Model-Based Systems-of-Systems Healthcare: Coordinating the Coordinators

Bernard P. Zeigler, Mark Redding, Pamela J. Boyers, and Ernest L. Carter

Abstract Achieving value-based healthcare – increasing quality, reducing cost, and spreading access – has proven to be extremely challenging. In recent years, a large variety of care coordination organizations have emerged at regional and national scales. Unfortunately, each such health entity lives in its own definition (silo) of care coordination leaving large gaps in care as well as duplicative or inconsistent interventions where care domains overlap. This situation leads to the need for higher-level coordination of the coordinators with well-defined population health metrics and means for sharing of information and control of patient-centered interventions. In "Value-based Learning Healthcare Systems: Integrative modeling and simulation" (Zeigler et al. 2018), we presented a modeling and simulation (M&S) approach to value-based healthcare within a system-of-systems framework that enables designing, testing, and implementing care coordination based on identifying and addressing risks at the individual and family level and tracking progress though health information technologies (HITs). In this paper, we discuss how a model-based system-of-systems design for HIT infrastructure can support innovative "coordination of the coordinators" assuring that critical modifiable risks spanning health and social issues are identified and addressed resulting in better health and social outcomes. We describe existing foundations for implementing such a design such as digital platforms, pathways-based community coordinator organizations, risk factor registries, as well as comprehensive simulation facilities where the design and its components can be tested. Research required to enable integrating such foundations into a working whole is also described.

B. P. Zeigler (✉)
RTSync, Corp, Chandler, AZ, USA
e-mail: zeigler@rtsync.com

M. Redding
Research and Quality Director, Pathways Community HUB Institute, Akron, OH, USA

P. J. Boyers
University of Nebraska Medical Center, Omaha, NE, USA

E. L. Carter
Health Department, Prince Georges County, MD, USA

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1 Introduction

In response to the need for coordination of health and social services to identify and address modifiable risks, a large variety of care coordination organizations have emerged at regional and national scales. Unfortunately, each such entity lives in its own definition (silo) of care coordination leaving large gaps in care as well as duplicative or inconsistent interventions where care domains overlap. This situation leads to the need for higher-level coordination of the coordinators with well-defined population health metrics and means for sharing of information and control of patient-centered interventions. In "Value-based Learning Healthcare Systems: Integrative modeling and simulation" (Zeigler et al. 2018), the objectives of value-based healthcare were broadly stated by the following equation:

$$\text{Objectives} = \text{low Cost} + \text{high Quality} + \text{wide Accessibility}$$

The exact meaning of the attributes, cost, quality, and accessibility can vary, as can their priority, or even applicability, in different contexts. Nevertheless, when we refer to measuring value, we mean some concrete formulation of increase in quality while reducing cost and increasing access. The importance of the equation becomes evident when we recognize that a healthcare service system is composed of a large number of distributed components that are interrelated by complex processes. Understanding the behavior of the overall system is becoming a major concern among health and social service system managers and decision-makers intent on increasing value for their systems.

An optimal health and social service delivery system requires methods to model large-scale distributed complex systems (Dahmann 2018), a challenge that has been identified under the rubric of model-based systems of systems (SoS) engineering (Wymore 1993, Jamshidi 2008, Zeigler et al. 2018) in that the optimization cannot be based on sub-optimization of the component systems but must be directed at the entire system itself. People with multiple health and social needs are high consumers of healthcare services and are thus drivers of high healthcare costs. The ability to provide the right information to the right people in real time requires a system-level model that identifies the various community partners involved and rigorously lays out how their interactions might be effectively coordinated to improve the effectiveness of the system in identifying and addressing modifiable risk in a whole person approach for whose care costs the most.

