J Med Syst (2012) 36:201–221
DOI 10.1007/s10916-010-9459-2

ORIGINAL PAPER

A Knowledge Based Search Tool for Performance Measures in Health Care Systems

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Received: 10 December 2009 / Accepted: 1 March 2010 / Published online: 14 April 2010

Abstract Performance measurement is vital for improving the health care systems. However, we are still far from having accepted performance measurement models. Researchers and developers are seeking comparable performance indicators. We developed an intelligent search tool to identify appropriate measures for specific requirements by matching diverse care settings. We reviewed the literature and analyzed 229 performance measurement studies published after 2000. These studies are evaluated with an original theoretical framework and stored in the database. A semantic network is designed for representing domain knowledge and supporting reasoning. We have applied knowledge based decision support techniques to cope with uncertainty problems. As a result we designed a tool which simplifies the performance indicator search process and provides most relevant indicators by employing knowledge based systems.

Keywords Performance measurement · Health care performance · Indicator search tool · Performance measurement ontology

Introduction

Measuring and assessing performance of health care systems is becoming one of the major concerns of many countries [1]. Although there are various studies undertaken by governments, nonprofit organizations, accreditation bodies, care providers and so on, we are still far from having accepted performance measurement models in both measurement indicators and assessment methods [2–4]. There are a number of reasons for this deficiency. Firstly, each health care delivery system has unique features. Countries have different health care systems, even within one country. Performance measurement models are context dependent and designed to meet special requirements of their health care system. Next, each measurement has a target of improvement, defined by stakeholders, and confronts certain problems of health care delivery such as effectiveness, safety, and acceptability. Lastly, health care providers are complex organizational structures and processes. A measurement model and an indicator can only reflect a partial view of the overall picture [5, 6].

To cope with these problem areas, researchers and developers are seeking comparable health care performance measurement and assessment models [7, 8]. There are several framework studies including the OECD Health Care Quality Indicator (HCQI) project, performance assessment system designed by the World Health Organization Regional Office for Europe (PATH) [9, 10]. These attempts are limited by indicators from one country or only cover certain levels of health care system [11, 12]. As a result, there is still a need for a comprehensive tool that can support performance measurement development processes.

Performance measurement in health care is relatively a new study area. Although many organizations seek to find good indicators for measuring their systems, there are not many attempts for supplying that need. In 2000, National Quality Measures Clearinghouse sponsored by Agency for Healthcare Research and Quality (AHRQ) established a public repository for quality measures. The developed tool called CONQUEST serve as data storage for quality measures which is categorized by set of dimensions such as indicators related to a disease conditions, developed by

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certain organization, its type, so on [13]. Although it is a useful tool for searching indicators by using categories, it does not provide a relation between health care settings and performance indicators. Therefore performance indicators only can be search according to predefined values sets. However, decision makers like to search for performance measurement indicators relevant to their care setting. In most cases decision makers are manager and they do not have to know details such as type of the indicator, or which organizations develop for what purposes. They can only define their health care setting and ask for relevant measures. Our system develops health care delivery and performance measurement ontologies in order to match different care providers in diverse health care settings. Performance indicators are related with their care settings by using these ontologies. Although ontologies and semantic networks are popular in medical terminologies such as UMLS, medical decision support systems, and knowledge representation in clinical guidelines [14], this study develops the first ontology in health care service delivery and finance domain.

In our study, we have employed the decision support methods to provide an indicator search tool for developers from different health care systems with various target improvements. This tool will help the domain expert to identify appropriate performance measures for his specific requirements. In this study, we first analyzed 229 performance measurement studies from literature and developed an original theoretical framework to compare individual and institutional performance measurement models. Analyzed studies were stored in a database in a structured way and theoretical framework is represented as a semantic network which forms the knowledge repository. Next, we developed a decision support tool. Our tool provides user interfaces for capturing specific measurement requirements from the users. These requirements were matched with health care settings via fuzzy modeling techniques of the semantic network. Resulted queries were formed and posted to the database. As a result, users can display the most relevant performance indicators and their referenced measurement studies within their own context.

Method

In first phase of this study, performance measurement health care reports from various countries are examined. Aim of this phase is to collect data for populating our knowledge repository. In order to obtain non bias distribution of measurement studies we employed a structured method for selecting related studies. Scopus academic search engine was used with the keyword "performance measurement" and "health care" or "healthcare". The search returned 815 studies from 436 journals. These studies were classified according to journal type and publication year. Letters, reports, conference papers were eliminated and 229 articles with a publication date of post-2000 were selected. The selected studies are first analyzed and categorized with the developed theoretical framework and then each measured entity is defined in our knowledge repository. And lastly performance indicators employed in these studies are stored in our performance measurement database in relation with measurement studies.

Clearly these selected 229 measurement studies cannot be able to cover all performance indicators meeting specific requirements for diverse care settings. There are many valuable studies which are not published in the form of manuscript. Also there might be other articles not indexed by Scopus academic search engine, or left out of our scope due to the preferred keywords. However, this structured search returned adequate data for populating an initial performance measurement studies knowledge base. This knowledge base can be extended by further searches or by collecting reports of measurement studies from various countries in future.

In second phase of study we have developed a knowledge base decision support search tool in health care performance measurement domain. During the system development phase we have constructed domain ontology for health care delivery system and performance measurement, employed networks to represent knowledge, and used classical and fuzzy modeling techniques for mapping user requirements to dimensions of our knowledge base. This section gives brief explanation of employed techniques.

Decision support systems are categorized under five groups based on dominant technology that drives or provides the decision support functionality. These are communications-driven, data-driven, document-driven, knowledge-driven and model-driven decision support systems [15]. In our study we have developed a knowledge driven system based on domain knowledge. Knowledge based systems are human centered systems which attempts to understand and initiate human knowledge in computer systems. A knowledge base system has four main components: a knowledge base, an inference engine, a knowledge engineering tool, and a specific user interface [16].

In a knowledge base, acquired knowledge can be represent in many forms, such as frames, decision trees, ontologies, production rules, and so on. In this study, we represent our acquired knowledge with a domain ontology. Ontology, as a word, refers to systematic analysis of knowledge of some domains of interest, so that it can be shared by others. It is a formal explicit representation of concepts in a domain, properties of each concept describes characteristics and attributes of the concept known as slots [17]. Domain ontologies captures the essential concepts and relationships among those concepts in particular application areas and provide descriptions of concepts in a domain of discourse, their properties, relationships among concepts and axioms [18, 19]. In actual applications, an ontology represents a set of vocabulary which consist of terms that are used for capturing the conceptualization of the domain and the identification of specific classes of objects, their properties, and their relationships [17]. Ontologies are typically used on the semantic web and software engineering applications [20].

Semantic networks are one of the formal representation forms of domain ontology. They are directed graphs consisting of nodes with connecting arcs, which represent relationships between nodes. The nodes are labeled with descriptive text, representing the concepts, and the arcs are often labeled with a relationship type. Semantic networks can have an expressiveness equivalent to first order logic. Semantic network formalism is used both for knowledge representation and processing. They can support inference through an interpreter that manipulates internal representations. [21, 22].

In our system Protégé environment is employed as ontology editor. The Protégé was first built in 1987 as a meta-tool for knowledge base systems. In the last decade Protégé has been continuously evolving and improving to provide an ontology engineering environment that supports the implementation of knowledge-based systems. The current version, Protégé -2000, can be run on a variety of platforms, supports customized user-interface extensions, incorporates the Open Knowledge-Base Connectivity (OKBC) knowledge model, interacts with standard storage formats such as relational databases, XML, and RDF [14, 23]. In this study, the Protégé 2000 is used for defining domain ontology, generating a knowledge-acquisition, and integrating components of knowledge-based system by defining mappings.

Fuzzy logic provides an inference structure that enables the human reasoning capabilities to be applied to knowledge-based systems. Fuzzy inference formulates suitable rules and based upon the rules the decision is made. Fuzzy inference uses if-then statements, and the connectors present in the rule statement are “or” or “and” to make the necessary decision rules. The basic fuzzy inference can take either fuzzy or crisp inputs, but the outputs that produced are almost always fuzzy sets. When a crisp output is desired a defuzzification method is adopted. The most important two types of fuzzy inference method are Mamdani’s fuzzy inference method and Sugeno or Takagi–Sugeno–Kang method. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas others employ linear functions of input variables as rule consequent [24, 25].

Results

Conceptual framework

In the first phase of study, we designed a multidimensional conceptual framework to identify features of performance measurement studies. This original framework enables us to compare different performance measurement studies from various care settings and health care systems. As a result of our literature analysis, we conclude that performance measurement studies have four main strata. Basically we can refer them as; stakeholder, data, indicator and target levels. These layers are abstracted in Fig. 1.

The uppermost layer is called the target layer. To improve performance, decision makers need to be able to measure the extent to which the system contributes to desired outcomes [26]. In health care domain, performance concept covers the improvement of systems functions through the multidimensional, definable and measurable targets [9]. Measurement targets are set to improve one or more relations between different stakeholders for a desired set of goals. Therefore, studies are defined and related with each other by their target improvements, so called dimensions of measurement. The conceptual framework is designed to classify performance measurement studies. The target layer of our conceptual framework has three main units; name of target improvement also called dimension, stakeholder perspective indicates the active role of stakeholders, and type of the performance studies. One study typically targets more than one dimension, and is generally designed for the needs of one of the stakeholder types. Table 1 gives the list of dimensions, stakeholders and type of works covered in this study.

