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Technology Management Maturity Assessment Model: An Exploratory Multi-criteria Approach for Healthcare Organizations

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***Abstract*-Maturity Models are organizational management tools that have been developed and used for decades as organizations' way of responding to the constant pressure of trying to achieve and maintain competitive advantage through concurrent innovation, quality improvement, and cost reduction. The decision makers in the healthcare industry have been no exception in reaping the benefits of determining the merits and weaknesses of strategies through systematic quality improvement provided by maturity models. Although there are many healthcare maturity models in literature, there is a lack of models that provides managers and decision makers with a systematic, multi-criteria, and quantifiable maturity model. This paper proposes an exploratory model to assess technology management maturity in healthcare organizations by using Hierarchical Decision Model (HDM). The model may help health organizations with pinpointing their strengths and weaknesses in the adoption and implementation of new technologies and technological approaches such as Learning Health Systems (LHS) and their socio-technical infrastructure, while giving them organizational and competitive self-awareness and guide them in setting their strategies and resource allocation. The model will serve as a much-needed technology management tool for hospitals to assess their technology management maturity for both public and organization's advantage in a more effective way.**

I. INTRODUCTION

The healthcare organizations in United States have been trying to handle problems such as significant time-gaps in the transformation of innovations in practice, high costs of care and medical errors and are constantly racing against time to be aligned with the goals of healthcare which are improving quality of care, patient experience of care, provider satisfaction, lowering the cost of care, and expanding access to care in [1], [2]. They need to maintain control over the mentioned issues to be able to keep on with the competition. Furthermore with the shift towards Value-based care, providers are paid based on their patient outcomes rather than the amount of care which is provided by them[3]. For health organizations this means that there is a significantly higher need of keeping track of different metrics in different areas of care. The hospitals are now encouraged to eliminate or reduce errors which may harm patients, adopt evidence based care standards and protocols that result in best patient outcomes, modify hospital processes to elevate patient experience, increase care transparency, and consequently provide higher quality of care at a lower cost [4]. As a result of these changes, health and government organizations are coming to realize that they are not always effective in managing the care process due to different reasons such as technological limitations and management deficiencies [5]. As one of the solutions to some of these shortcomings, Maturity Models have been used to bolster organizational management. Healthcare organizations constantly need to achieve and maintain competitive advantage by innovating, while concurrently stay on top of the other goals already mentioned. Therefore, there is a constant imperative to develop maturity models in order to assist decision makers to assure the alignment of initiative with goals [6]. Maturity models can be used to address different problems as they enable organizations to have a better structured approach in mitigating their shortcomings. With the use of these models, decision makers are provided with a sense of self-awareness and can come up with roadmaps to clarify where they are and where they need to be in different areas and pinpoint strengths and opportunities [7]. These roadmaps can bolster health organizations efforts to adhere to Centers for Medicare & Medicaid Services (CMS) and its Hospital Value-Based Purchasing Program (VBP) in order to improve their clinical outcomes and benefit from the improved reimbursements continuously. Learning Health Systems (LHS) has been lauded as one of the ways in which health organizations can keep up with these changes [1]. In LHSs, healthcare systems are aligned with continuous improvement and innovation from scientific, informatics, incentives, and culture aspects and knowledge about best practices is consistently captured, assimilated, and embedded within the system [8]. Maturity models may be great tools in keeping track of the progress health organizations make and managing their continuous improvements while adopting LHSs.

Although maturity models were initially used in software related applications, healthcare organizations have also been using them as organizational management tools. Normally, the result of using these models is different levels/stages of maturity and activities/checklist items that they encompass. However, few studies focus on multiple perspectives of care and healthcare organizations simultaneously and even fewer provide any quantifiable scoring system where healthcare organizations can actually measure their improvements and the areas of strengths and opportunities. This paper will propose an exploratory technology management maturity model in healthcare which considers the multidimensionality of technology management in healthcare organizations while potentially bolstering the

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decision-making process by having the ability to be quantified and compared throughout time for more traceability, transparency, and accountability in healthcare organizations. Different perspectives and their sub-criteria affecting the maturity models in healthcare technology management (in the case of learning health systems) are mined from literature and Hierarchical Decision Model (HDM) has been used to prioritize these factors.

