolation considers the organization and evolution of networks of systems as a system with components that are operationally and managerially independent systems, and, that over time, exhibit emergent behavior based on component interactions. High levels of performance induced by force multipliers can be thought of as "emerging" through SoS component system-system interactions.

A widely recognized military systems force multiplier is enhanced situational awareness (SA)[3] that describes a person's or organization's knowledge and understanding of the circumstances, surroundings, and influences with regard to an unfolding situation, thereby enabling effective timely decisions. SA typically requires information technology/network connectivity to the "right", potentially diverse, real-time data sources reflecting the situation, and analytics that can "fuse" disparate evidentiary clues to create a coherent "picture" enabling recognition of the contextual meaning of dynamically changing raw data[4]. Moreover SA is only useful if it can be effectively delivered in a timely manner as "actionable information" to decision makers for immediate exploitation when engaged in high stress workflows[5]. Enhanced SA is an emergent property[6] of SoS comprised of sensor platforms, fusion centers, command and control, communications and battlefield operations.

Unlike the global success of U.S. military actionable intelligence systems, enabling effective preemptive, highly precise/coordinated/timely warfighting operations worldwide, we have not leveraged information technologies for a comparable dominance in healthcare[7]. Compared to other developed nations, the delivery of safe and high-quality healthcare in the U.S. has reached a crisis in terms of comparative personal loss due to preventable morbidity and mortality, excessive/uncontrolled costs, and poor care coordination across the continuum of care delivered by trans-domain networks of independently managed/operated heterogeneous systems. From the point of view of a systems engineer, it is clear that healthcare, as it exists in the U.S. today, is neither a force multiplier-enhanced "system" nor a "System of Systems" (SoS), and continues to rely on a fragmented delivery model that is highly dependent on the immediate findings and expertise of an individual provider. Most patients receive services that are poorly integrated with complementary services and relevant information resources. Consequently, unlike our military operations, healthcare operations generally lack Situational Awareness (SA) and therefore are not effectively "preemptive" (e.g. effective preventive care), and/or capable of delivering highly precise/coordinated/timely care. Moreover, inconsistent component capabilities and lack of coordinated repeatable processes towards common objectives limit the capacity for continuous improvement.

It is asserted that what is missing in the national healthcare industry is an overarching "systems of systems engineering" (SoSE) foundation, heavily used by the DoD[8], that applies sound, proven systems engineering tools to the identification, understanding, and optimization of interrelated legacy and evolving constituent care delivery systems processes as a collective SoS .

The foundational tools of any SoS engineering process includes[9]:

Definition of the measurable objectives/capabilities or goals of the SoS

Elaboration of the interdependencies/interfaces between and among system components (e.g. constituent systems)

Clarification of the roles of the constituent systems necessary to achieve system of systems level capability/performance (e.g. decomposed functional/performance/operational SoS level requirements allocated to component systems)

Healthcare as a whole is not managed as a set of well-defined interrelated processes driven by end-to-end SoS goals that have been decomposed and allocated to component systems, but instead performance requirements and interdependencies between component systems (in-patient care, ambulatory care, specialty care, EMRs, patient portals, medical devices, etc.) are loosely defined at best[10]. Government incentives/penalties designed to reward/encourage value based care and information exchanges using "standards" have been unable to shift the existing fee-for-service environment and overcome the barriers to SA bred by the proliferation of proprietary, information intensive healthcare systems that were not initially developed for an integrated SoS mission.

The growing role of information intensive systems in clinical practice SoS (composed of clinicians/providers, information systems and institutional equipment devices used across the care continuum) provides the opportunity for positive digital technology force multiplicative transformation of care delivery. However today's U.S. healthcare lacks a clear definition of overall objectives or goals at the SoS level, lacks clarity on the interdependencies between component systems (including critical human factored man-machine and interoperable machine-machine interfaces), and most importantly fails to allocate critical care requirements to these components necessary to achieve overall system of system goals.

Without these most basic formative systems engineering underpinnings, our emerging digitally supported healthcare system will continue to fail to meet force multiplicative performance expectations and instead deliver care that, at best, represents the suboptimal sum of constituent systems, and at worse, reflects new technology use challenges for safety and quality[11].

[1] https://en.wikipedia.org/wiki/Force_multiplication

[2] http://www.incose.org/

[3] https://en.wikipedia.org/wiki/Situation_awareness

[4] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.563.206&rep=rep1&type=pdf

[5] http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf

[6] http://www.dtic.mil/ndia/2012system/track1014745.pdf

[7] In this paper we use "healthcare" or "healthcare system" to mean the organization of people, institutions, and resources (e.g. facilities, equipment, information systems) used to deliver healthcare services that meet health needs of the target population

[8] Charles B. Keating, Polinpapilinho F. Katina (2011) "Systems of systems engineering: Prospects and challenges for the emerging field," International Journal of System of Systems Engineering, 2(2/3), 234–256. http://doi.org/10.1504/IJSSE.2011.040556

[9] http://www.incose.org/ChaptersGroups/WorkingGroups/analytic/system-of-systems

[10] http://www.jhuapl.edu/techdigest/TD/td3104/31_04-Ravitz.pdf

[11] http://perspectives.ahima.org/impact-of-electronic-health-record-systems-on-information-integrity-quality-and-safety-implications/