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Structuring and Visualizing Healthcare Claims Data Using Systems Architecture Methodology

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Abstract—Healthcare delivery systems around the world are in crisis. The need to improve health outcomes while decreasing healthcare costs have led to an imminent call to action to *transform the healthcare delivery system*. While Bioinformatics and Biomedical Engineering have primarily focused on biological level data and biomedical technology, there is clear evidence of the importance of the delivery of care on patient outcomes. Classic singular decomposition approaches from reductionist science are not capable of explaining complex systems. Approaches and methods from systems science and systems engineering are utilized to structure healthcare delivery system data. Specifically, systems architecture is used to develop a multi-scale and multi-dimensional characterization of the healthcare delivery system, defined here as the Healthcare Delivery System Knowledge Base. This paper is the first to contribute a new method of structuring and visualizing a multi-dimensional and multi-scale healthcare delivery system using systems architecture in order to better understand healthcare delivery.

Keywords—Health informatics, systems thinking, systems architecture, healthcare delivery system, data analytics.

I. Introduction

Healthcare delivery systems around the world are in crisis. Despite the rising expenditures on the US healthcare delivery system, a multi-scale and multi-dimensional complex system targeted to tertiary care, health outcomes among middle-aged people are if anything getting worse, with the prospect that the next generation could experience shorter lifespans [1], [2]. The cost of such a system also continues to significantly increase [3]. The need to improve health outcomes while decreasing healthcare costs have led to an imminent call to action to *transform the healthcare delivery system* [4].

The primary field of study concerned with transforming the healthcare delivery system is healthcare delivery science. Healthcare delivery science is a new field of study arising from the need to understand, change and optimize the healthcare delivery system to improve outcomes and decrease cost. While healthcare delivery science is focused on understanding the healthcare system, it does so using classical healthcare studies focused on specific aspects of the healthcare system (i.e. healthcare services or healthcare personnel within specific disease areas or specific departments). Such analyses include singular views and typically simple summary statistics such as expenditures, hospital stays or physician visits. Furthermore, these measures do not capture the complexity of healthcare provided and therefore do not reflect the multiple providers and multiple sites of care and different rates of intensity of various services.

In the quest to transform the healthcare delivery system, Engineering has been identified by the "Building a Better Delivery System: A New Engineering/Healthcare Partnership" Report [5]. The classic application of engineering to healthcare delivery science has been focused on increasing efficiency, reducing errors and improving healthcare utilization for specific healthcare processes (i.e. emergency room and surgical processes). This application utilizes the industrial engineering mathematical tools to understand utilization, capacity management and workflow to specifically focus on, and is therefore limited to, the optimization of the *transportation* of a patient through the healthcare delivery system.

While the fields of healthcare delivery science and engineering are critical to transforming the complex healthcare delivery system, the applications of these domains have focused on limited spatial and temporal scale & scope. Understanding a complex system requires a multi-dimensional, multi-scale aggregation rather than many singular decompositions. The fields of engineering can bring critical complex and systems knowledge, methods and concepts, while the field of healthcare delivery science can bring rich data to the understanding of complex healthcare delivery systems.

This paper develops models of the healthcare delivery system from an engineering systems perspective using healthcare delivery system data. Specifically, systems architecture, designed to aid in architecting complex systems, is used to develop a multi-scale and multi-dimensional characterization of the healthcare delivery system, defined here as the Healthcare Delivery System Knowledge Base.

II. Background and Theory

The ability to transform a system is predicated on the the ability to understand a system (i.e. to conceptually model a system). Systems thinking and engineering has emerged as an approach to *synthesize* and design large complex systems [6], [7]. Within this knowledge, the discipline of systems architecture can be utilized to develop a conceptual model as a formal description and representation of the structure

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and behavior of a system. In this section, specific Systems Architecture concepts are applied to healthcare delivery system data to develop a model of the healthcare delivery system called a healthcare delivery system knowledge base.

A healthcare delivery system knowledge base is architected based on the fundamental ideas in systems thinking that a system has 1.) one or more functions, 2.) a physical form or structure, and 3.) an allocation as the mapping between the former to the latter and can be described at various 4.) scale and scope.