Modeling and simulation (M&S) brings the latest methods and technologies being adopted in SoS problems, ranging from missile defense systems to population management systems. M&S is fast becoming the core knowledge generator for

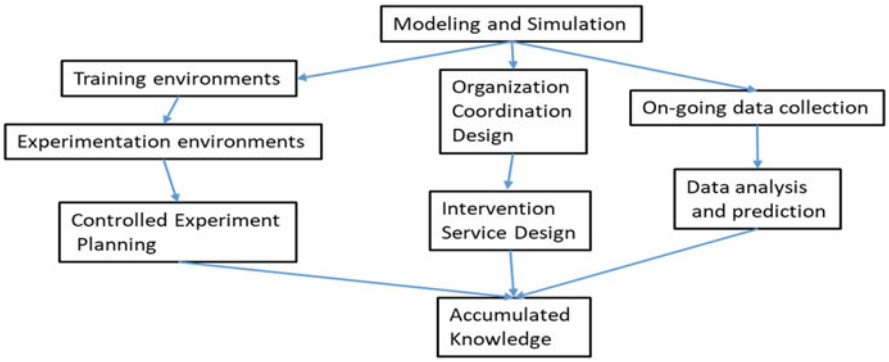

Fig. 1 Modeling and simulation healthcare development paradigm

complex systems engineering. As illustrated in Fig. 1, the new holistic paradigm places M&S at the top of ongoing knowledge accumulation in a learning health and social service system in which it is at the center of multiple related core activities involving a variety of health and social service providers. M&S spawns new ambitious training and experimentation treatment simulation environments enabling controlled experiments, design and engineering of interventions and their coordination across multiple scales, as well as ongoing data collection from multitudes of sensors with associated data analysis and prediction. We return to this discussion in the "Research and Development" section. A modeling and simulation methodology and framework model the entire health and social service system as a loosely coupled distributed system (Zeigler 2016, Madni, 2018). The criteria for such a model were laid out by Zeigler et al. (2018). Such a model systematically represents the behaviors of patients who require coordinated care interventions and the providers of such coordination services to render such behaviors amenable to health and social service system design and engineering. Unfortunately, most of the work concerning health and social service system modeling and simulation (M&S) in the literature is unit or facility specific rather than taking a consistent global whole person and family view. In contrast, Zeigler et al. (2018) present a framework that encompasses common perspectives taken in the research literature but also goes beyond them toward their integration with additional perspectives that are becoming critical in today's environment. It proposes a stratification of the levels of abstraction into multiple perspectives. In each of these perspectives, models of different components of healthcare systems can be developed and coupled together. Concerns from other perspectives can be abstracted as parameters in such models. The resulting global model can be coupled with a holistic experimental frame to derive results that cannot be accurately addressed in any of the perspectives if taken alone.

2 Population Health Context

The health and social service system framework of Zeigler et al. (2018) is extended here to include the level of population as is being developed in the context of a population wellness management. The system design objectives expressed earlier are replaced by the Triple Aim: the simultaneous pursuit of improving the patient experience of care, improving the health of populations, and reducing the per capita cost of healthcare. Introducing the population level is necessitated by the proliferation of various care coordination service providers with independently defined domains of care coordination leaving large gaps in care as well as duplicative or inconsistent interventions where care domains overlap. This situation leads to the need for higher-level coordination of the coordinators which can only be addressed at a population level.

Figure 2 sketches in broad strokes, a UML system design that extends the framework of Zeigler et al. (2018) by employing risk management and pathways of care to provide SoS-level coordination of specialized modifiable risk identification and mitigation interventions and coordination services. The process of induction of a patient into coordinated care starts with a full-scale screening and assessment of medical, social, and behavioral health risks and assignment to one of a small set of categories of risk, each with its own distinct portfolio of interventions and care coordination services. A primary distinction with current practice is that a *patient is assigned to single primary care provider* (*PCP*, *doctor*) and connected care coordination team who are responsible for all subsequent patient interactions with the system. The PCP employs the output of risk screening and patient category of risk to assign pathways that lay out steps of interventions and services toward mitigation of modifiable risks. Interventions for identified risks span medical, social, and behavioral health service interventions. The same PCP team is continually updated with results of the patient's encounters with such interventions and mitigations of risk through system-provided tracking, thus enabling monitoring of progress in addressing modifiable risk.

