Ontology- and Model-Based Quality Indicators Designing Framework

Osamu Takaki
Gunma University Hospital
Gunma University
Maebashi, Japan
takaki@gunma-u.ac.jp

Izumi Takeuti
Research Institute for Secure Systems
National Institute of Advanced Industrial Science and Technology
Tsukuba, Japan
takeuti@ni.aist.go.jp

Noriaki Izumi
Intelligent Systems Research Institute
National Institute of Advanced Industrial Science and Technology
Tsukuba, Japan
n.izumi@aist.go.jp

***Abstract*—Though quality indicators play an important role in assessment of medical service quality of hospitals, there still exists no universal framework to collect or select adequate quality indicators for certain assessment of medical service quality. This paper provides a set of models called "Medical Service Assessment Models (MSAM)" that help collect adequate quality indicators to assess medical service quality from the patients' viewpoint. To this end, we focus on a set of semantic patterns of medical service quality assessment and develop an ontology called "Medical Service Assessment Ontology (MSAO)", which is a vocabulary to construct MSAM based on the patterns. The framework consisting of MSAM and MSAO plays a role in guidelines for collecting adequate quality indicators to assess medial service quality from the patients' viewpoint, and helps explain the basis for the collection of quality indicators.**

Keywords-quality indicator; medical service assessment; ontology

I. INTRODUCTION

Quality indicators play an important role in assessment of medical service quality of hospitals. Recently, medical assessment organizations such as the Agency for Healthcare Research and Quality (AHRQ) [1], the National Institutes of Health (NIH) [11] and the Organisation for Economic Co-operation and Development (OECD) [12] have provided a lot of quality indicators to hospitals and toolkits to calculate values of their indicators based on data in medical databases in hospitals. Moreover, they have compared the values above on the international scale. Such comparisons will expand in the future.

However, there still exists no universal framework to collect or select adequate quality indicators for certain assessment of medical service quality, and hence, each medical assessment organization provides a series of quality indicators in its own and it is not easy to fairly compare medical service qualities based on quality indicators.

This paper provides a set of models that help collect adequate quality indicators to assess medical service quality from the patients' viewpoint. The models are called "Medical Service Assessment Models (MSAMs)". To this end, we focus on a set of semantic patterns of medical service quality assessment and develop an ontology that is a vocabulary to construct MSAM based on the patterns. The patterns and ontology are called "Medical Service Assessment Description Patterns (MSADPs)" and "Medical Service Assessment Ontology (MSAO)", respectively. MSAMs are constructed with instances of concepts and properties in MSAO. MSAO is developed by an ontology developing tool "Semantic Editor" [5].

The framework consisting of MSAO and MSAMs plays a role in a guideline for collecting adequate quality indicators to assess medial service quality from the patients' viewpoint, and helps explain the basis for the collection of quality indicators.

The remainder of this paper is organized as follows. Section 2 explains MSADP. Section 3 introduces MSAO based on MSADPs, and Section 4 introduces MSAMs based on MSAO. Section 5 explains how to design quality indicators based on MSAMs. Sections 6 and 7 explain related works and the conclusion.

II. MEDICAL SERVICE ASSESSMENT DESCRIPTION PATTERNS

Medical Service Assessment Description Patterns (*MSADPs*) are semantic patterns of medical service quality assessment, which are obtained from organizing assessors' thinking how to assess medical services of medical staff in hospitals.

MSADPs consist of the following patterns.

1. What types of medical staff and instruments are there in the hospital?
2. What types of patients have been accepted by the hospital?
3. What treatments have been executed to the patients?
4. What results have the patients obtained after the treatments?
5. In the 4th phase above, how do the results differ from estimates?

MSADPs can be considered to be semantic or description patterns of Donabedian's assessment of medical service

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quality based on the aspects of "constructions, processes and outcomes" of medical services [4] plus acceptance situations of patients. One can also consider that MSADPs are organized from the patients' viewpoints. Therefore, the viewpoint of medical service quality assessments based on MSADPs might be limited more than Donabedian's viewpoint. However, by limiting the scope of the assessment, the way to design quality indicators based on MSADPs can be more systematic than Donabedian's method.