Indicators layer is the sublevel of target stratum. Performance indicators are quantitative measures that reflect health care systems performance by means of process and outputs [27]. Performance measurement examines the overall system functionality by measuring the pieces of the processes. Therefore, performance indicators give only indirect information with an abstraction. Each indicator corresponds to one or more target dimensions. For that reason, each measurement intrinsically corresponds to a set of targets. Indicator stratum of our conceptual framework composed of title, type, nominator and denominator of the indicator. Donabedian classification model is implemented to define types of indicators. It classifies indicators into three as structure, process and outcome. Structure indicators correspond to means and resources utilized in their production of health services. Quantity and qualification of health personnel, as well as geographical distribution, existence of regulatory programs such as quality guidelines are considered as structural measures. Process indicators refer to all interactions

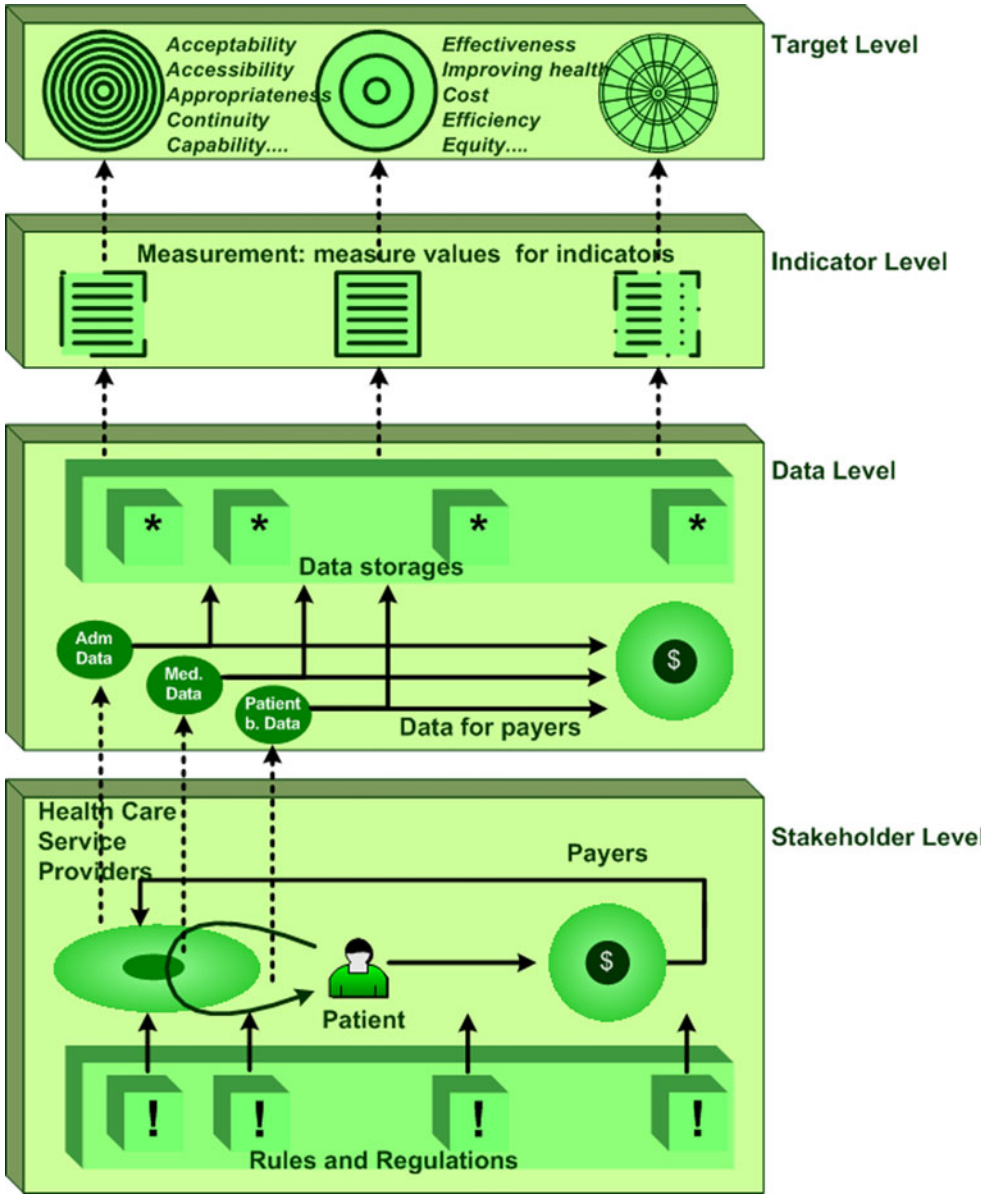

Fig. 1 Layers of the performance measurement

between service providers and patients; whereas outcome indicators refer to pros and cons observed as a result of health care processes. Outcome of a service was comprised of both physical and perceived benefits such as improvement in health status, satisfaction from the service, having health related information and changing habits in preserving personal health [28].

Data layer represents available types and sources of information. Structure and architecture of a performance measurement are closely related with underlying categories of data types. Data types are categorized as medical data, administrative data and patient based data. Medical data includes all types of medical records and all other medical oriented sources such as discharge reports, MRI images, registries, and so on. Administrative data are related with billing information, such as claims. On the other hand patient based data refer to data obtained directly from the patient via questionnaires and interviews. This type of data reflects patients' subjective evaluation on their health status or satisfaction levels [6]. Another data layer is the source of data. Information could be retrieved from various sources. Qualifications of these sources are a key factor that affects architecture of measurement studies. Data could be obtained from the original source such as information systems. Alternatively reports and cumulative data sources could be utilized. Claims and quality reports could be named as main types of reporting. Conversely demonstrative examples of cumulative data sources could be given as data warehouses and registries where data are collected for statistical or governance purposes [29].

In a health care system, stakeholders have complementary relationships with each other. Payers reimburse providers for

Table 1 Attributes of the theoretical framework

Target level	
Target improvement	Acceptability, accessibility, appropriateness, care environment and amenities, continuity, competence or capability, effectiveness, improving health or clinical focus, expenditure or cost, efficiency, equity, governance, patient centeredness or patient focus or responsiveness, safety, sustainability, timeliness, utilization.
Stakeholder perspective	Patient, provider, payer, regulator
Type of work	Development, enhancing, evaluating, measurement
Indicator level	
Title	Title of measure
Indicator type	Donabedian classification: structure, process, outcome
Indicator description	Numerator and denominator inclusion / exclusion
Data level	
Data types	Administrative data, medical data, patient based data
Data sources	Information systems and other sources, reports, cumulative data
Stakeholder level	
Service provision	
Delivery level	Primary, secondary, tertiary, etc.
Service provider	Family practice, specialties, hospital, clinics, networks, etc.
Continuity of care	[Preventive, curative, rehabilitative, public health]; [acute, chronic, sub acute, long term, etc]; [Inpatient, outpatient]
Disease	Diagnosis of disease: diabetes, hearth failure, etc.
Sub entities of provider	Environmental context: programs and policies, Inner system: Personnel, facilities and infrastructure, processes, equipment.
	Products: Received services
Reimbursement	
Payer	Payer organizations like Medicare, medicaid, state,etc., commercial, etc.
Reimbursement type	Managed care, fee for service, case/prospective payment, capitation and global/balanced budget, etc.
Other financial attributes	Pay for performance, etc.

given services; providers supply health services to patients; patients finance payers either with taxes or premiums. These relations form various delivery systems, organization types, and reimbursement types. From the perspective of performance measurement, it is important to understand the underlying dynamics between them [30]. With this in mind we have designed a stakeholder stratum for this purpose.

Stakeholder stratum is composed of two main parts; service provision and reimbursement. At service provision side, organizational structure of delivery, type of service provider, sub entities of provider, continuity of care and disease are considered as attributes. Organizational structure both covers the Dawson model that reinforces a patient flow from primary care to tertiary care, and other country-specific mechanisms [31, 32]. Service provider type simply refers to the title of provider such as family practices, specialist, hospital, and so on. However, same provider title could function diversely in a different country's health system. Similarly, different providers may accomplish same functions. Therefore, each provider should be evaluated together within continuum of care. Continuum of care is conceptualized as a range from preventive care to long term care. Diverse performance programs are applied for each niche of the continuum of care spectrum [33, 34]. Another attribute of the service provision sub layer is disease type. Today disease management has become one of the major study area of health care performance [35, 36]. As a consequence, in our conceptual framework, performance studies based on a specific disease group are considered as a classification attribute.

Providers sub entity concept is a contribution of our conceptual model. Each provider can be defined by its environmental context, inner system, and products. Performance studies focus one or more of these areas. Measurement studies that focus on environmental context, cover performance of insurance policies such as health plans, or applied programs such as pay for performance programs. Inner system of a provider consists of processes, facilities and infrastructure, and personnel. Processes cover all regulations, such as total quality assurance programs, clinical guidelines, and so on, that arrange the way of the service provided [37]. Lastly services are the output of the health care process, either as a change in health status or as a perceived benefit.

Second part of the stakeholder stratum is reimbursement. Payers of health care vary from one system to another. Local state, national state, insurance companies, and so on, could be source of payment. Another important concept is how these payers reimburse the health services. Performance measures are developed for different models like managed care, managed care, fee for service, case/prospective payment, capitation and global/balanced budget, and so on. Beside these structural attributes, there are new payment polices such as pay for performance or pay for reporting. These features of the health care reimbursement systems are covered in our conceptual framework [30, 31].

Main attribute titles and their set definitions of the conceptual framework layers are given in Table 1.

Architecture

Our search tool aim to find best match performance measures for specified care setting and targets. Studies show us various performance measures are applied in highly diverse care settings. For a health care manager or a researcher it is impossible to evaluate all similar health care systems by means of service provision or reimbursement characteristics. By using this tool, each user defines their performance targets and key concepts of their health care system. And tool searches the knowledge base for similar examples, and return best match performance indicators. Advantage of this architecture is that, users could retrieve all semantically related performance indicators from the care setting of all over the world, even though they have not known the features of countries.

Graphical user interface is designed to capture user performance requirements and characteristics of their health care setting. However since users are not always a health service domain expert their health care context definition would have incompleteness and imprecision problems. They would be able to define some of the features of their health care setting, some of the organizational structure, and some the elements of payment system. Beside some of the defined attributes might be misstated or might be ambiguous. This incomplete and inaccurate set results to an uncertainty problem. To handle this uncertainty we have proposed knowledge based fuzzy modeling techniques.

The basic idea behind our design is to simplify the search process for end users and provide most relevant information by employing knowledge based system. The search tool has four main components. First one is requirement capturing part. In this part we design detail and easy to use user interfaces which help system to identify context and targets of the users. Interface is composed many subunits such as properties of health care delivery system, available data sources, organizational structure and financial rules. Each requirement is captured with certain degree of importance which will form degree of membership in the fuzzification step. Captured requirements are posted to the knowledge repository to form database queries.