A Central Referral System (CRS) (Fig.3) provides the underlying digital infrastructure to initiate induction into the system as well as a host of necessary services. The Consent2Share consent management tool is the key application which not only controls the information that a patient allows to be shared but, most importantly, serves as the patient registration portal that guarantees the unique coupling of patient and PCP. Sharing of electronic, medical, and other patient health records is mediated by a regional health information exchange (HIE) which allows health information to move electronically among disparate health information systems employed by hospitals and other providers. The goal of the HIE is to deliver the right health information to the right place at the right time – providing safer, timelier, efficient, effective, equitable, patient-centered care. Further this infrastructure supports monitoring and tracking of a holistic registry of risk mitigation efforts tracked within pathways and includes patient interactions with providers and agencies, progress evaluation, health record keeping, and information sharing.

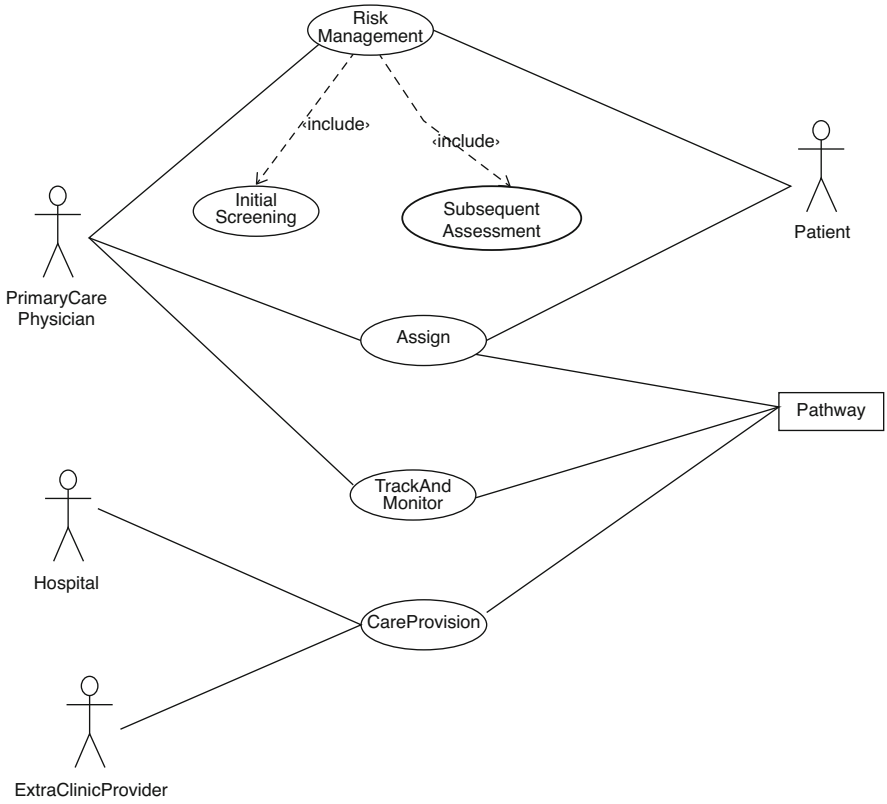

Fig. 2 Sketch of UML system design

3 Risk Factor Registry

The health, social, and behavioral health assessment of modifiable risks and the related risk stratification in the patient induction screening is an ultracritical component of the system design. This sets up requirements for the management of a comprehensive approach to identifying and addressing risk factors, including their individual and combinatorial effects on outcomes. Risk factors spanning medical, social, and behavioral health are interlocking and interconnected in their impact across medical social and behavioral health domains. Current research is starting to develop complete registries of risk factors (Redding et al., 2018) with quantitative information including relative weight of impact of these factors on dependent variable outcomes such as hospitalization, emergency room use, total cost of care, school performance, and employment. Such research is needed to discover the signature risk combinations, groupings of specific factors, across health and social domains that exponentially amplify impact. Such a registry is critical