II. Technology Management Maturity

The maturity models are instruments to facilitate organizational management [9].These models have been used with different goals and purposes for benchmarking system development or organizational management for years. Maturity models have been proven to be useful in a myriad of different fields such as software, system engineering, project and program management, energy management, technology roadmapping, healthcare technology management and other areas with goals of facilitating process improvement [10]–[17].

In the field of software, Paulk et al. (1993) came up with Capability Maturity Model (CMM) which could be used as a maturity framework for bolstering organizational processes with goals of development and management of software and it encompasses five levels of maturity including initial, repeatable, defined, managed, and finally, optimizing [11]. The Software CMM has been replaced by CMM Integration (CMMI) since 1997, which integrates System Engineering with Software Engineering and Integrated Product Development in a single model [10]. Also in the project management side, there are maturity models such as OPM3, P3M3, and the project management maturity model. The P3M3 has the same levels compared to CMM model with the exception that the first step in P3M3 is awareness instead of initial. However the project management maturity model includes common language, common processes, singular methodology, benchmarking, and continuous improvement as its maturity levels [12] [18].

A. Technology Management Maturity in Healthcare

Maturity models have also been used for in the healthcare domain specifically in the information system technology sector [9]. There models such as IDC's mobility maturity model for mhealth and models such as HIMSS maturity model for electronic medical records (EMRAM), patient record/content management maturity model (Forrester model), and maturity model for electronic patient record (EPRMM) for the field of electronic medical records [15], [16], [19], [20]. There have been other maturity models designed for different fields in healthcare such as interoperability, infrastructure IT, data warehousing, analysis networking, telemedicine, and usability among other [17], [21]–[25]. **Error! Reference source not found.** presents a myriad of maturity models in areas such as software, energy, systems engineering, project management, road-mapping, and different sides of healthcare and their number of stages in terms of maturity.

As for LHSs, a mature system is defined as a system that generates timely actions to the information that it derives (or it can be derived) from data in order to create meaningful measurement regarding system learning [26].

III. Learning HEALTH sYSTEMS

The term Learning Health Systems (LHS) was coined by National Academies of Medicine in a 2007 [8]. A LHS is associated with some characteristics.The patient information, experience, and characteristic of every consented patient is an opportunity for the health system. Furthermore, evidence and scientific based knowledge regarding best practices are immediately available to help with the decision-making processes in order to ensure continuous quality improvement. Finally, the LHS way of thinking becomes a piece of the employees' and stakeholder's culture through appropriate leadership as a part of a socio-technical infrastructure [27]. Milstein (2013) stresses the adoption of LHS as one of the things that United States needs to pursue to cut down care costs [28]. As for the adoption of LHSs by healthcare organizations, many stakeholders and factors are involved. These factors can range from areas such as government legislations, funds, and initiatives concurrent to the acceptance of its culture in terms of organizational and personal levels. The role of community and socio-technical infrastructure among many other aspects cannot be forgotten[1]. However, although many health organizations consider themselves as a learning one, there is no way of measuring their performance and maturity in terms of efficiency and effectiveness. Therefore, a model that can quantify the different aspect of the organization's movement towards becoming a learning system and assist decision-makers in prioritization and allocations of their strategies and resources respectively can be beneficial to health organizations. It can give them a sense of where they are in their specific goals, where they want to be, and then gives them a better perspective in choosing how to get there.

Table 1: Maturity Models in Different Areas

Model	Area	Stages	Reference
CMM/CMMI	System Engineering Capability, Software Engineering and Integrated Product Development	5	[10], [11]
OPM3	Organizational Project Management	Binary	[29]
P3M3	Portfolio, Program, and Project	5	[18]
Project Management Maturity Model	Project Management	5	[12]
Energy Management Maturity Model	Energy Management	5	[13]
Roadmapping Maturity Model	Roadmapping	6	[30]
Roadmapping Influence model	Roadmapping	4	[14]
Quintegra Maturity Model for Electronic Healthcare (eHMM)	Healthcare Information System Technology	7	[24]
IDC Healthcare IT (HIT) Maturity Model	Healthcare Information System Technology	5	[15]
IDC's mobility maturity model	Healthcare, mHealth	5	[15]