Knowledge repository component has a semantic ontology represented in the form of networks. This network represents patterns of beliefs, causalities and inferences beside the generalization or subsumption relations. User requirements corresponds the leave nodes of the semantic network. However performance measure database has more general attributes. Therefore a backward chaining with fuzzy inference method employed for deriving queries in the third component.

Finally derived queries are posted to the relational data storage component which is called as performance measures database. Database is searched for matching patterns by employing association rules. Returned set is displayed to user with confidence and support values. Figure 2 represents architecture and basic flow of the performance measure search tool.

Ontologies

We have utilized semantic networks for representing properties of health care delivery systems and diverse performance targets. Protégé ontology editor and knowledge base frame work, developed by Stanford University, is

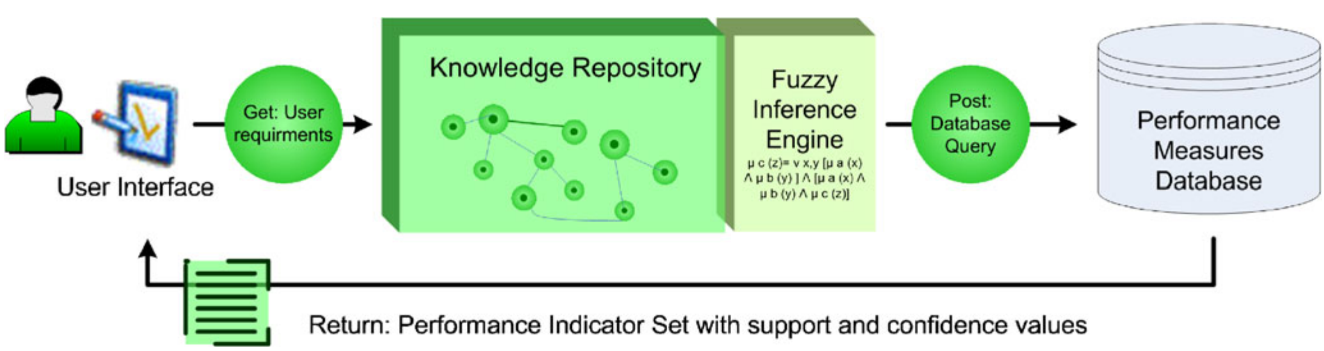

Fig. 2 Architecture of the performance measure search tool

utilized both for developing a health care delivery system and performance measurement ontologies in health care domain [38]. Concepts and systems are presented in patterns of interconnected nodes and arch. Semantic net representation is used both to represent domain knowledge and to support an automated system for easoning.

We have constructed our knowledge base in four main parts, including two domain ontologies and two knowledge repositories. Figure 3 shows these parts in Protégé. First domain ontology called 'delivery system' represents health care delivery system and the relations between the main stakeholders in this system. Second domain ontology named 'performance measurement' and captures characteristics of performance measurement studies. Those ontologies are based on conceptual framework presented in former sections.

We have also developed a 'health systems knowledge base' and a 'performance measurement knowledge base' by using Protégé. Each case of performance study is defined performance measurement knowledge base, and the related countries' systems are defined in health systems knowledge base.

Cases are populated into two parts. Firstly a knowledge repository for health care systems is formed. In this part, country systems are defined with the dimensions of delivery system ontology. This part can be extended as new cases from different health care systems are covered. Later, each performance measurement study is defined. Dimensions of delivery system and performance measurement ontologies are used in defining characteristics of each case. Defined cases are also related with the corresponding entries in health system knowledge repository. Cases are named with regard to identification codes of measurement study, measured entity and utilized performance indicators. Detailed descriptions of these identification codes are stored in database.

In following sections we will explain each part of knowledge base and describe its dimensions in detail.

Delivery system ontology

As we mentioned in our conceptual framework, health care delivery systems have four main actors: patients, payers, providers and regulators in every system. Providers deliver health care services to patients, customers, and also healthy peoples; expenditures of providers are compensated by payer organization; payer organizations finances directly or indirectly from population. Having these basic roles, various types of health care delivery system can be represented. In some cases payer and provider organiza-

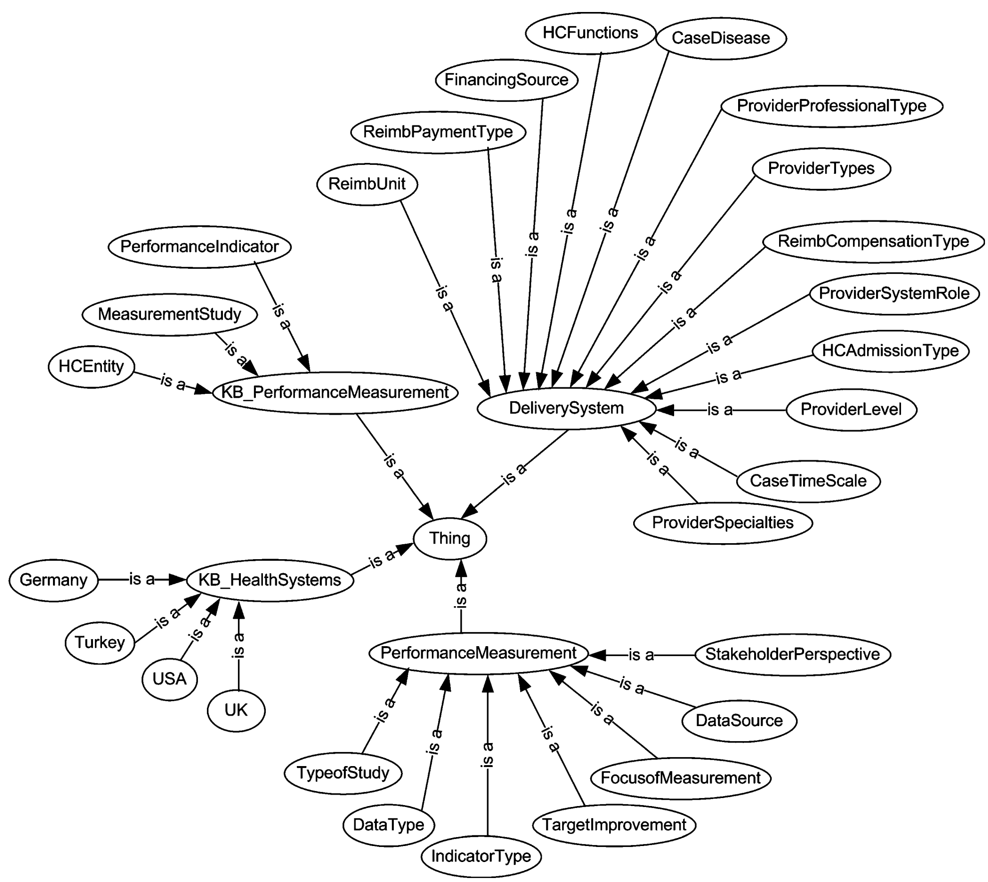

Fig. 3 Four main parts of the domain ontologies and knowledge based implemented in Protégé

tions are the same where as in others they are separated; in some cases patients are directly purchasing health care plans where as in others financing provided by taxes from the pool of general government, and so on. Regulators, some cases these are governmental institutions or in other cases they are initiatives, set up rules of both health care financing and delivery.

In our ontology, we have represented health care delivery system components and the relations between them in five sub domains. These sub domains correspond to collection of financing sources, reimbursement of providers, provider characteristics in health care system, delivery processes, and status of patients by means of their health status. Figure 4 present this representation. Dashed regions corresponds a set of dimension in our ontology. Now we will briefly explain each of them.

The financing of health care is represented with sources of funding dimension developed in International Classification for Health Accounts (ICHA) by OECD. This classification is preferred since it is design to serve increasingly complex regulations of health care financing in OECD countries with a wide range of institutions involved. This ICHA-HF three digit classification sets a basic distinction between social health insurance and other health insurance. Social insurance is either organized and controlled at various levels of government or organized privately [32].

Reimbursement systems can have many variations and these variations might coexist in one health care system. By this terminology we cover all form of money allocation to provider of care by health care payer (governments, insurers, patient, so on). In order to classify diverse reimbursement system we refer to Jegers and friends' classification [39]. Jegers and friends propose a typology with basic dimensions of retro-versus prospective and fixed versus variable systems. They also suggest that unit of financing can be another classification dimension. With related to that study we have defined three dimensions for classifying reimbursement systems.

First dimension is reimbursement type whether fixed or variable. A payment system is considered as 'fixed' when the reimbursed amount does not change as activities increase or decrease, and it is considered as 'variable' when variation in activities induces changes in payment. A reimbursement system can even be considered as more fixed (or less variable) as the unit of reimbursement is on a more aggregate level on the following continuum: per item-of-service, diem, case, patient, period [39]. Second dimension is compensation type of reimbursement systems. This can be retrospective or prospective. In a retrospective payment system provider's cost reimbursed ex post, where as in prospective payment systems provider's payment rates or budgets are determined ex ante. Third dimension is unit of reimbursement. There are many different units such as item of services, diem, case, patient, or period. In our knowledge base reimbursement systems are defined according to these three dimensions. Figure 5 presents a knowledge base entry of a case/prospective payment example under funds of social security.