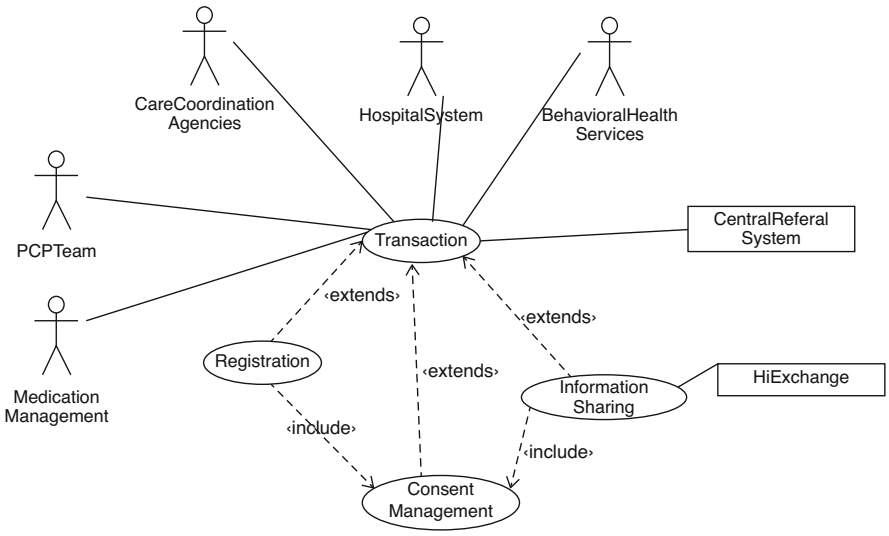

Fig. 3 UML sketch of transactions guarded by consent management

to the ability to intervene, enabling laser targeting of preventive actions toward individuals likely to experience catastrophic and expensive outcomes. Moreover, it is necessary to distinguish *individually modifiable factors of risk* spanning medical social and behavioral health (reference) from those that are not so modifiable so that intervention and coordination services can be targeted in the most effective manner.

4 Comprehensive Healthcare Simulation

For testing of SoS designs such as Fig. 1 prior to fielding, an approach involving live, virtual, and constructive (LVC) simulation is advisable as has been developed in defense system contexts (Wikipedia LVC). Figure 4 illustrates the functionality and enabling capacities of such a comprehensive facility that is designed to replicate the various healthcare settings. The generic description of Fig 4. is based on the Dr. Edwin G. & Dorothy Balbach Davis Global Center (Davis Global Center) at University of Nebraska Medical Center as detailed in the section "Davis Global Simulation Center" (see below). Domains of simulation include both clinical (hospital), social, and behavioral health individually and in combination. Types of simulation include surgical and interventional, as well as simulated communicated care and prehospital preparation. Live simulation includes human acting patients. Virtual simulation includes virtual reality portrayal of internal anatomical and physiological systems and clinical settings. Constructive model-based simulation includes computerized representations such as simulated responses, manikins, robot surrogates, etc. Supporting infrastructure includes networking including middleware

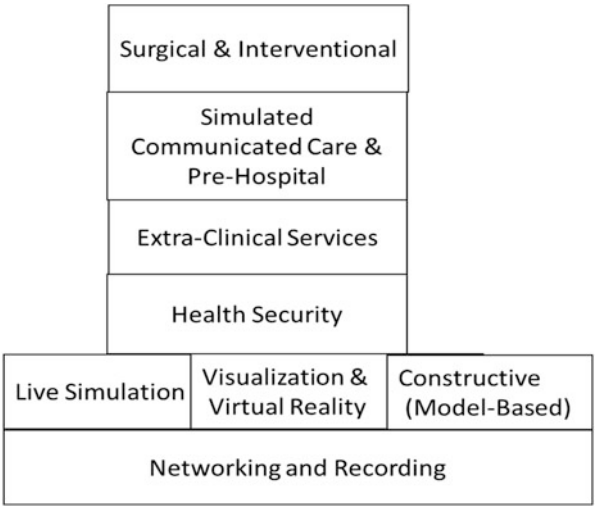

Fig. 4 UNMC Davis Global Center Design: A Comprehensive Healthcare Simulation Facility

supporting real-time and abstract simulation (Wikipedia High-Level Architecture). Furthermore, pervasive recording of all events occurring with simulation experiences enables post-event analysis and rerunning of protocols later for training.