A. System Function

The healthcare delivery system is described as providing functions typically referred to as services. These services are a composition of functions and tasks that deliver healthcare (i.e. surgery, consults, etc.). Given that healthcare is a highly regulated, insurance based service industry, it has developed several coding schemes to describe and characterize services into a standardized ontology. Some of these include surgical procedure codes (Sx codes), current procedural terminology (CPT codes), healthcare common procedure coding system (HCPCS codes), berenson-eggers type of service (BETOS codes or aggregated BETOS codes).

B. System Form/Structure

These services (i.e. functions) are performed by the form or structure of healthcare personnel and/or technology. Healthcare personnel are an incredibly important *structure*, not because they represents a human performing the service, but because they represent specific qualifications (i.e. training, knowledge and experience) of the human performing the service. Form or structure can be represented by the healthcare personnel at the smallest scale, but can also be represented at higher scales such as the facility at which the healthcare personnel performs the service. Typical healthcare system structures include: clinicians, clinician types, specialties, facilities, facility types, regions, aggregated regions.

C. System Allocation of Form to Function

The allocation of service performed to the healthcare personnel performing it is fundamental and reflected in the reimbursement claims requirement of identifying the healthcare personnel and therefore their credentials when filing a claim for reimbursement for a service. Such an allocation exists due to the highly regulated nature of the healthcare system.

D. System Scale and Scope

The concepts of scale and scope are critical when trying to understand the various analysis and terminology used to understand the healthcare delivery system. For example, the *form* of the healthcare delivery system may be the healthcare personnel providing a service (typically referred to as the clinician). But at a different scale, the *form* may be aggregated to a specialty or to a facility. Scale and scope can also be used to help understand an aggregate service, which may be represented as a bundled service (i.e. surgery or baby delivery) and typically requires multiple personnel. Scale and scope can also be used to describe a temporal scale. Cardiovascular surgery is typically thought of as a service where a patient enters a facility is operated on and then released from a facility. The temporal scale here is the primary surgical time scale within the facility. However, currently healthcare insurance plans are paying on the basis of bundled payments, that is the surgical stay plus 30 days to accurately reflect true health outcomes and costs.

E. Architecture Model

Definition 1. Healthcare Delivery System Knowledge Base [8]–[15]: A binary matrix J representing the allocation of form (v) to function (w) whose element $J(w, v) \in \{0, 1\}$ is equal to one when service w is executed by form v. Form and function are represented here at the lowest decomposition level.

Each element in the Healthcare Delivery System Knowledge Base matrix represents a *capability* of the system.

Definition 2. Capability Map: A non-binary matrix representing the Healthcare Delivery System Knowledge Base or the aggregation of the Healthcare Delivery System Knowledge Base in either form, function or form & function. The elements in the Capability Map represent a capability *quantity*, which is based on the application or example it is applied to (i.e. % of decedents utilizing a capability).

A healthcare delivery system knowledge base can generate several capability maps at various aggregation levels. Depending on the structure of the data, the aggregation can be performed algorithmically or it can be generated for each aggregation level.

In the case of healthcare, the healthcare delivery system knowledge base and other capability maps can be generated using large data sets that come from claims data. The healthcare insurance system had dictated a very rigorous claims structure and therefore standardization, which allows for the construction of these knowledge bases and maps. One of the larger data sets comes from the Medicare program; however, similar data sets can be used from private claims data available from private insurers.

III. A Healthcare System Knowledge Based Example: Miami vs. Minneapolis

This example develops two healthcare delivery knowledge bases to characterize the complicated patterns of End-Of-Life care and how they differ across two regions. Two cities expected to vary in their healthcare delivery practices and systems [16], [17] were chosen: Miami, Florida (MI) and Minneapolis, Minnesota (MN).

A. Methods

A healthcare delivery system knowledge base was constructed for each city based on Medicare claims data (i.e. a federal program insuring individuals ages 65+). In order to construct the End-of-Life healthcare delivery system knowledge bases, data was included from individuals that died in the 2nd quarter (Q2) or 4th quarter (Q4) of 2014, called decedents. The data used for each decedent spanned 3 months prior to their Date of Death. Specifically, the data collected included: Part A, collected into single stays referred to as MEDPAR (i.e. coverage for hospital care – facilities, etc.) and Part B (i.e. coverage for medical care – clinician services, etc.).

The following capability maps were generated from the primary knowledge bases.