III. MEDICAL SERVICE ASSESSMENT ONTOLOGY

The purpose of this paper is to provide a set of models to design adequate quality indicators for assessment of medical service quality according to MSADPs. To this end, we introduce *Medical Service Assessment Ontology* (*MSAO*), which is a vocabulary to construct the models.

A. Patients

In MSAO, a patient denotes a type of people who share common problems, and problems are mainly classified into problems to be solved by medical services and others called background problems (Fig. 1). The former denotes mainly diseases, while the latter is classified according to age, pregnancy or congenital disorders.

In Fig. 1, yellow (highly-colored) rotundate rectangles describe concepts, while pink (softly-colored) rotundate rectangles with dotted lines describe attributes of concepts. For example, a concept "patient" has two attributes "background" and "target disease", and "background" has the range "background problem", which is a subclass of "problem", where the range of an attribute denotes the set of values of the attribute.

B. Patients' Values and Purposes

A value denotes what a patient wants in solving his/her problems (diseases). A value consists of 8 types of value components in Fig. 2 on the next page. A purpose is regarded as a value plus criteria to attain its value components (Fig. 2).

C. Medical Services

A medical service denotes what is executed to a patient to solve his/her problem(s). Medical services are mainly classified into events and activities (Fig. 3 on the next page). An event is a set of one or multiple activities or smaller events, while an activity is what a medical staff directly executes on the spot. For example, a surgery is regarded as a medical service, while laparotomy is an activity by an operating surgeon in a surgery.

A service in Fig. 3 has four attributes: "target purpose", "approach", "tool", and "then" that indicates the next service of the service. A process of a medical service is a path consisting of events or activities to attain the medical service.