Third part of the delivery system ontology is related with providers and their roles in the delivery systems. There are five dimension is defined related with the caregivers. First dimension classifies the type of the provider such as hospitals, offices of physicians, ambulance services, so on. We have employed ICHA-HP providers of health care services three digit classification for defining provider types [32]. Second dimension is level of provider whether it is a primary care giver, or secondary, so on. Beside the level providers further can be classified with their gatekeeper or referral role in the delivery systems. Moreover providers can be classified according to specialty of care giver and type of occupation such as medical doctors, dentist, and pharmacist, so on. In these dimensions we have utilized the list of the 'Accredited Specialties and Subspecialties' by The Accreditation Council for Graduate Medical Education

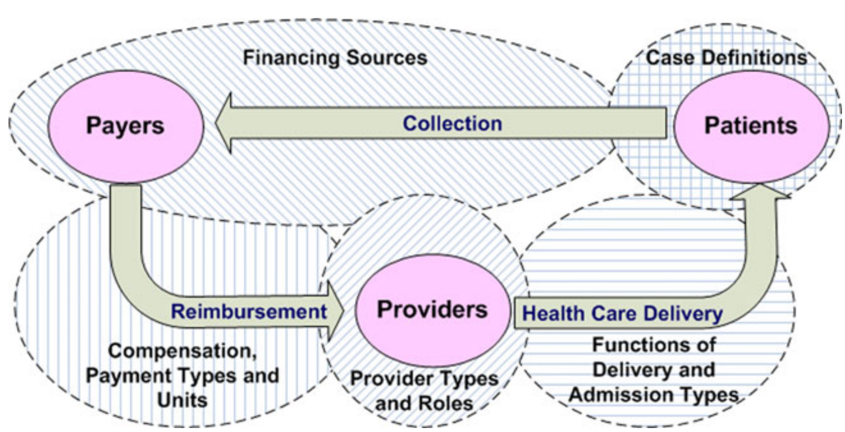

Fig. 4 Basic components of health care delivery and their representations in ontology

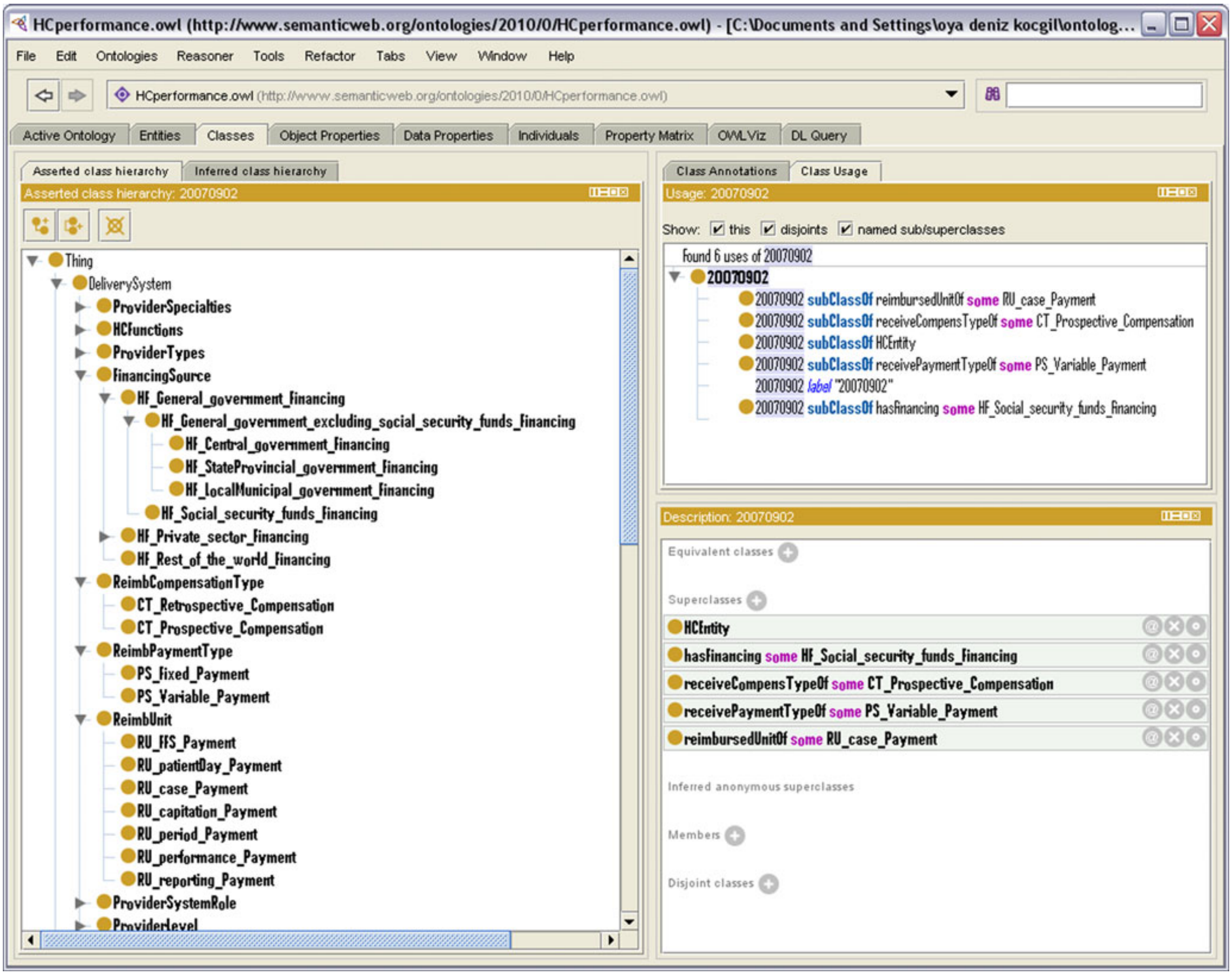

Fig. 5 Funding and reimbursement properties of a case/prospective payment example under funds of social security

(ACGME), which is responsible from the accreditation of post MD medical training program within the United States; and the classification of 'ISCO-88 the International Standard Classification of Occupations' by International Labour Organization (ILO).

Fourth part of the delivery system ontology is covers dimensions related with how health care is provided to patients. In this part we have defined health care functions such as curative, rehabilitative, long term, preventive, so on, by using three digit ICHA-HC health providers classification [32]. We have also classified admission types such as inpatient, outpatient and day care in a separate dimension.

Lastly, our ontology covers patient related issues such as disease type by using World Health Organizations (WHO) International Classification of Diseases (ICD 10) and time scale of disease such as acute, subacute, chronic and convalescent.

Table 2 presents dimensions of health care delivery system ontology and their coding and classification references. Each performance measurement study is classified according to these dimensions. For example, a study for assessing the accuracy of hospital clinical performance conducted in 449 acute care hospitals in two different states, California and Massachusetts, for patients discharged with an acute myocardial infarction (AMI), based of the medical record data of a cohort of elderly fee-for-service (FFS) Medicare patients aged 65–89 years at the time of their discharge was classified as follows:

Health Care Financing: Social security funds
Reimbursement Compensation Type: Retrospective
Reimbursement Payment Type: variable
Reimbursement Unit: per item
Provider Types: General hospitals
Provider System Roles: null

Table 2 Dimensions of health care delivery system ontology and their coding and classification references

Sub domains	Dimensions	Coding and classification references
Financing source	Health care financing	OEDC ICHA-HF Classification of Health Care Financing
Reimbursement	Compensation type	{Retrospective; Prospective }
Reimbursement	Payment type	{fixed, variable}
Reimbursement	Unit	{per item; per patient; per case; per diem; per period; pay for performance}
Provider	Provider types	OEDC ICHA-HP Classification of Health Care Providers
Provider	System roles	{gatekeeper; referral}
Provider	Level	{primary; secondary; tertiary; quaternary}
Provider	Health care professional type	ILO ISCO-88
Provider	Specialties	ACGME-Accredited Specialties and Subspecialties
Health care delivery	Health care functions	OEDC ICHA-HC Functional Classification of Health Care
Health care delivery	Admission type	{inpatient; outpatient; daycare}
Case definitions	Disease	ICD 10
Case definitions	Time scale of a disease	{acute; subacute, chronic; convalescent}

Provider Level: secondary
Health Care Professional Type: null
Specialties: Cardiovascular Disease
Health Care Functions: In-patient curative care
Admission Type: inpatient;
Disease: I21, I22
Time Scale of a Disease: acute

Performance measurement ontology

Performance measurement domain ontology defines characteristics of performance measures and their data sources. We defined each characteristic as a dimension in Protégé and related them with each other by using semantic nets.

In our performance measurement ontology an indicator might have attributes of focus and type. Figure 6 gives the semantic network representation of indicators. Focus refers to the scope of measurement by means of internal organization of service provider (such as processes, facilities and equipment, personnel, and so on). Type refers to Donabedian classification of an indicator as process, structure or outcome. Each indicator also serves as a means for a target improvement (such as acceptability, equity, and so on), and in knowledge base, instances of these indicators are associated with these targets.

All measurements use a data source. In semantic network, data sources are represented by their types (clinical, patient based or administrative) and their retrieval source such as surveys, reports, medical records and other medical data sources, registries and other cumulative data storages. Figure 7 presents the map of data definitions of the designed semantic network.

Performance measurement knowledge bases

Aim of this knowledge base is to provide information repository to system to make inferences. In this knowledge base, performance studies carried out in various countries are stored. When a new query arrived, inference rules are applied, and relevant studies with the given query is returned. By this way system supplies user the most relevant indicators with given health care setting. In order to enable inference mechanism, each entry to performance measurement knowledgebase is defined by the dimensions of delivery system and performance measurement domain ontologies presented above.

Performance studies are represented with a three tier structure. Fist measurement study is entered. Than the health care entity, such as service providers that measured in the study are populated. And lastly performance indicators employed for the measurement is defined. Relations between the tiers can be one to n, means that there can be more than one indicator for measuring health care entity, and also there can be more than one entity in a performance measurement study.

In the performance measurement domain we represent both care settings of analyzed systems and general concepts of the health services research domain. By archs we map each health care setting with general properties of service delivery. With the help of inheritance, we are able to define the health care systems of different countries in an effective way without duplicating data.