5 Current Research and Development

The system design outlined earlier is forward looking, but several existing technological developments can serve as foundational for its realization. Here we briefly review such technology components as well as the continued research needed to bring them readiness for deployment in the near future.

5.1 Population Health Management

Maryland is the only state with Medicare waiver that affects all patients treated in Maryland hospitals. Under its rules, every payer pays the same charge for the same care. In return, Maryland must slow the rate at which total hospital costs are increasing. The goal of the new waiver is to simultaneously improve health, quality, and affordability. Prevention Link is a program being developed under a 5-year cooperative agreement between the Centers for Disease Control and Prevention (CDC) and the Prince George's County Health Department to lead the collaborative development of regional infrastructure for chronic disease prevention

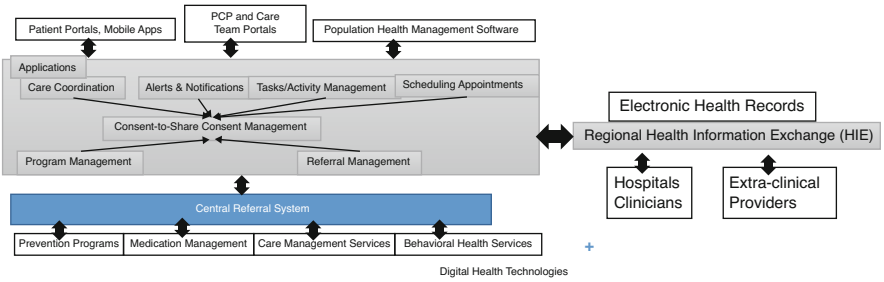

Fig. 5 Central Referral System Platform for Coordination of Coordinators

and care across Southern Maryland. It combines evidence-based prevention and care approaches, technology, and communications strategies to create a multifaceted integrated system for improving health and wellness related to chronic disease in Southern Maryland. The hypothesis is that a well-developed care management program is the key to better outcomes and cost savings, especially in populations with chronic disease. The ultimate goal is an effective, sustainable, and replicable model to demonstrate how the All Payer Maryland model can be adopted by other states. A system design, which is abstracted in Fig. 5, is being developed to implement such a management program. The CRS hosts a suite of tools aimed at improving the facilitation of care for linked care providers. Such software tools include tools for Population Health Management, Care Coordination, Alerts and Notifications, Tasks/Activity Management, Scheduling Appointments, Program Management, Referral Management, and Prevention Programs. Maryland's statewide HIE (CRISP) allows providers to track the current location of their patients and provides a variety of alerts and notifications about their statuses. External services such as Medication Management, Care Management Services, and Behavioral Health Services are integrated into the system via the HIE and CRS.

As described below, pathways developed through the Pathways Community HUB Institute (PCHI) can be utilized to confirm identification and mitigation or failure of mitigation of modifiable risks spanning medical, social, and behavioral health domains. These granular measurements of meaningful work product completions in mitigated risk are critical, quality, payment, and tracking components to implement effective coordination of the coordinators and related reporting required at the population level. As they represent meaningful events with future impact on health and the ability to live normal productive lives, each confirmed risk mitigation within the Pathways Community HUB model approach represents an intermediate or final patient outcome. These risk mitigation outcomes work individually and in combinations to impact larger outcomes of disease control, birth outcomes, cost of care, future school and job performance, etc. Experience with physicians working closely with community health workers in the Pathways HUB located in Alaska should be exploited in the development of PCP-based coordination of coordinators.

5.2 *Prerequisites for Healthcare Learning System*

A learning health and social service system must provide the right data and models to support human selection of alternatives likely to improve the quality of its services. It follows that a) there must be working definitions of quality of service, for example, Porter's Healthcare Value, defined as outcome divided by cost; b) there must be systems implemented to measure, in an ongoing manner, the elements of clinical, social, and behavioral health interventions that can be aggregated to compute quality of service as defined; c) there must be implemented systems that allow alternative component configurations (protocols, processes, procedures) to be continually tested; and there must be systems to correlate measured quality with component configurations to provide evaluations that humans can employ to help select the most promising options. A prerequisite for such conditions to prevail in such a system is that sufficient organization and infrastructure exist to support their implementation. The CRS infrastructure of Fig. 5 must be extended to satisfy these requirements in order to become a true learning healthcare system.