Data normalization was performed to generate capability maps that can be compared between the two cities. This was achieved by normalizing the capability maps (CM_{norm}) such that the value of each capability represented the percent of decedents receiving that capability as shown in (1).

$$CM_{norm} = 100 \times \frac{\sum(CapabilityForAllDecedents)}{NumberofDescendants} \quad (1)$$

Next, capability map differences (CM_{diff}) were directly calculated from the normalized capability maps as shown in (2) and represent a difference in percentage.

$$CM_{diff} = normCM_{MI} - normCM_{MN} \quad (2)$$

B. Results

Several capability maps can be generated from the constructed healthcare delivery system knowledge base. To illustrate an example of these capability maps, Two Part A capability maps are shown at the abstraction levels of Aggregated Surgical Procedure Codes by Facility Type (Fig. 1) and MS-DRG by Facility Type (Figure 2). Two Part B capability maps are also shown at the abstraction levels of Aggregated Surgical Procedure Codes by Facility Type (Figure 1) and MS-DRG by Facility Type (Fig. 4).

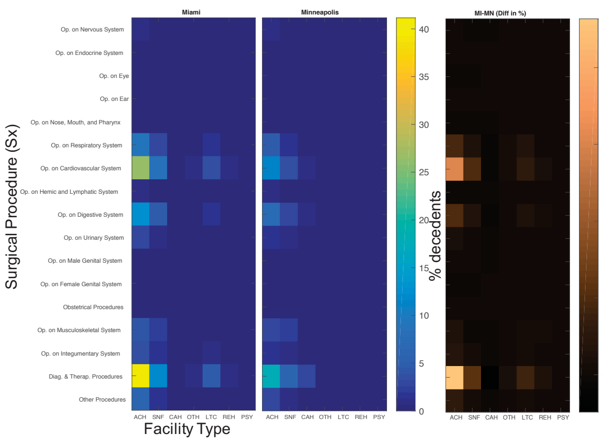

Fig. 1 *Surgical Procedure Codes by Facility Type Capability Map* for Miami, Minneapolis and the difference between them

The visualization of the capability maps at various abstraction level allows for fast and easy identification of similarities and differences between the healthcare delivery systems of these two cities. Visual inspection capitalizes on the incredible human pattern recognition ability to quickly and

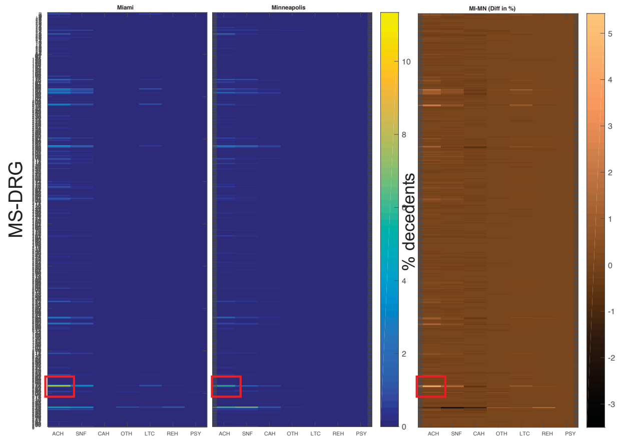

Fig. 2 *MS-DRG by Facility Type Capability Map* for Miami, Minneapolis and the difference between them. The largest capability difference between Miami and Minneapolis was for MS-DRG *Septecemia* by Facility Type *Acute Care Hospital* (boxed in red)

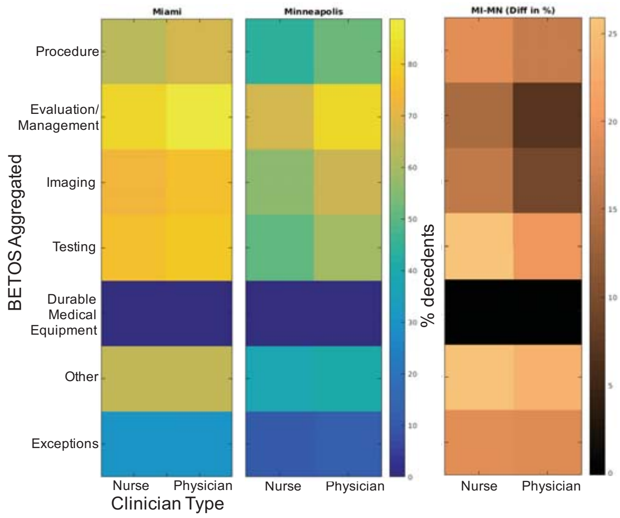

Fig. 3 *BETOS Aggregated by Clinician Type Capability Map* for Miami, Minneapolis and the difference between them

easily identify disparate differences that may otherwise take much more effort to identify with data analytics alone.