In performance measurement ontology, measurement instruments are represented as indicators. An indicator measures the performance of the provided care within a continuum of care and financial relations context. Therefore, we model these relations as interrelated concepts of

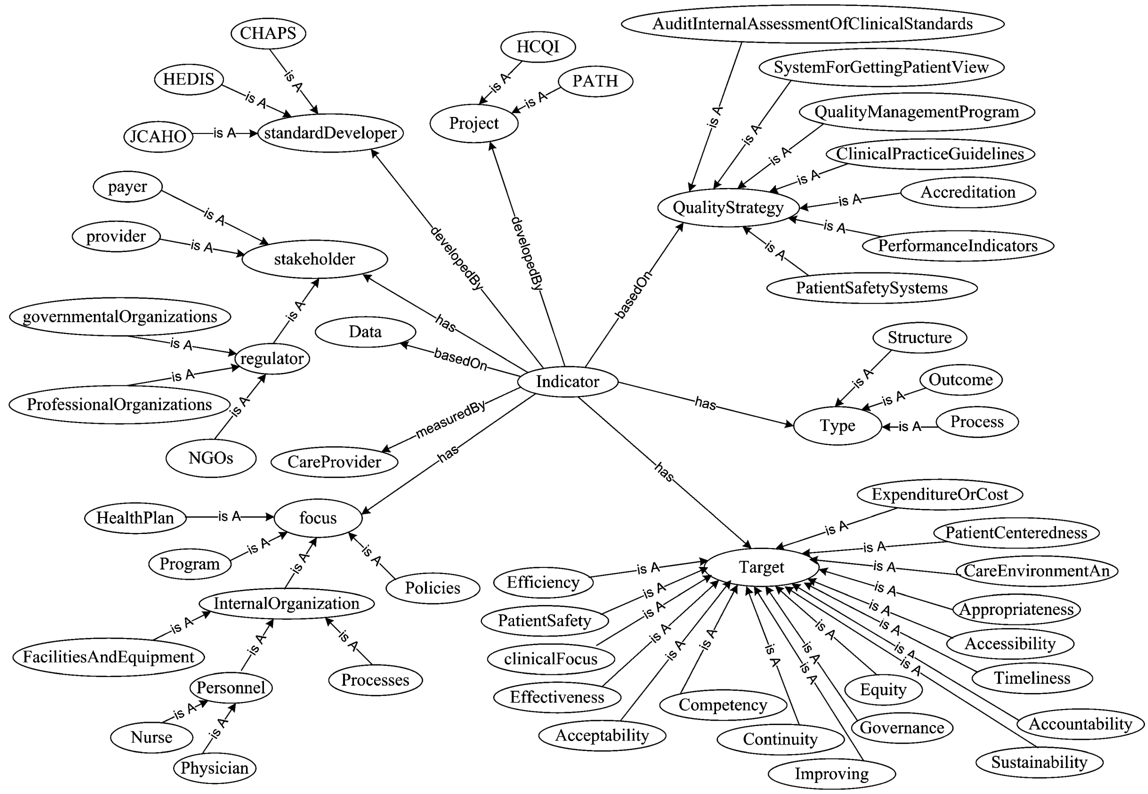

Fig. 6 Knowledge representation in semantics networks: indicator representation

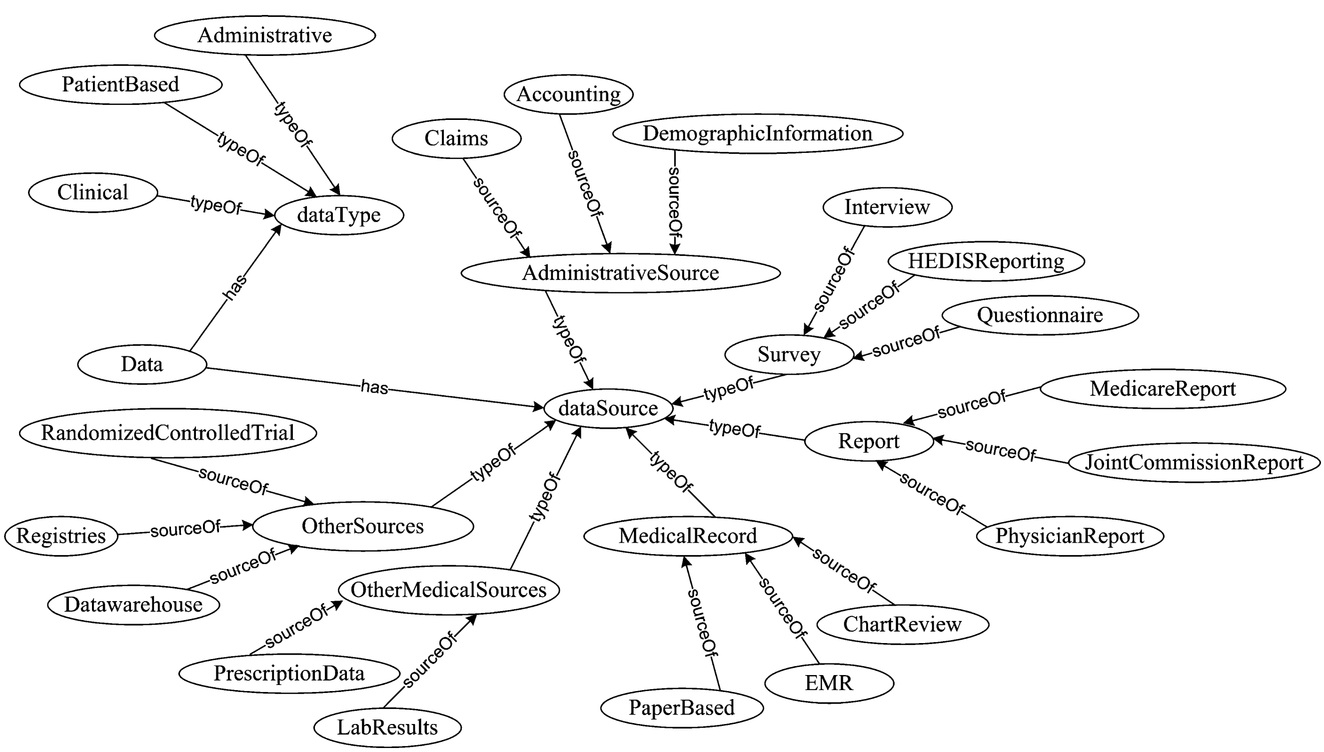

Fig. 7 Knowledge representation in semantics networks: data representation

health systems of country settings, care provider types in continuum of care and certain provision level (such as primary, secondary, and so on). Table 3 represents a model of continuum of care. Each performance measurement study case is analyzed and mapped by these nodes.

Patients are represented as having disease, referring to care provider with an admission type such as inpatient or outpatient. Patients who do not apply to any care provider are left out of scope.

Provider types are placed in continuum of care and level, and they are associated with their specific country settings. Figure 8 presents partial view of the designed semantic network displaying relations and hierarchies between provider types.

Health system knowledge bases

In health systems knowledge base, health systems of countries are examined and represented as nodes. We have limited this study with the scope of our performance measurement knowledge base. Only countries has performance measurement cases in our repository is included. This part of knowledge base can be extended a new cases are arrive. Each health system node is described by means of their financial attributes, and related with financial system types of our ontology. Financial system is concept composed of collection type (such as taxes, Premiums, Foundations, local governments) and reimbursement (fee for services or managed care) subcomponents.

Figure 9 present United States example. We represent US system with two type of classification. First one is plan types whether it is fee for service or managed care, second one is finance system. Finance systems covers public and private insurance, private payments and government sponsored programs. As it can be seen from Fig. 9 different types of systems such as HMOs, Veterans, PPOs, IPAs, Medicare, so on, classified according to these two dimensions. Other countries like United Kingdom, Australia, New Zealand, Turkey, and so on entered into health system knowledge base.

User interfaces

Performance measurement search tool can be used by various user types with diverse objectives. Although we need excessive amount of information about care settings and target of these users, it is important to minimize number of questions ask to increase efficiency and decrease imprecision problems. Therefore we developed profiling method.

In our profiling method, first main questions are asked to map user in to three dimensional profiles. Each profile has three components, as focus of performance measurement,

Table 3 Continuum of care

–	*Continuity of care*					
		Preventive services				
			Public Health System			
			Screening			
			Preventive care			
			Community health centers			
–		Treatment Services				
–			Ambulatory care			
				Community health centers		
				Urgent care		
–				Solo practitioner		
					Ophthalmology	
					Genecology	
					Cardiology	
					Dermatology	
					Gastroenterology	
					Pediatrics	
					General Practitioner	
–				Primary care practitioner		
					Family practitioners	
					Internal medicine	
					Obstetrics	
					Pediatrics	
					General Practitioner	
				Acute outpatient		
–		Acute institutional care				
–				Hospitals		
					Acute inpatient	
					Specialized hospital	
–					Departments	
						Clinics
						Urology
						Cardiology
						General survery
						……
						Intensive care
				Subacute		
–		Long term care				
–			Home and community based care			
					Supportive housing	
					Home care	
					Residential care	
					Assisted living	
–			Long term institutional care			
					Subacute	
			Psychiatric			
			Geriatrics			
			Assisted living			
			Nursing homes			
			Convalesant care			