HIMSS Maturity Model for Electronic Medical Record (EMRAM)	Healthcare, EMR	8	[25][16]
HIMSS Continuity of care maturity model (CCMM)	Healthcare, Healthcare Information System Technology	8	[5]
Patient records/content management maturity model (Forrester Model)	Healthcare, EMR	3	[20]
Maturity Model for Electronic Patient Record (EPRMM)	Healthcare, EMR	6	[19]
NEHTA Interoperability Maturity Model (IMM)	Healthcare, Interoperability	5	[21]
NHS Infrastructure Maturity Model (NIMM)	Healthcare, Infrastructure IT	5	[22]
Healthcare Analysis Adoption Model (HAAM)	Healthcare, Data Warehouse, Analysis	9	[17]
Hospital Cooperation Maturity Model (HCMM)	Healthcare, Networking, Cooperation	4	[6]
PACS Maturity Model (PMM)	Healthcare	5	
Telemedicine Service Maturity Model	Healthcare, Telemedicine	5	[23]
Healthcare Usability Maturity Model	Healthcare, Usability	5	(HIMSS, 2018.)

IV. METHODOLOGY

A. Hierarchical Decision Model

The Hierarchical Decision Model (HDM) was initially proposed by Cleland and Kocaoglu in 1981[32]. HDM is a methodology to analysis strategic decisions in a hierarchical structure by formulating consensus among participants who are mostly experts in specific areas related to decisions. It is mostly applied for evaluating alternatives or selecting best fitting options in order to accomplish an objective previously specified [33]. Munkongsujarit et al. (2009), argues that HDM aids the decision maker by presenting the decision problem as a hierarchy of problems that are more facilitated in terms of handling [34]. This model breaks the various elements of the problem down to simpler sub-problems in a way that the decision problem morphs into a hierarchy [35]. HDM is a tool used in a decision making to rank and evaluate the available alternative that are available followed by determining the most suitable choice among them [34]. It is a tool that assists decision makers in quantifying and incorporating quantitative and qualitative judgments into a complex problem [35].

In the general form HDM has five levels named as Mission-Objective-Goal-Strategy-Action (MOGSA), yet there is no restriction on the numbers of levels, but elements at the same level have to be "preferentially independent". As HDM structure is set, pair-wise comparisons among sub-elements for each branching nodes are made. The weights of each criterion are derived from pair-wise comparisons. Thus, in the generalized form of HDM researchers need to make pair-wise comparisons among objectives, goals under each objective, and strategies under each goal separately (Figure 1) [36], [37].

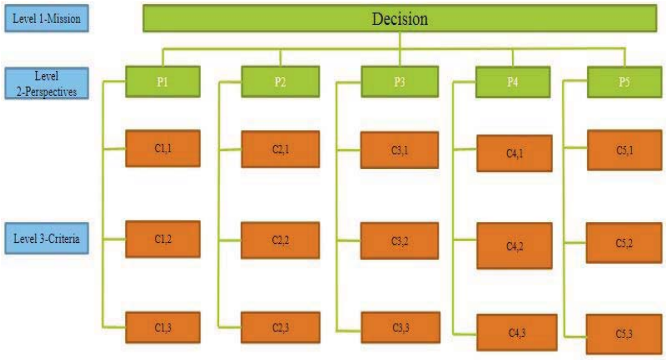

Figure 1: Hierarchical Decision Model (HDM)

With the intention of evaluating alternatives, performance scores of alternatives for each criterion are required as well. Performance scores can be determined by using scoring for scalar scores or desirability functions for discrete scores. A desirability function is a transformation function which converts actual performance value to a score ranging from 0 to 100 based on market desirability or expert opinion[38].

Simply, HDM breaks down contributing factors to an objective into perspectives and criteria on different hierarchical levels and enables the analysis of contribution of each factor or criterion to the objective. Then each option is evaluated in terms of the criteria to have a final point of achieving the objective, between 0 and 100 [39]. Final score for each alternative is calculated by using Equation below:

$$M = \sum_{K=1}^{K} \sum_{JK=1}^{JK} P_K \times C_{(jk)} \times D_{(jk)}$$

Where:
M: Maturity Score
Pk: Weight of Perspective (k), k=1...k
Cjk: Relative importance of Criterion (jth) for Perspective (kth) (k), j=1…j and k=1...k
D(jk): Desirability value (Maturity Assessment Value) of Criterion (jth) for Perspective (kth) [37].