5.3 *Pathways Community HUB*

The Pathways Community HUB model is a delivery system for care coordination services provided in a community setting (28). The model is designed to identify the most at-risk individuals in a community, assess modifiable risks, connect them to evidence-based interventions to mitigate risks, and measure the results (17). Specific nationally standardized pathways spanning medical social and behavioral health are utilized to track each specific risk identification including mitigation success, failure, and time to completion. Community care coordination works to coordinate care of individuals in the community to help address health disparities including the social barriers to health.

The Pathways Community HUB model is a construct that enforces threaded distributed tracking of individual clients experiencing certain pathways of intervention, thereby supporting coordination of care and fee-for-performance based on end-to-end outcomes (Redding et al. 2018). As an essential by-product, the pathway concept also opens up possibilities for system-level metrics that enable more coherent transparency of behavior than previously possible, therefore greater process control and improvement reengineering.

Zeigler (2016) developed a *Coordination Model* that abstracts essential features of the Pathways Community HUB model so that the kind of coordination it offers can be understood and employed, in a general SoS context. This allows development of a M&S framework to design, test, and implement such coordination models in a variety of SoS settings, exemplified by healthcare, that present the issues that such coordination models address. Formalization provides a firm basis for capitalizing on the transparency that is afforded by the Pathways Community HUB model

(Redding et al., 2018). Such pathways were represented as DEVS atomic models with implementation in the form of an active calendar that combines event-based control, time management, and data architecture capabilities (Zeigler et al., 2016). Further, such DEVS Pathways can become components of coupled models, thereby enabling activation of successors and sharing of information. Such pathway models represent steps in a pathway as states that can constrain steps to follow each other in proper succession with limited branching as required; external input can represent the effect of a transition from one step to next due to data entry. Moreover, temporal aspects of the pathways, including allowable duration of steps, can be directly represented by the DEVS atomic model's assignment of residence times in states.

The Pathways Community HUB model is being implemented in 40 community networks in eight states. The span of care coordination services extends from infancy through adults and elders. Health, social, and behavioral health factors are all required components of risk identification and mitigation. Initial publications have described and demonstrated improved outcomes and reduced cost of care (Alley et al., 2016; Redding et al., 2015). The Pathways Community HUB Certification Program (PCHCP) within the PCHI holds the national standards and certification of HUBs and has committed to modification of the standards based on the available scientific evidence. The model is currently deployed in programs focusing on maternal and child health, adults with chronic disease, the justice involved, behavioral health, substance abuse disorder, high-risk elementary students, and others.

5.4 Risk Registry

Effective modeling and simulation outcomes research is clearly needed to produce the guiding registries to inform the risk mitigation interventions and payment approaches to improve health and economic success, starting with the most at-risk individuals and families. Such research is needed to identify the signature combinations to screen for supporting laser targeting of individuals and families with specific, relationship empowered risk mitigation interventions with proven predictive improvements in health and cost. The same modeling can inform hospital systems, social service, childhood education, strategies for parenting intervention, and related learning and behavior change approaches. The breadth of US health and social services fits well within the strategic analysis of identified and addressed risk. There is no current tracking or accountability for risk identification and mitigation. Consistent with Toyota production methodology, LEAN production strategies, and value chain analysis (Porter and Teisberg, 2006), this new strategic taxonomy, work item tracking, and evaluation structure can help health and social services produce outcomes using the driving and quality-focused approaches in American business. Research is needed to help in finding the granular meaningful chunks of outcome which can then be linked together in value chain analysis.