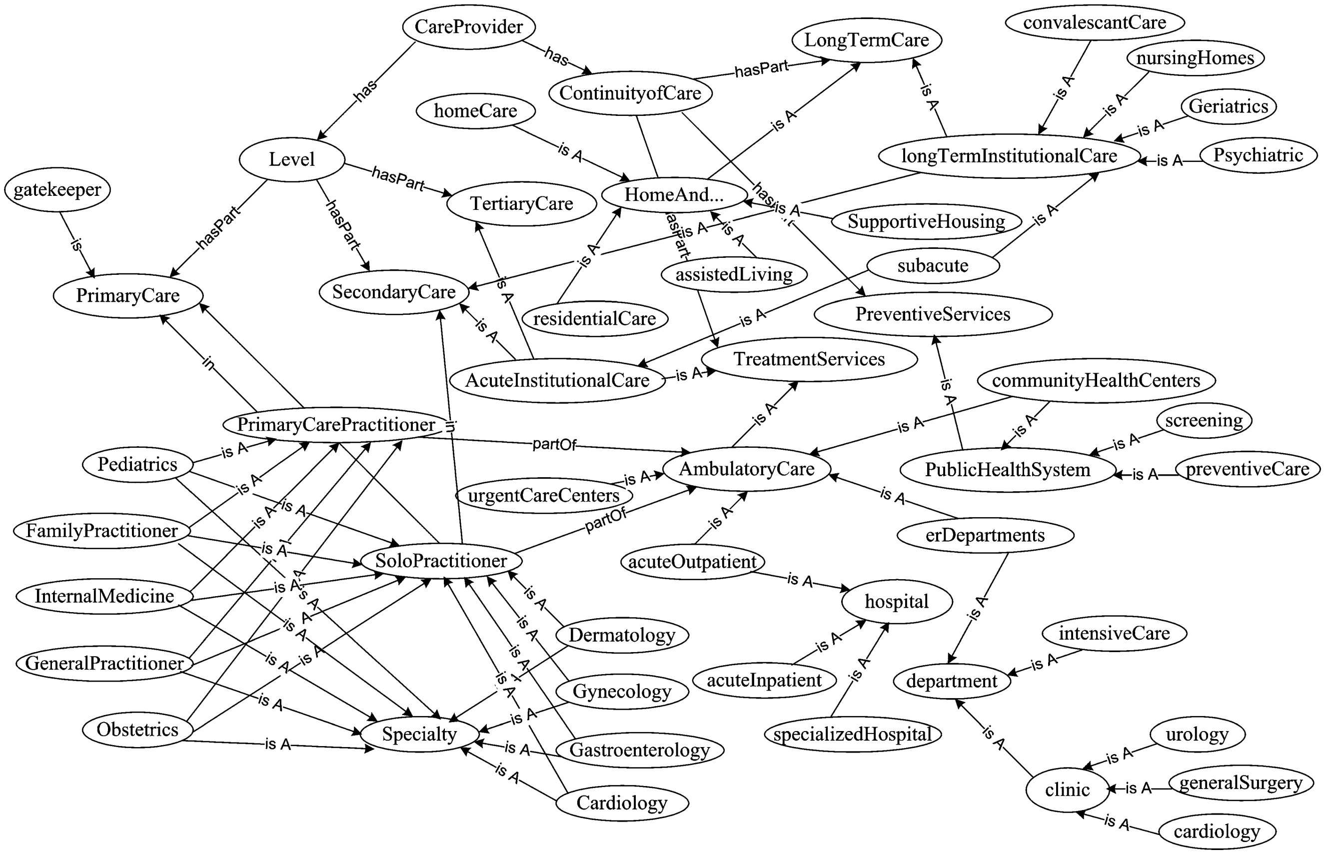

Fig. 8 Knowledge representation in semantics networks: continuity of care

main targets and the role of the user in the health care system. These components are shown at Table 4.

After profile finding, customized user interfaces are designed for getting information on care setting, health care system properties, reimbursement policies, applied programs such as pay for performance, as well as main problem areas, available data sources, and improvable areas of the health care delivery system. All main questions asked to user with an importance degree in order to capture fuzziness in the requirement set.

We have developed graphical user interfaces with java swing components. Figure 10 presents an example grafical user interface from the search tool.

Fuzzy modeling techniques

Main aim of the knowledge repository is transformation of captured user requirement to the queries for the data storage. As explained before, users define their requirements with a level of uncertainty. These requirements corresponds some of the nodes in our semantic networks with certain degree of fuzziness. However, our data storage contains performance measurement studies and indicators with a higher level of abstraction. Reasoning infers input nodes to output nodes to develop the queries.

As display in Fig. 10, we have applied fuzzy requirement capturing for users.

Delivery levels in health care research are generally classified as primary, secondary, tertiary. Although this conventional approach seems to be clearly distinguishing among different types of providers, boundaries of these levels are quite ambiguous. These boundaries are subject to discussion among different countries, even different health systems within one country. Therefore, we have introduced a new fuzzy approach to classify various providers of different health care settings in to one continuum of care. The fuzzy search mechanism of user interfaces is based on this approach.

In this fuzzy approach, we have first identified an ideal prototype healthcare provider for each level, based on given health care services, included specialties, and existence of inpatient outpatient admission. Then it is assumed that all real life providers are distributed linearly between these ideal providers according to similarities and dissimilarities.

To apply fuzzy search, users use scroll bar and locate slide any place between primary, secondary, and tertiary

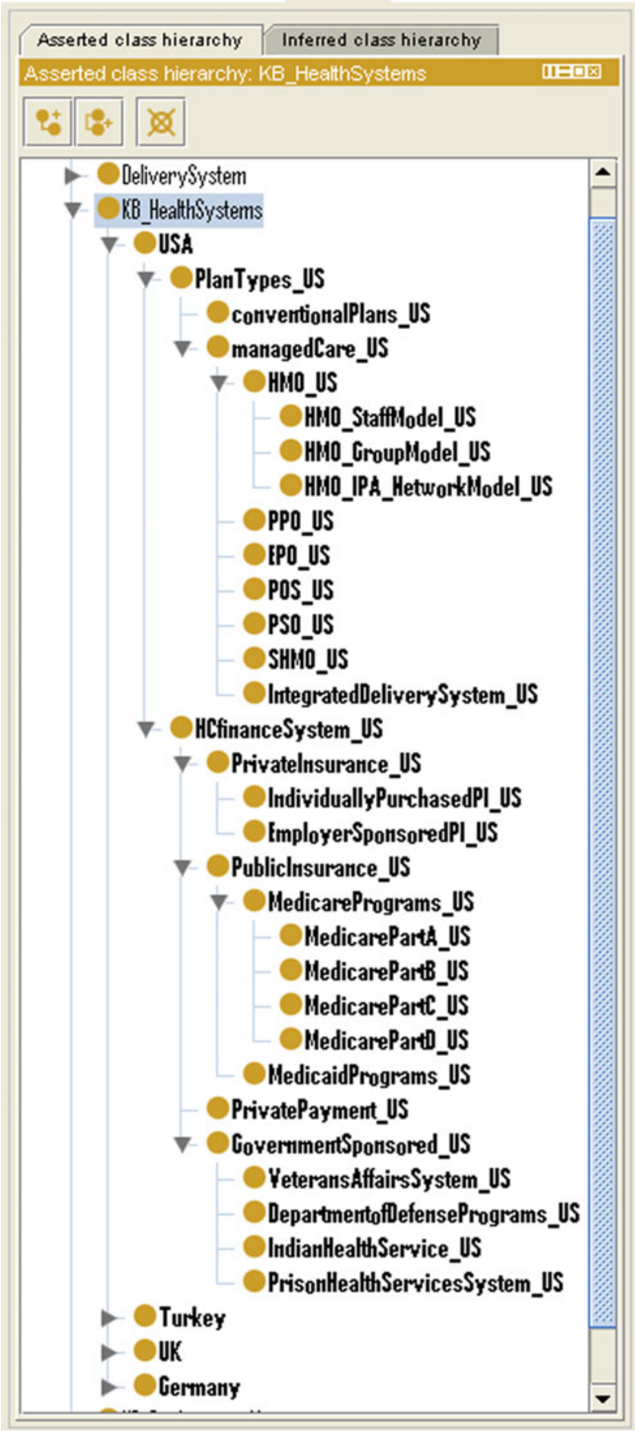

Fig. 9 Health system of United States

prototypes. Each position corresponds to a relative degree between different levels. Also each case in knowledge base has a calculated level value. The system matches between these relative degree values and calculated level values and returns closest cases within a range.

In most of the performance measurement studies, level of the measured provider is not explicitly stated. Therefore we have developed a systematic approach to determine calculated level values for these cases in knowledge base. This approach has been developed with reference to Turkish health care system, and utilizes dimensions of provider type, provider professional type, admission type and health care function. For each case, values of these dimensions are evaluated, and then a fuzzification process is applied for each rule set. Fuzzyified values of the rule sets are aggregated, and then by applying defuzzification process calculated level values are determined for each case.

Our fuzzy search studies are in progress. Studies on confirmation of parameters, tuning of membership values, and diversification of rules are ongoing. Details of this fuzzy search method are subject to another article, and only briefly can be mentioned in this manuscript.

Data storage

Performance measurement studies are stored in a structured way. They are preprocess and reviewed by using the designed theoretical framework. Their health care setting descriptions and indicators are identified. The obtained information is stored in a relational database.

In the database design, we implemented relations in denormalized form. We formed a fact table with reference dimension tables. Each dimension table corresponds to an attribute in the conceptual framework and also link with a node in semantic network. Fact table references these dimension tables and includes binary data for absence or presence of the referenced dimension. Although this design leads redundancy, it simplifies executing the association rules for each submitted query.

In present data storage is populated with 229 articles that obtain from literature searched mentioned in method part. In future search can be extended and number of performance measurement studies can be increased.

Evaluation of knowledge base system

We have evaluated the knowledge based tool by applying to the Turkish Health Care system. In this evaluation, firstly we have defined Turkish health care finance and delivery system with delivery system ontology, and then use our tool to infer relevant performance measurements. For the validation of system, we refer to field experts. We have asked experts whether the returned performance indicators are relevant with delivery units and they are useful for measuring performance of relevant health care systems. Experts verify that knowledge base system provides appropriate performance indicators and they are relevant with the specified health care units. In this section we will present the evaluation system on Turkish health care delivery and finance system.

Table 4 Components of profiling

Focus	Main target	Role
Clinical focus	Effectiveness , improving care	Physician/manager
Institutional focus	Resources allocations, efficiency	Physician/manager/stewardship
Patient focus:	Responsiveness, patient centerness	Stewardship/NGOs
Health system focus	Outputs, governance, equity, appropriateness	Payer/stewardship/NGOs

As first step we have defined Turkish health care finance system in our health system knowledge base. We have used delivery system ontology dimensions for defining the Turkish health system in Protégé. Before presenting the knowledge base descriptions, we will give a brief introduction to Turkish health care system.

Turkish health system is in a transition as a part of the government's reforms called Health Care Transition Programme. These reforms that begin in 2003 reorganize health care financing and delivery systems [40]. Hence reforms continuous, Turkey is in a transitions period, legacy and new items in system are coexist. Prior to 2003, the Turkish health system was characterized by the presence of several different public agencies funding and providing health care, some vertically integrated and others relying on contractual relationships. The funds derived from private and public sector sources were transferred to service providers; through Ministry of Health (MoH) , Turkish Army Forces, social health security schemes; Social Insurance Organization, the Government Employees Retirement Fund, the Social Insurance Agency of Merchants, Artisans and Self-Employed, and active civil servants, university hospitals, state economic enterprises, municipalities, other public institutions and establishments, special funds, foundations and private health insurance companies. There were also out of pocket payments.