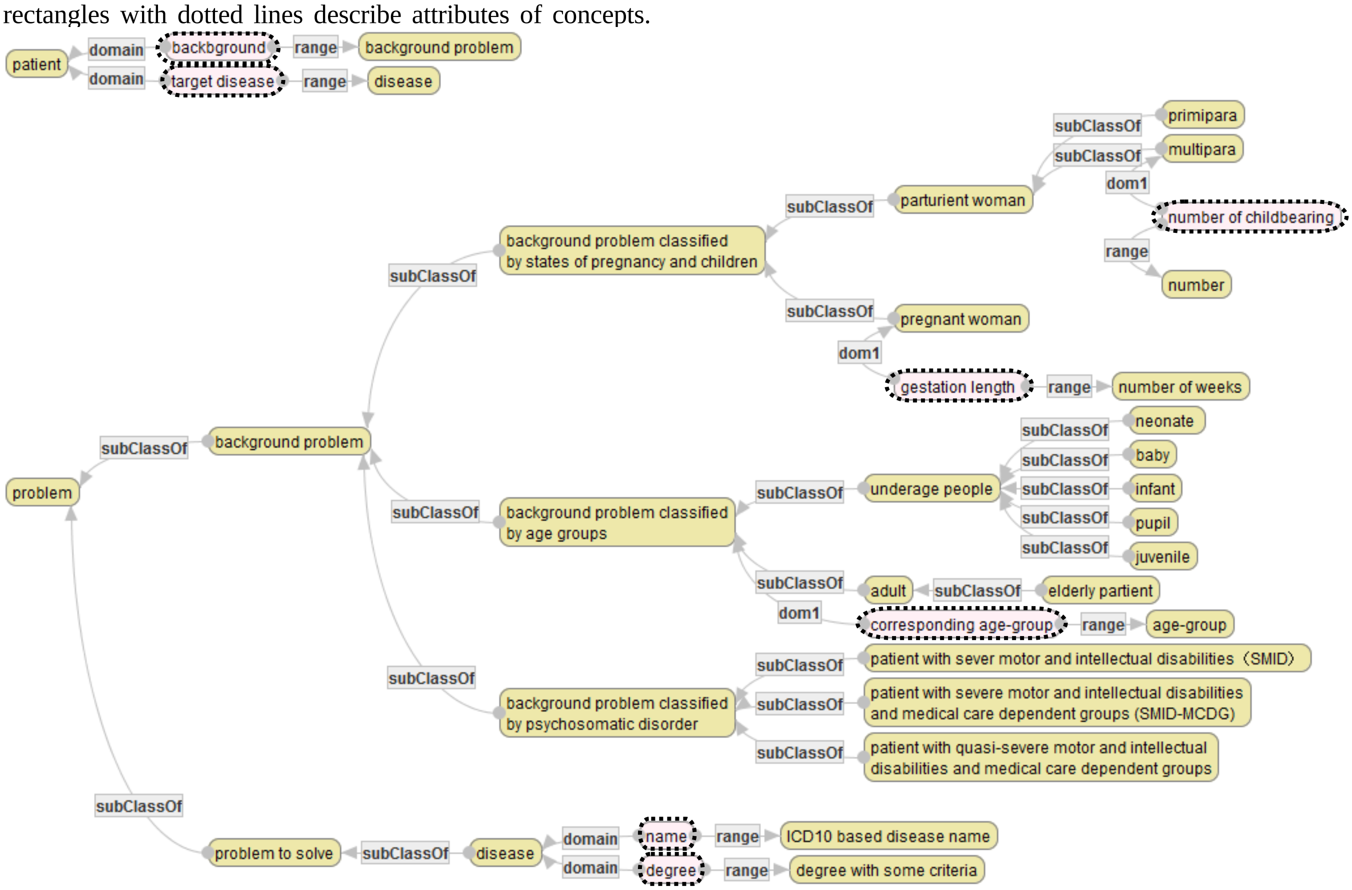

Figure 1. Patients and their problems (Partial)

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One can develop process models of medical services by combining instances of medical service concept (cf. Fig. 8 on the last page).

D. Medical staff, instruments and facilities

Medical service providers consist of medical staff, instruments and facilities (Fig. 4).

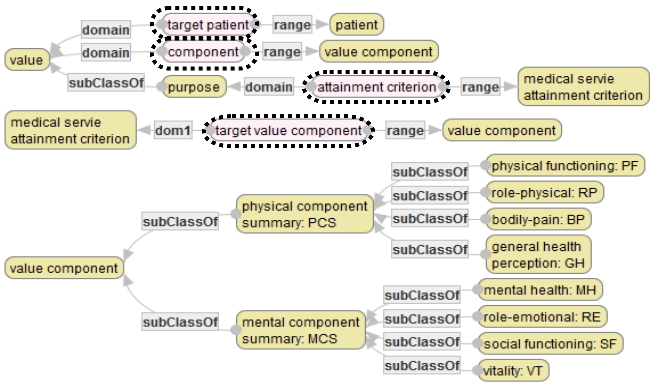

Figure 2. Values and purposes (Partial).

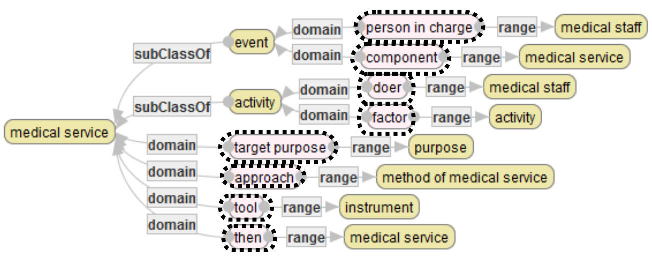

Figure 3. Medical services.

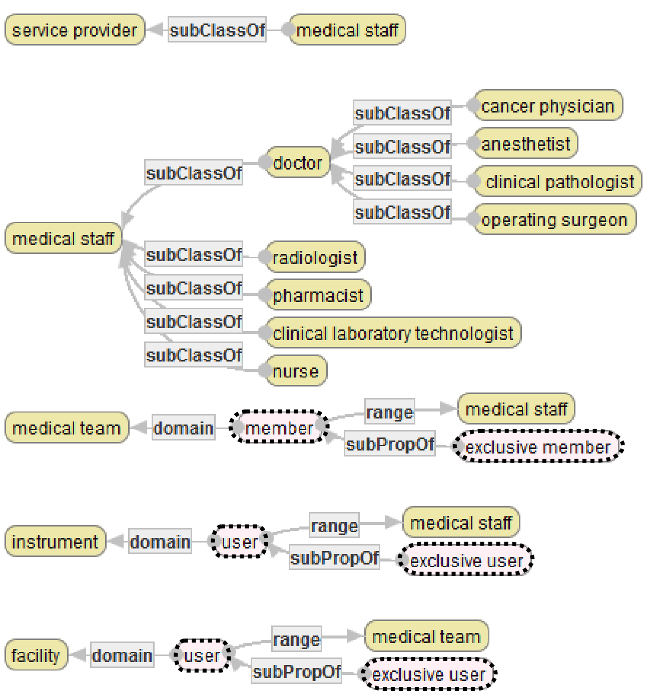

Figure 4. Medical service providers (Partial).