Each item in the hierarchy is given weights. Each item will have a "global" weight against all other items, and a "local" weight within the category it belongs to. Then, the alternatives are evaluated against the lowest level of the hierarchy, which is the decision criteria, to find the best decision possible.

The experts evaluate criteria hierarchy and alternatives by conducting pairwise comparisons, with constant-sum measurement scale (1–100 scale) for comparing each two elements. For example: each expert can evaluate the perspectives through pairwise comparison similar to the following example: (P1 40:60 P2), which means, in terms of importance, Perspective 1 is less important than Perspective 2

with the ratio of 40 to 60. All experts will do the same for perspectives and criteria under each perspective. Then, based on HDM mathematical formulas, the experts' evaluation will be aggregated in order to calculate the weights of perspectives and criteria, with the total sum of 1, for each level within the hierarchy and on the whole hierarchy. As well as weights for the alternatives against each other for each criterion. And a final score for each alternative in compare with the other alternatives based on the aggregated evaluations of all experts, to find out the best decision possible [36], [39].

HDM also includes the calculations for disagreement, inconsistency, and sensitivity analysis in order validate the reliability and robustness of the final model [36], [37], [39]–[42]. Additionally, in instances which there is a need in having a reusable model, or in instances of having many alternatives, desirability curves can be used. The combination of desirability curves with HDM is used to identify levels/ metrics for each criterion. Each level/metric connected to a criterion acts as a useful value to assist decision makers. Using desirability curves approach, the experts need to evaluate related levels/metrics for each criterion (desirability matrix) while giving each metric a scaled quantitative value. This enables the normalization of the evaluation results by experts across all the criteria (Figure 2/Table 2) [40], [41], [43]. In order for the desirability curves to be used, there is a need to identify each criterion's metrics/levels. Following this, the experts are asked to assign quantitative values to each level/metric and the number assigned (the average desirability in case of having more than 1 expert) will be the maturity assessment value.

Figure 2: An Example of Desirability Curves

TABLE 2: METRICS/LEVELS FOR STAKEHOLDER TRUST DESIRABILITY CURVE

Metric/Level	Desirability
Stakeholder Impasse	0
Support by Minority of Stakeholders	20
Support by Half of the Stakeholders	50
Support by Majority of Stakeholders	75
Support by Overwhelming Majority of Stakeholders	100

V. THE MODEL

Based on the literature review which identified the defined perspectives and criteria the initial hierarchical model is presented in Figure 3.

Table 3 provides the definition and descriptions for the perspectives taken into account in this model and Table 4 through Table 8 provide information on the sub-criteria for each perspective while providing the references for the studies which they were mined from during the literature review process.

A. Perspectives

As it has been discussed by some studies in the literature, adoption of a socio-technical approach such as learning health systems is multi-dimensional procedure [1]. Furthermore, maturity of different projects and technology in healthcare need to be assessed from different angels. Table 3 demonstrates the different perspectives that are going to be considered in this study. Each perspective has been chosen based on the existing literature on this topic and contain a number of sub-criteria.

TABLE 3: TECH MANAGEMENT MATURITY MODEL IN HEALTHCARE PERSPECTIVES FOR THE CASE OF LEARNING HEALTH SYSTEMS

P	Definition
Technology	This perspective covers topic such as data management and handling of technology in terms of infrastructure, security, privacy, and knowledge flow and sharing in healthcare organizations.
Social	This perspective encapsulates topics such as public acceptance, trust, accessibility, equity, and engagement. The stakeholders can take the shape of patients, providers, policy makers, payers, and physicians. This perspective also includes the ability of healthcare organizations in attracting and acquiring skilled workers and talents.
Organizational	This perspective covers certain organizational aspects of technology management in healthcare such as leadership, change management, organizational culture and transparency, strategic management, and quality improvement.
Regulatory	This perspective includes regulatory and legal aspects needed to assess the maturity of technology management in healthcare organizations (LHS) such as governance, regulative and legal influences, and standard compliance.
Financial	This perspective encapsulates the financial side of assessing the maturity of technology management in healthcare organizations. Topics such as investment resource allocation, funding, and cost reduction fall under this category.