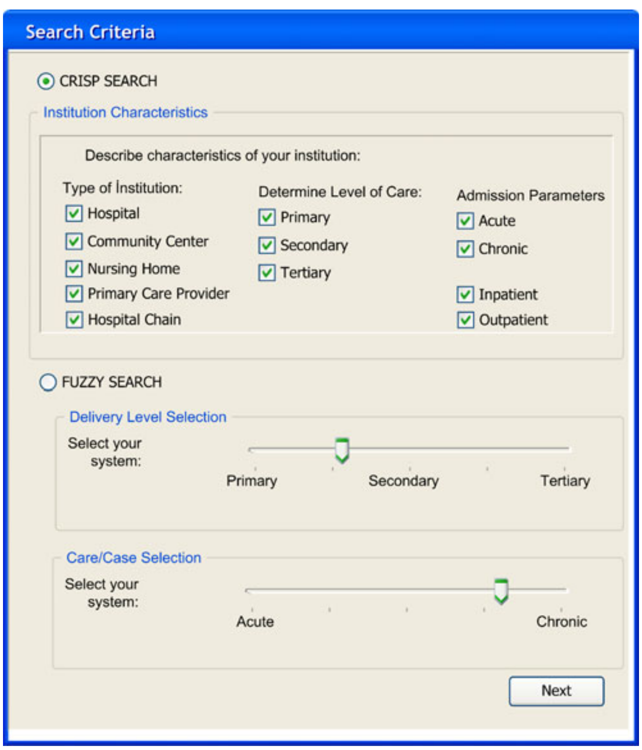

Fig. 10 An user interface example

Main targets of Health Care Transition Programme is establishing the MoH as a planning and supervising authority and implementing a universal health insurance covering all citizens of Turkey under a single social security. After 2003, there were significant changes in health care system in Turkey. The majority of public hospitals in Turkey, including those previously managed by a social security institute, are now integrated under one umbrella (the MoH), thereby resulting, in principle, in the separation of the purchaser of health services from the provider. Moreover, the various social security institutions are integrated under one institution, and share common beneficiary databases and claims. In 2008, a single payer system is established [40].

Today we can classify Turkish health system under four main categories. First one is public insurance, with single structure integrated under one institution called General Social Security (SGK). Second one is private insurance. Private insurance covers less than 0.5% of population in Turkey. Third one is Private Payment which is mostly in the form of out of pocket co payments. And lastly there are general budget government sponsored programs such as Turkish Army Forces (TAF), Green Card, Parliament, and Presidency. Figure 11 presents components of Turkish Health Care System.

In health systems knowledge base each Turkish health system category has been identified with the dimensions delivery system ontology. We have utilized four dimensions to identify characteristics of health care system. First we have defined source of finance for each component, then define reimbursement type with dimensions of retrospective or prospective, variable or fixed payment, and unit of reimbursement. Turkish system in a transition process, and provider payment mechanisms are shifting away from atomised, retrospective, fee-for-service systems towards prospective-payment systems incorporating pay-for-performance [40]. Under general social security system, Ministry of Health (MoH)

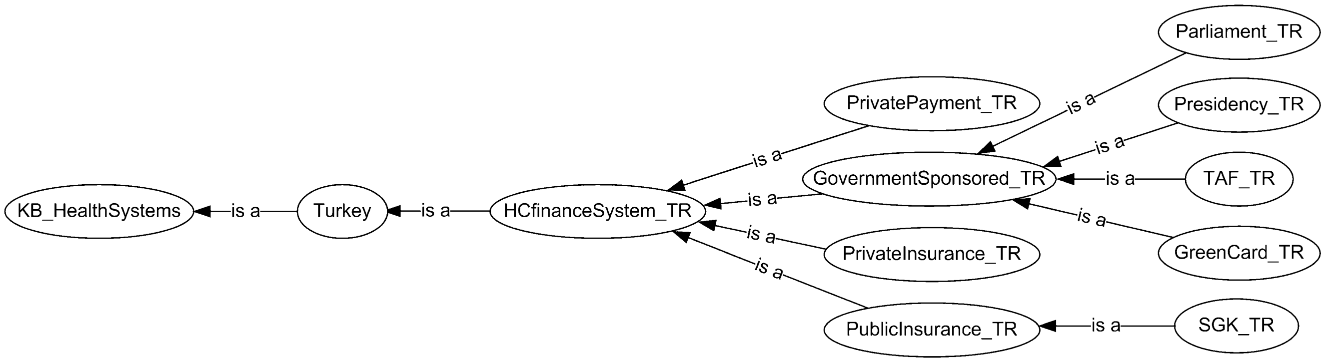

Fig. 11 Turkish health care finance system

providers receive prospective compensation, where as others receive retrospective payments. There are also attempts to apply cased base reimbursement rather than fee for services, however case base payment are not used in system wide. Main finance source is social security funds for general social security; however co payments are also exits with exception of some predefined populations. Central government finance systems such as Turkish Army Forces, and Green Card for poor and vulnerable populations. However transition process in continuum. Table 5 presents the descriptive dimensions of Turkish Health Care System defined in our knowledge base.

Second step of the evaluation study was identifying Turkish health care delivery components to our performance measurement knowledge base. Today in Turkey, health care deliverers are in transformation too. Public hospitals are being more autonomous, new primary health care system based on the model of family medicine under implementation in 23 out of 81 province of Turkey, a new referral system has been establishing, and so on. Providers of new system and legacy ones are functioning together. There are more than 65 different types of providers in Turkey. List of different provider types are given in Table 6. Most of these providers are owned by mainly Ministry of Health (MoH). We have categorized MoH providers as legacy delivery units and transformed delivery units. Private sector health care delivery has been a growing sector in Turkey. We have alsı defined different health care provider types in private sector. Moreover universities and Turkish Army Forces owns considerable amount of health care providers. We have defined these providers in a separate category. And there are other establishments like municipalities, foundations, and public institutions provide health care which is treated under others category. Right side of Fig. 12 presents all these main groups and sub categories of MoH legacy units.

We have defined each provider category, given in Table 6, by utilizing delivery system ontology in Protégé. Each provider is identified with dimensions of provider types, function in health care, level, available admission

Table 5 Definition of Turkish health care system in health system knowledge base with dimensions of ontology

Finance system	Source of finance	Reimbursement: compensation type	Reimbursement: Payment Type	Reimbursement: Unit
General Social Security (SGK) 1	HF_Social_security_funds_Financing	Retrospective for Others, Prospective for MoH	Variable, Fixed	Fee for service
General Social Security (SGK) 1	HF_Social_security_funds_Financing HF_CostSharing_social_security_funds_Financing	Retrospective for Others, Prospective for MoH	Variable, Fixed	Fee for service
Private insurance	HF_Private_insurance_enterprises_Financing Cost-sharing: other private insurance	Retrospective	Variable	Fee for service
Private payment	HF_OutOfPocket_excluding_costSharing_Financing	Retrospective	Variable	Fee for service
Turkish Army Force (TAF) 1	HF_Central_government_Financing	Retrospective	Variable	Fee for service
Turkish army force (TAF) 2	HF_Central_government_Financing Cost-sharing: central government	Retrospective	Variable	Fee for service
Green card	HF_Central_government_Financing	Retrospective	Variable	Fee for service
Parliament	HF_Central_government_Financing	Retrospective	Variable	Fee for service
Presidency	HF_Central_government_Financing	Retrospective	Variable	Fee for service

Table 6 List of the provider categories in Turkey

Ministry of health (MoH): Legacy delivery units
Health posts
Health center
Tuberculosis dispensary
Mother child health/family planning center
Health center
Hospital and district policlinic_ MoH
Branch hospital and district policlinic_Obstetrics and gynecology_ MoH
Branch hospital and district policlinic_ Bone diseases, physical therapy and rehabilitation_MoH
Branch hospital and district policlinic_Heart, Cardiovascular surgery and chest and chest surgery_MoH
Branch hospital and district policlinic_Mental health_MoH
Branch hospital and district policlinic_Skin and venereal diseases_MoH
Branch hospital and district policlinic_Other_MoH
Education and research hospital and district policlinic_ MoH
Special branch education and research hospital and district policlinic_Heart, Cardiovascular surgery and chest and chest surgery_ MoH
Special branch education and research hospital and district policlinic_Obstetrics and gynecology_ MoH
Special branch education and research hospital and district policlinic_Bone diseases, physical therapy and rehabilitation_ MoH
Special branch education and research hospital and district policlinic_Mental health_ MoH
Special branch education and research hospital and district policlinic_Eye diseases_ MoH
Special branch education and research hospital and district policlinic_Oncologic diseases_ MoH
Special branch education and research hospital and district policlinic_Other_ MoH
Cancer early diagnosis and screening centers
Dialysis centers
Refik Saydam Hygiene Centre
Public Health Laboratories
Ministry of Health (MoH): Transformed Delivery Units
Family practitioner/center
Community health center
Integrated district hospitals
Dentistry center_Public
Private initiatives
Physician_ Workplace
Policlinic_Private
Physician office_ Private
Dentist center_ Private
Dentist policlinic_ Private
Dentist office_ Private
General hospital_ Private
Special branch hospital_ Obstetrics and gynecology_Private
Special branch hospital_ Bone diseases, physical therapy and rehabilitation_Private
Special branch hospital_ Heart, Cardiovascular surgery and chest and chest surgery_Private
Special branch hospital_Mental health_Private
Special branch hospital_Skin and venereal diseases_Private
Special branch hospital_Other_Private
Medical center_ Private
Special branch medical center_ Private
Diagnostic laboratories
Diagnostic imaging center
Special therapy centers
Pharmacies
Opticians
Medical material suppliers
Thermal spring
Universities
Hospital and district policlinic_University
Health application and research center_University
Dentistry faculty_University
Turkish Army Forces (TAF)
Primary Care Unit_TAF
Hospital_TAF
Medical faculty hospital_TAF
Education and research hospital_ TAF
Others (Municipalities, Foundations, Public Institutions)
Physician_Public Institutions
Policlinic_ Municipal
Hospital_ Municipal
Education and research hospital_ Vakıf Gureba
Hospital_Istanbul Governorship of Istanbul
Special branch center_ Public institution
Medical center _ Public institution

types, specialties they have included, professionals they have included, and time scales of covered cases. Table 7 presents definition of a Ministry of Health's Health Center, which is a primary care provider that gives both inpatient and outpatient curative services and the preventive services. Figure 12 demonstrates dimension definitions of legacy health care providers of MoH in Protégé.