Medical staff are doers or people in charge of a medical service. For example, doctors, anesthetists, radiologists and nurses are typical medical staff. On the other hand, instruments and facilities are hospitals' resources used by medical staff in medical services. In this paper, a medicine is regarded to be one of those instruments. For example, MRI is an instrument, while an operation room is a facility.

E. Patient outcome

A patient outcome denotes a state of a patient that might change through an activity (Fig. 5 on the next page). Patient outcomes are classified into (i) completion, (ii) completion with potential risk, (iii) failure, and (iv) emergency, according to degrees of activity attainments, risks that patients might have through the activity and costs that patients pay for the activity attainments. "Completion" denotes a patient outcome that is obtained by a complete activity with no problem. "Completion with potential risk" denotes a patient outcome from which the next activity is feasible but which has some potential risk(s) that might be actualized in the future. "Failure" denotes that the doer could not complete the activity. Finally, "emergency" denotes that the patient falls into critical situations such as the patient's death by the activity. An accident denotes a negative outcome that a patient conclusively has. Possible outcome (or possible accident) is a pair of a patient outcome (or accident, respectively) and its possibility.

"Completion with potential risk", "failure" and "emergency" have attributes "risk outcome" and "risk accident" whose ranges are possible outcome and possible accident respectively, which means that, if these types of patient outcomes occur, then (negative) patient outcomes or accidents might occur in the future. Moreover, "failure" and "emergency" have an attribute "result" with range "fatal accident", which denotes a serious accident that might halt the medical service including the activity.

IV. MEDICAL SERVICE ASSESSMENT MODELS

In this section, we explain *Medical Service Assessment Models* (*MSAMs*). MSAMs show situations related to medical services from the viewpoints of the five patterns of MSADPs, and they are constructed with instances of concepts in MSAO. Thus, we will explain MSAMs according to the five patterns above.

Prior to constructing MSAMs, one has to set a main service such as "an open abdominal surgery of stomach cancer" that he/she will assess eventually.

The main service above is called a conclusive service. The conclusive service is set by using concepts of patients in MSAO, as follows.

1. Set problems of patients to make clear a conclusive medical service for stomach cancer patients.
2. Set a type and/or stage of target cancer in order to make clear the problem to solve by the medical service.
3. Set background problems of target patients. (As an example, we here consider all patients of stomach cancers with stage II.)