MEDPAR data from the two capability maps show considerably higher overall treatment intensity in Miami. These differences are not consistent across treatment categories or provider groupings, but arise in specific sectors and for specific treatments as demonstrated visually by the capability maps. The analysis of the capability map, based on visual inspection of Fig. 2, shows that the percentage of decedents in the last 3 months hospitalized for Septicemia (i.e. sepsis) in Miami was 11.3% compared to 5.9% in Minneapolis. While calculating that the overall MEDPAR surgical procedures between the two cities were similar (63.6 per 100 decedents in Miami compared to 63.2 Minneapolis), visual inspection of Fig. 1, aided in quickly and specifically identifying that Miami performed 2.5 times

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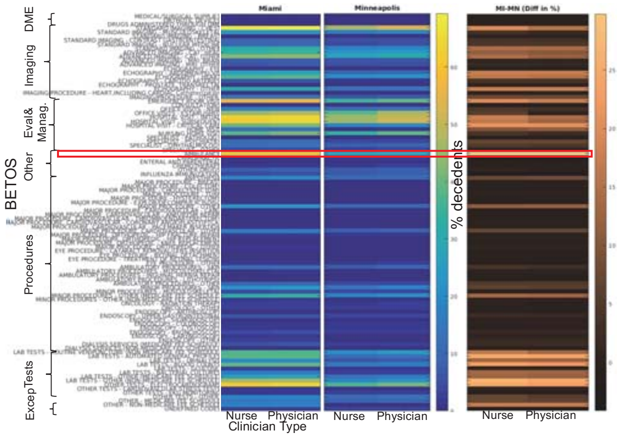

Fig. 4 *BETOS by Facility Type Capability Map* for Miami, Minneapolis and the difference between them. The largest capability difference was for BETOS Code *Ambulance* by either clinician type (boxed in red)

as many cardiovascular procedures and 2.2 times as many diagnostic and therapeutic procedures, Figure 1. It was also easy to identify calculate that surgical procedures performed in long-term care facilities were 5 times higher in Miami compared to Minneapolis.

Part B data, from Fig. 3, show that the percentage of decedents with any evaluation and management services was similar in the two cities (88% in Miami, 82% in Minneapolis). A capability map decomposition down to BETOS by Clinician Type, Fig. 4, identified the largest difference between the cities occurring for ambulance service, where 60% of decedents in Miami received at least one ambulance service compared to 30% in Minneapolis.

The limitation of this analysis will depend on the reliability of the data. For example, this dataset revealed a difference in Septicemia. The question becomes is this difference due to 1.) a difference in manifestation of Septicemia or 2.) a difference in how Septicemia is coded. Given that healthcare is a highly regulated field, we suspect that this should be a minimal concern, although in Miami, fraudulent activity has been detected in the past [18].

IV. Conclusion

This paper developed a healthcare delivery system model from a systems perspective, implemented using real healthcare delivery system data based on Medicare claims. Specifically, systems architecture concepts were used to develop a healthcare delivery system knowledge base from which capability maps could be generated to show the multi-scale and multi-dimensional characterization of the healthcare delivery system.

Similar system architectures, based on form and function, have been developed for several applications including: healthcare human resources, energy, water, transportation and production systems [8]–[15]. To our knowledge, this is the first study utilizing knowledge bases to develop a healthcare delivery system model.

The utilization of this healthcare delivery system model for regional comparisons, such as the End-of-Life Care example in this paper, is one possible application. The architectural design of the healthcare delivery system knowledge base allows for several other applications (i.e. examining the effect of policy changes on the healthcare delivery system and understanding how the capabilities of a healthcare system change as more clinicians practice at the top of their license). As the transformation of the healthcare delivery system continues, this work presents a system model to develop, understand, visualize and analyze the healthcare delivery system.

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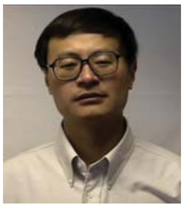

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