1) Technological

As the implementation of technologies and approaches like LHS need socio-technical infrastructures, assessing the maturity and adoption of its technological side is very important. The adoption of EHRs, advances in fields such as genomics and wearables facilitating the collection of big data for health systems. Health organizations need to keep track of their technological adoption maturities and make sure that the maturity they are seeking is aligned with effectiveness, efficiency and better patient and cost outcomes.

The technological perspective covers topic such as data management and handling of technology in terms of infrastructure, security, privacy, and knowledge flow and sharing in healthcare organizations.

TABLE 4: THE TECHNOLOGY PERSPECTIVE'S CRITERIA

P	C	Definition	References
Technology	Data Management	Management of big data resources in terms of security, privacy, and ethics	[44][45][46][47][48][49][50]
	Supporting Infrastructure	The socio-technical infrastructure needed to improve and provide capacity to capture, compile, and protect clinical, care delivery process, and financial data which enables the evaluation, adjustment, analysis, and dissemination of learned knowledge	[51][47][52][53][46]
	Real-time Knowledge Access and Sharing	Data systems and tools used to capture, share, and integrate data, information, and knowledge gained from biomedical, clinical, and managerial research into the organization in real-time.	[47][45][54][55]

2) Social

As one of the main goals of health organizations is to deliver safe, efficient, and accessible care to patients, patients are involved in processes as an important stakeholder. Therefore, they need to trust and be invested with the approaches organizations choose to tackle their problems and improve in terms of quality. On the provider side of things, health organizations need to attract skilled employees to be able to come up with timely solutions and actually implement the strategies they are seeking.

TABLE 5: SOCIAL PERSPECTIVE'S CRITERIA

P	C	Definition	References
Social	Stakeholder Trust	Ability to realistically elaborate to stakeholders (patients, providers, payors, policymaker, purchasers, families) the need for LHS, the current limitations (without undermining any of their roles) that it will mitigate through a system which supports clinical and translational research, public health information, and comparative effectiveness.	[56][57][58][53]
	Accessibility	The degree to which public is benefiting from the advantages of LHS through its availability and encouragement and incentivizing of sustainable participation of the stakeholders while addressing inequalities.	[44], [45][53][58]
	Stakeholder Engagement	The degree to which a health system can engage stakeholders (patients, providers, payors, policymaker, purchasers, families)	[52], [53][47][59]
	Talent Acquisition	Organization's ability to acquire talented staff in different areas (physicians, nurses, researchers, data scientists, managers, public health promoters, epidemiologists, administrative staff, …)	[60][58][61][62]

The social perspective encapsulates topics such as public acceptance, trust, accessibility, equity, and engagement. The stakeholders can take the shape of patients, providers, policy makers, payers, and physicians. This perspective also includes the ability of healthcare organizations in attracting and acquiring skilled workers and talents.

3) Organizational

The path towards a better healthcare service needs leadership. Some health organizations may have no shortage of funding and technological infrastructure but may still fail in their attempts to achieve their goals in different areas. An efficient and effective organizational culture can bolster the positive maturity that an organization needs towards getting better.

The organizational perspective covers certain organizational aspects of technology management in healthcare such as leadership, change management, organizational culture and transparency, strategic management, and quality improvement

TABLE 6: ORGANIZATIONAL PERSPECTIVE'S CRITERIA

P	C	Definition	Reference
Organizational	Leadership	Broad leadership which has the ability to expand stakeholders' commitment to the goals of learning health systems.	[47][45][60][54][44][63]
	Strategic Management	Health systems ability to improve through mergers and expansions, managing competing priorities, research partnerships, and problem identification and solution	[46][54][53][45][64]
	Organizational Culture and Transparency	The level to which an organization (in all levels) has adopted and committed to the culture of LHS and continuous improvement and is transparent to safeguard stakeholder trust to bolster the health of individuals, communities and diverse populations through training and inclusiveness.	[53][8][65][45][44][66][47][8][67]
	Quality Improvement	Organizations ability in conducting research implementation, process and quality improvement, and healthcare delivery evaluation	[68][69][70][71][72][73][74][75]