Multiple national research centers, policy centers, and a network of community initiatives are engaged in research to develop the initial and ongoing registry of trajectory intelligence for modifiable risks. The intent is to inform policy and payment approaches to address risk mitigation. Research lines include:

- Continued growth of the risk registry and validation of the registry contents, as well as the development of educational and training representational forms of the registry.
- Modifiable risks that must be mitigated with learning-based (behavior change) focused interventions represent more than one third of the total registry of risks. These risks that include critical factors such as safe sleep, nutrition, parenting, childhood education support, medication compliance, and many others represent a substantial contribution to the outcomes the health and social service system seeks to improve. The positive effect of supportive professional relationships that serve to personally engage and substantially modify the learning-based risks is a critical component that has been built into successful care coordination approaches (Agency for Healthcare Research and Quality, 2016). It is known that community engagement and involvement of community health workers in these transformative efforts play essential roles in the culturally competent, interpersonal relationships that empower and support behavior change and the related risk reductions achieved as part of coordination of care (Redding et al., 2018).
- Characterization of individually modifiable risks (need of a medical home, medication adherence, clothing) and household risks (lack of housing, utilities, food access) in contrast to population risks (such as lack of housing supply, racism, neighborhood safety). Clarifying this taxonomy of risks further in the published literature will substantially improve our ability to share strategic information and improve the effectiveness of our efforts to focus programming and payment on the specific components of the system where there are gaps. For example, high recordings of incomplete pathways in Ohio for homeless expectant mothers are helping to provide specific numeric data to inform the need for the population-level interventions needed to increase the overall supply of housing in communities.
- Continued development of appropriate metrics for pathways and the comparison of their effectiveness in pay-for-performance in contrast to Healthcare Effectiveness Data and Information Set (HEDIS), shared savings, and others.

6 Davis Global Simulation Center, Omaha, Nebraska

A simulation center and state-spanning network is well under development centered at the University of Nebraska Medical Center in Omaha. The Davis Global Center is a highly advanced clinical simulation facility purposefully designed to foster the practice of patient care in highly functioning and effective interprofessional

teams. The Center provides realistic replicated healthcare settings in which teams can practice and experiment safely. Its mission (iEXCEL) is improving human performance and effectiveness in healthcare by providing "Next-Gen" training that is early and throughout a lifetime of training. The aim is to develop a truly interprofessional training model (nurses, doctors, pharmacists, allied health, public health, dentistry, etc.) and work together, using simulation to do hands-on (experiential) procedures, team training, complex medical scenarios, etc. Simulated care is patient centered with special focus on "hand-offs" from one provider or team to a second. Training is to be outcomes-oriented, i.e., competency-based (including communication, professionalism, value-based care, etc.) using XReality (Wikipedia XReality) including holographic technology to foster innovation, new ways of learning, patient care, etc. A high capacity/high speed network that connects across the state (and globally) provides state-wide outreach using digital and visual technologies (remote and distributed learning.) The simulation facility attempts to replicate the entire healthcare system (home to hospital and back!) which includes the following capabilities:

- Advanced simulation – including in situ live, virtual, constructive exercises
- Surgical and procedural labs
- XReality Labs – including immersive environments (CAD walls, interactive digital walls, 5-sided CAVE, etc.)
- Clinical test bed for research and development using simulation and visualization
- Disaster preparedness training and emergency management skills
- Biocontainment and infectious disease readiness training
- Data capture capabilities (enabling computation of metrics for human performance)

7 Conclusion

A design for a model-based system-of-systems design for HIT infrastructure can support innovative high-level coordination of the coordinators. We described existing foundations for implementing such a design such as digital platforms, pathways-based community coordinator organizations, risk factor registries, as well as comprehensive simulation facilities where the design and its components can be tested. Challenging research and development based on modeling and simulation are required to enable integrating such foundations into a working whole. Research in population management coordination of coordinators, risk registry, and comprehensive simulation facility will be particularly motivated in applications that require integration of all three. For example, in learning-based risks, development of appropriate learning pathway resources in which new parents are supported to achieve parenting strategies is proven to reduce adverse childhood events, decrease protective service involvement, and improve school performance. This intervention combined with identifying and addressing interlocking risks of access to medical

care, housing, food, and others can be coordinated through interaction with all agencies related to baby care, care team providers, and health workers. Team-based providers of care as well as the individuals and families served can be educated though virtual reality simulation critical to achieve the behavior change of parents.

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