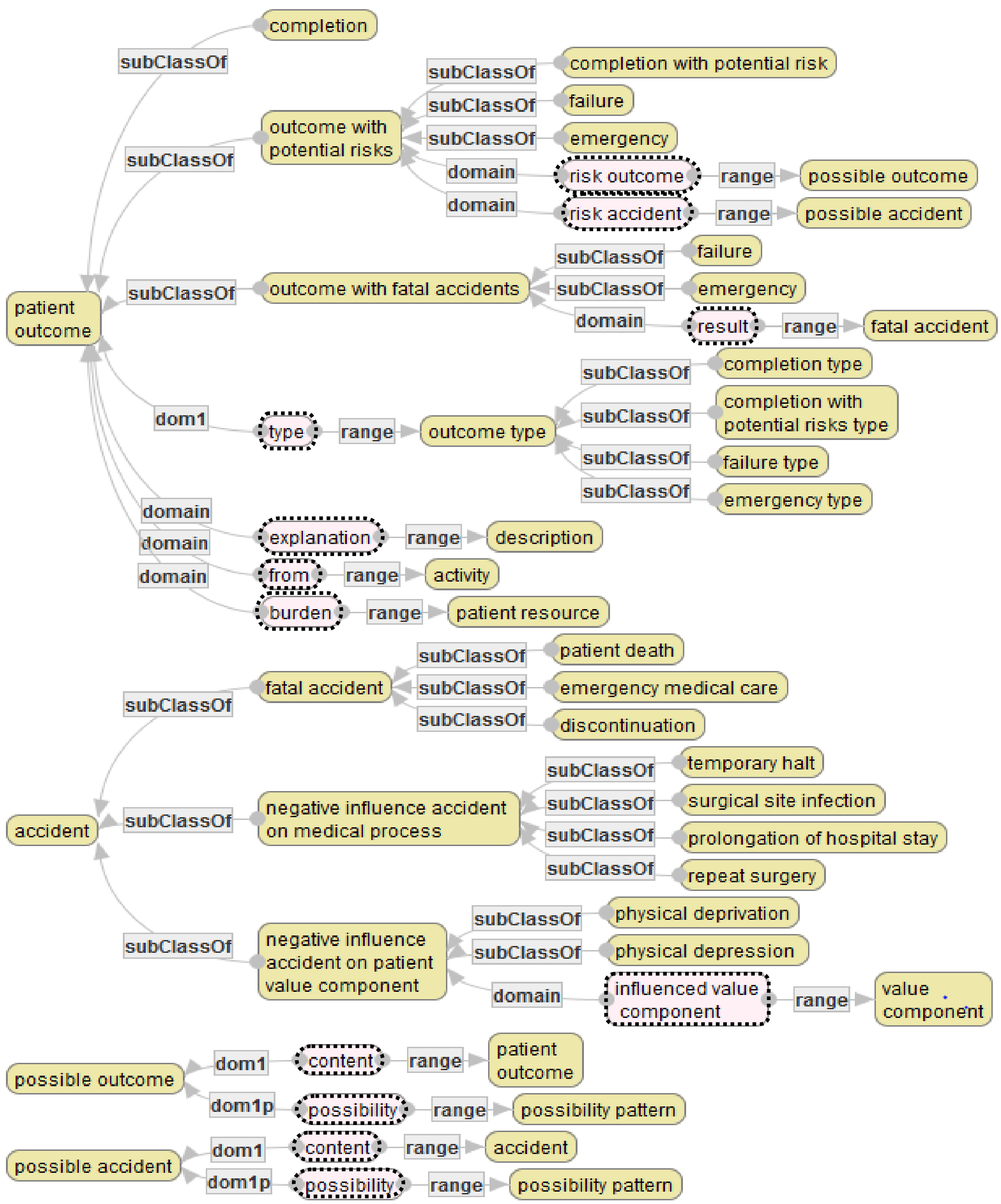

Figure 5. Outcomes of patients (Partial).

4. Set values and purposes for the patients according to the 8 types of value components in Fig. 2. Then, one can also set attainment criteria of patients' satisfaction about the values.

5. Finally, set a conclusive medical service as well as an approach of the conclusive medical service.

As an example of a conclusive medical service, we here consider an open abdominal surgery of stomach cancer. In the following subsections, we construct MSAMs based on the conclusive medical service above.

A. *Medical Service Provider Model*

A *Medical Service Provider Model* (*MSPM*) is a model that shows provisions for a given conclusive medical service. The model is employed to design quality indicators in the first phase of MSADPs.

MSPM consists of medical staff, instruments, facilities and dependency relationships between them. Here, a "dependency relationship" means a relationship between a medical service or a thing related to a medical service such as an instrument or a facility and what plays an exclusive role for the service or the thing. The dependency relationship

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is a transitive relationship. Therefore, for example, the medical staff "operating surgeon" is an exclusive medical staff of an event "open abdominal surgery of stomach cancer". Fig. 6 defines the dependency relationship by the properties "exclusive ...".

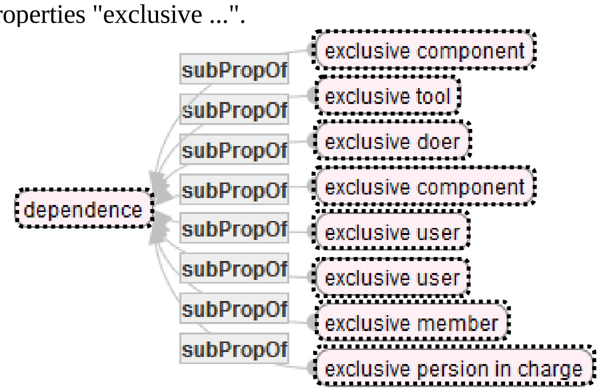

Figure 6. Dependency relationships.