4) Regulatory

Although care has become more compatible with individual patient needs (with goals of population and patient outcome betterment [76]) in the recent years, the regulatory and legal climate in United States' healthcare system is still unpredictable. From the other side, the governance is needed be provided to support sustainable operation for standard setting, building and maintaining stakeholders trust and ongoing innovation stimulation. Last but not least, healthcare organizations are always under significant scrutiny to adhere to compliances and regulations. These all make the regulatory and legal side of health organization maturity assessment a very important one.

The regulatory perspective includes regulatory and legal aspects needed to assess the maturity of technology management in healthcare organizations (LHS) such as governance, regulative and legal influences, and standard compliance.

TABLE 7: REGULATORY PERSPECTIVE'S CRITERIA

P	C	Definition	References
Regulatory (Legal)	Standards Compliance	Organization's adherence and compliance with standards and regulations to ensure clarity for stakeholders, easier analysis, aggregation, interoperability while conforming to meaningful use and joint commissions	[56][65][77][60][8][78]
	Regulative and Legislative Influences	Organization and system's flexibility in adapting to new regulations and legislations in terms of sensing and adaption (in terms of resource, policy, strategy, and management).	[79][54][80][78]
	Governance	The governance which is necessary to support sustainable operation to set required standards, build and maintain trust with stakeholders and ongoing innovation stimulation	[44][45][46][8]

5) Financial

One of the most important metrics and outcomes that healthcare organizations can evaluate their performance based upon is their financial performance. The shift from fee for service to value based systems in hospitals has totally shifted the priorities and initiatives for reducing costs and increasing efficiency. Hospitals need to actually keep the patients out of the hospital by making sure they are healthier through different initiatives and follow-ups upon their release from hospital.

Furthermore, maturity assessment is connected to the financial side of the management as many strategic decisions and resource allocations can be bolstered by better assessment of organization's current and desired positions.

The financial perspective encapsulates the financial side of assessing the maturity of technology management in healthcare organizations. Topics such as investment resource allocation, funding, and cost reduction fall under this category.

TABLE 8: FINANCIAL PERSPECTIVE'S CRITERIA

P	C	Definition	References
Financial	Resource Allocation	Organization's ability to prioritize and decide to invest its resources in which aspects of LHS. Balancing Resource Investments	[81][53][82][61]
	Incentives (Funding)	The level to which incentives and funding are aligned with encouragement of LHS, continuous improvement, waste elimination, and rewarding high care value.	[83][54][79][8][61]
	Cost Reduction	Organization's ability to cut costs through learning, continuous improvement, waste eliminations.	[47][84][65][8][85][67]