Third step of evaluation is to match relevant knowledge base cases with Turkish System Delivery Components. By applying inference mechanism, performance measurement cases in knowledge base related with Turkish delivery system components. Figure 13 presents this inferred model. In figure dark color nodes represents Turkish delivery system categories, and light color nodes represent relevant performance measurement cases. System gives the results as each delivery system unit can be measured by the performance indicators of its sub level cases.

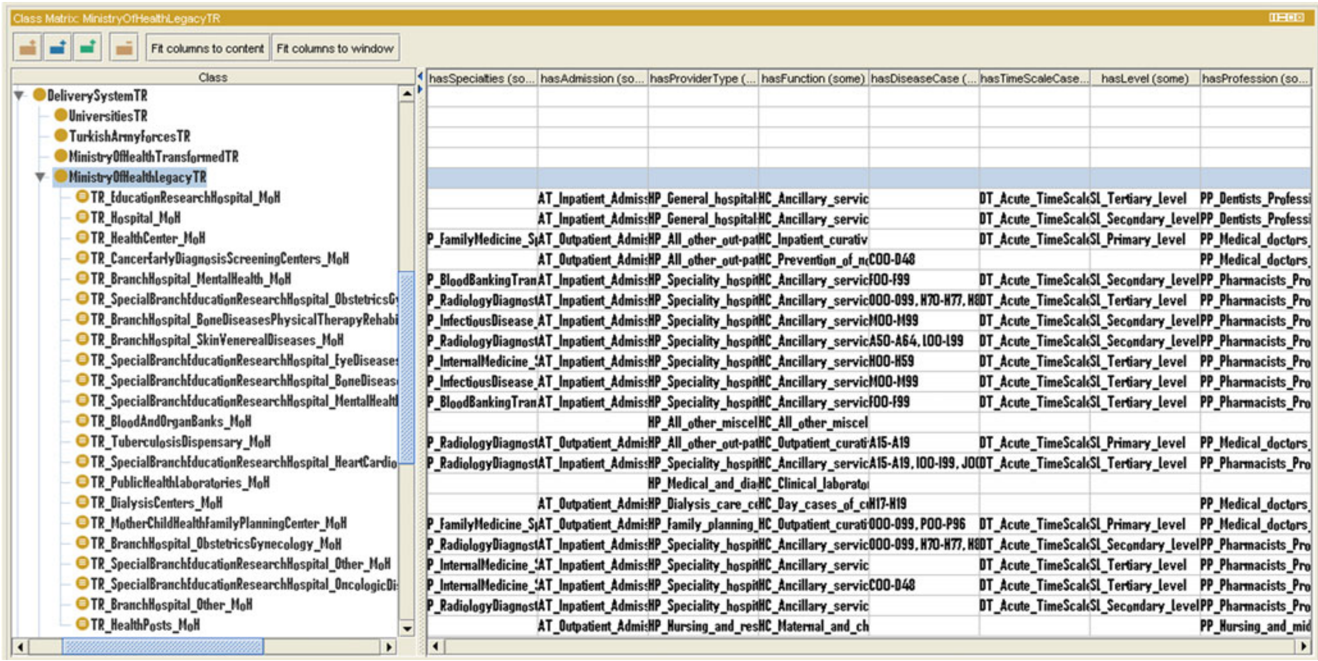

Fig. 12 Dimension matrix of legacy health care providers of MoH in Protégé

As a last step, we have evaluated whether given performance measurement sets are relevant with delivery unit. Domain experts reviewed the returned indicators for each delivery unit and verify that they are relevant and can be use to measure performance in delivery units. This evaluation results show that, our health care delivery system domain ontology and inference system is functioning properly. System is validated. However hence our knowledge base is limited with 229 cases, number of returned performance indicators was not sufficient. This drawback can be improved in future by populating knowledge base with new performance measurement cases.

Table 7 Definition of MoH health center category in Protégé

TR_HealthCenter_MoH
hasFinanceSystemTR some SGK_TR
hasProviderType some HP_All_other_out-patient_community_and_other_integrated_care_centres_Provider
hasLevel some SL_Primary_Level
hasProfession some PP_Medical_doctors_Profession
hasProfession some PP_Nursing_and_midwifery_Profession
hasFunction some HC_Inpatient_curative_care_Functions
hasFunction some HC_Day_cases_of_curative_care_Functions
hasFunction some HC_Outpatient_curative_care_Functions
hasFunction some HC_Clinical_laboratory_Functions
hasFunction some HC_Diagnostic_imaging_Functions
hasFunction some HC_Maternal_and_child_health;_family_planning_and_counselling_Functions
hasFunction some HC_Prevention_of_communicable_diseases_Functions
hasFunction some HC_Prevention_of_non-communicable_diseases_Functions
hasAdmission some AT_Outpatient_Admission
hasTimeScaleCase some DT_Acute_TimeScale
hasTimeScaleCase some DT_Subacute_TimeScale
hasSpecialties some P_FamilyMedicine_Specialty

Discussion and conclusion

Performance measurement studies are carried out by many various stakeholders in different countries [41, 42]. All stakeholders are seeking for indicators which are appropriate to their care setting and target improvements [43–45]. The developed performance indicator search tool and measure database will be helpful for many researchers as well as developers of performance programs.

Beside this search tool, we have also developed an original theoretical framework for comparing performance measures. Domain knowledge is analyzed in different health care settings and system concepts are stored in semantic network ontology.

A performance measure database is populated with the studies obtained by literature search. Two hundred twenty-nine studies are analyzed and inserted into the database. This source provides a valuable reference for domain experts.

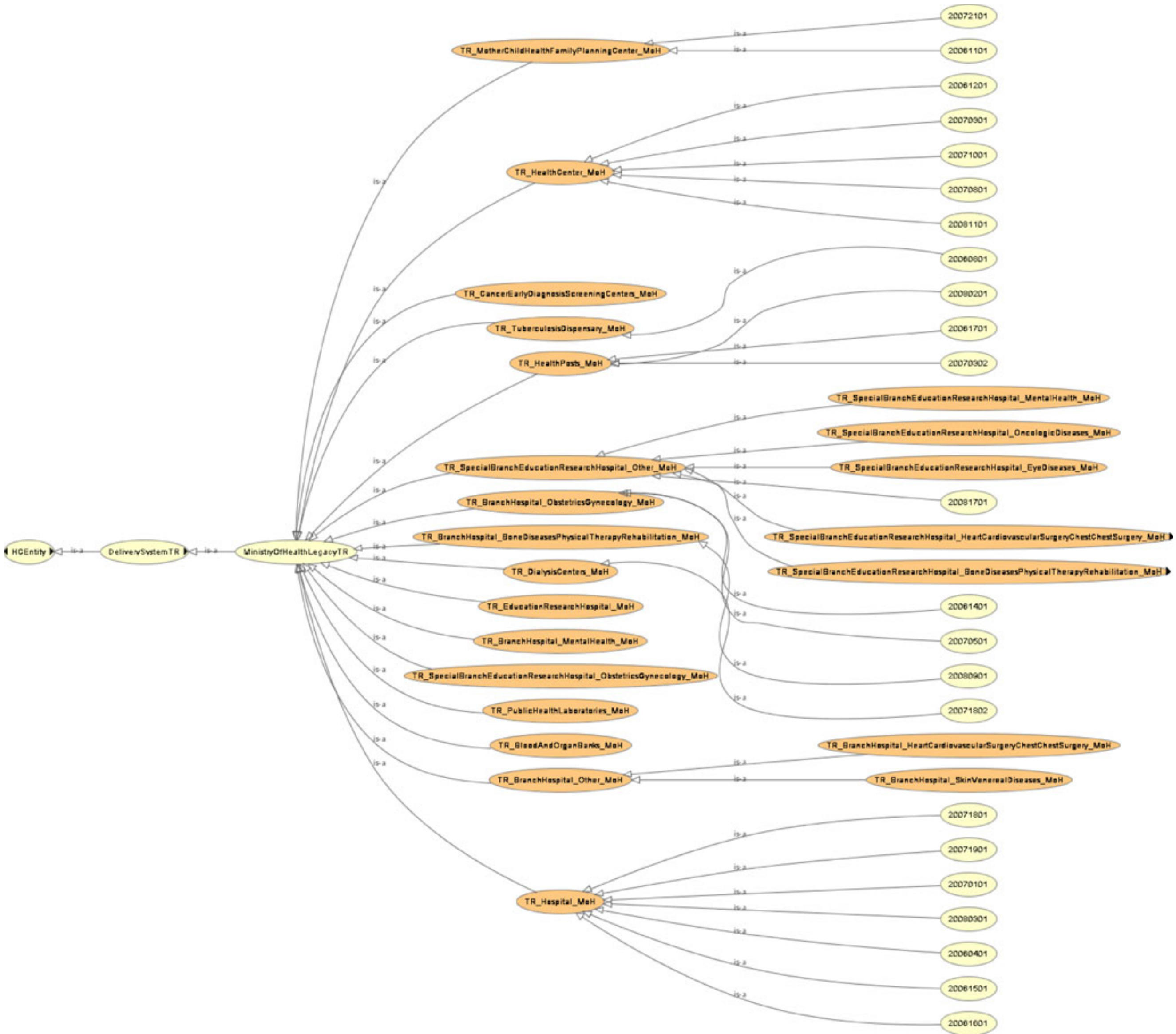

Fig. 13 Inferred model for Turkish delivery systems

The performance indicator search interfaces are designed in a user-friendly way. Different profiles support easy requirement capture phase. Via our knowledge base, the system processes obtained requirements and returns the best match performance indicators to users.

As a result, the developed performance indicator search tool will help hospital managers, health plan administrators, accreditation bodies, and governmental bodies for finding best indicator alternatives customized to their care setting.

Performance of knowledge base systems is limited with their capacity of cases. Main limitation of our system is the size of knowledge base. The knowledge base is initially populated with 229 cases. Hence these cases extracted from academic search engine, they cover scientific studies conducted mainly in United States. This initial knowledge base can be extended by adding new cases in future.

As a further study, new clinical dimension on delivery system ontology can be developed. As new dimensions evidence based medicine based on the guidelines could be included in performance measurement in clinical domain.

Another further study can be to extend system not only for searching performance indicators but comparing performance of different health care providers. The developed framework can be utilized for performance assessment.

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