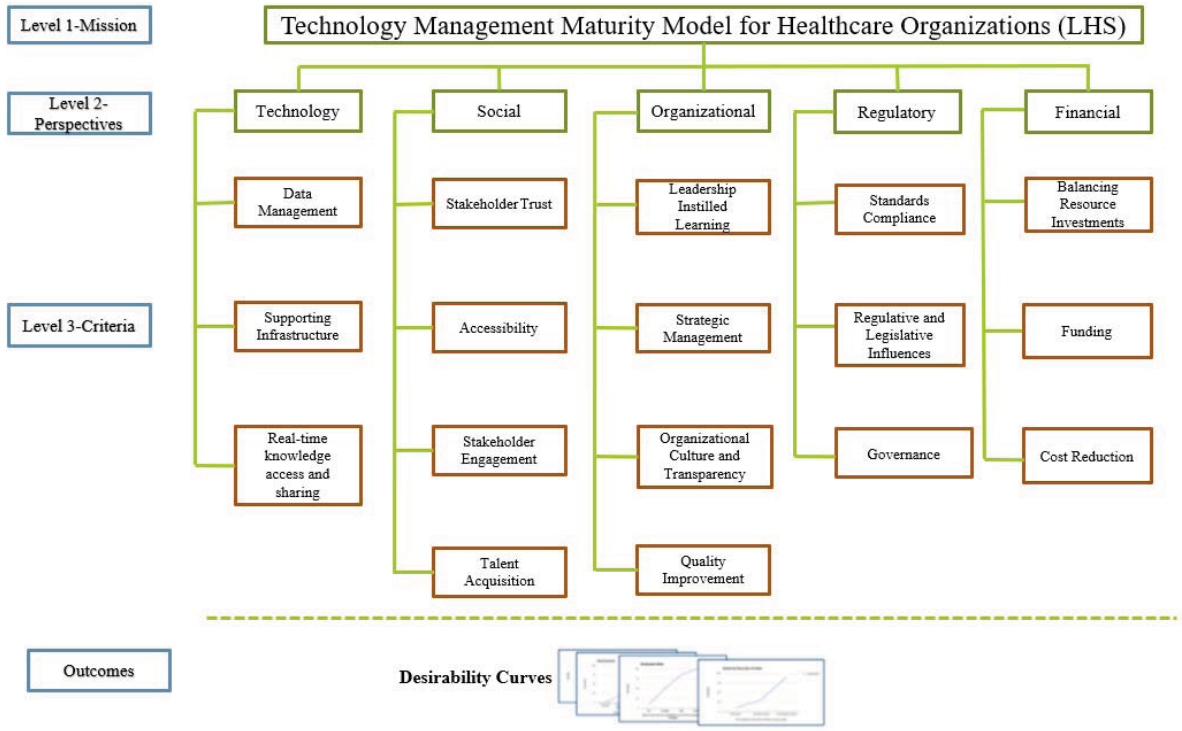

Figure 3: The HDM model for Technology Management Maturity Mode for Healthcare Organizations for the case of Learning Health Systems

VI. Discussions

This part will discuss the limitations and future research regarding this study. As it will be discussed, this is the initial step in building this model and thus, this paper serves as the introduction to the exploratory model and does not include the model quantification. As it is shown in the research framework (Figure 4), future research includes model validation and quantification followed by results and analysis.

Figure 4: Research Framework

A. Limitations/ Future Research

This research is only a first step towards implementing the proposed healthcare maturity model. Future studies will focus on actually quantifying this model using experts in this area. Experts will be chosen using different methods such as social network analysis (SNA), and researchers' connections. It should be taken into account that all experts may not be in all panels. In other words, experts will divided into panels and each expert will be matched and assigned to a certain area of the proposed model of this research in terms of validation and/or quantification. This means that each expert is able to join more than one panel based on relevant expertise. In other words, the model will be validated and quantified by experts following this research and then results will be analyzed. Furthermore, although this research is focusing on the case of Learning Health Systems specifically, it can be modified and adapted to accommodate other new healthcare related technologies and thus, able to be generalized to other areas.

VII. Conclusions

This research contributes to the technology management body of knowledge on technology management maturity assessment in the healthcare industry while delving deeper into how healthcare organizations can achieve a sense of self awareness in terms of where they are and where they need to be in dealing with their technology management issues. More specifically, this research aims at increasing the knowledge on how healthcare organizations assess the implementation and adoption of becoming a learning health system by proposing a technology management maturity model assessment tool. According to the literature review and gap analysis conducted in this study, there is a lack of structured and comprehensive understanding of the managerial issues around the maturity assessment of technology management in healthcare generally and more specifically in the growing and imminent field of learning health systems which can bolster the continuous quality improvement goals of the healthcare organizations.

The research introduce an effective mechanism to assess a hospital's maturity in terms of adoption and implementation of the learning health system mentality and philosophy. This research will attempt to reach its goal through the identifying of weak areas within the firm, which probably will undermine the adoption and implementation of LHS in a hospital that is already trying adopt this mentality or has intents of becoming a learning health organizations. This assessment model will help health organizations classify and organize their priorities and bolsters their judgment in terms of actions needed to be taken to achieve the goal of becoming and staying a learning health system in all frontiers.

This maturity model can result in a better decision making in health organizations and can be used as a step in the right direction in reaching better results regarding patient satisfaction, quality care, and cost of care.

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