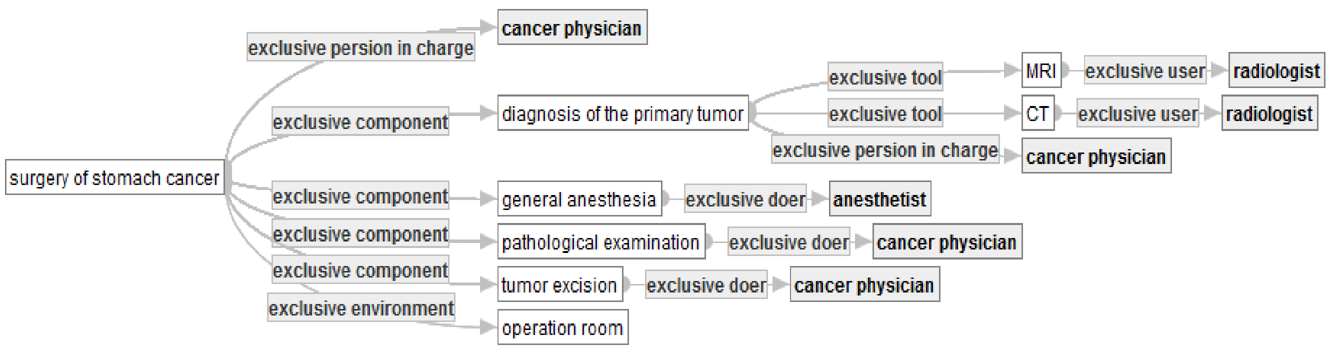

Figure 7. MSPM for open abdominal surgery of stomach cancer (Partial).

Fig. 7 shows an example of MSPM that indicates exclusive or significant medical services, instruments, facilities and medical staff for open abdominal surgery of stomach cancer. Since each instance in Fig. 7 is connected by dependency relationship labelled by "exclusive ...". All instances in Fig. 7 are exclusive or significant for the conclusive medical service.

For example, the small event "diagnosis of the primary tumor" is an exclusive component event of the surgery above, "MRI" and "CT" are exclusive instruments for the diagnosis and "radiologist" is an significant staff who can exclusively use the instruments. Therefore, the small event, instruments and staff above are all exclusive for the surgery.

B. *Patient Model*

A *Patient Model* (*PM*) is an instance of a patient's concept of MSAO. Thus, the content is what we already have explained in Section 3.1. Here we give an example of a PM "patients of stomach cancers". Moreover, as examples of patients' purposes we give (1) life extension, (2) recovery of life function, (3) recovery of physical function and (4) alleviation of physical and mental pain caused by diseases.

C. *Medical Service Process Model*

From a given conclusive medical service such as "open abdominal surgery of stomach cancer", some concrete approach and constraints of the medical service can be decided. According to such an approach and/or constraints, one can construct a process model of the medical service, which is called a *Medical Service Process Model* (*MSPrM*). The example of an MSPrM is partially shown in Fig. 8 on the last page.

Fig. 8 shows a process from “diagnosis of primary tumor” to “surgery performance”. Each small event or activity that constitutes the conclusive medical service is assigned to a person in charge or a doer. For example, the small event in Fig. 8 "performance of surgery" consists of eight activities and the person in charge of the small event is a "doctor", while the activity "general anesthesia" in "performance of surgery" is assigned to a doer, an "anesthesist". Moreover, some small events and activities are assigned to instruments and/or facilities.

D. *Patient Outcome Model*

A *Patient Outcome Model* (*POM*) shows the status of a patient that chances by activities and/or events according to the process of the conclusive medical service. A POM is expressed as a list that consists of possible statuses of a patient through the last small medical service that constitutes the conclusive medical service. A status of a patient through a small medical service that constitutes the conclusive medical service is determined based on the completion degree of the service, potential risks and costs caused by the service.

A POM is constructed through the following steps.

1. Given an MSPM, PM, and MSPrM, sort out patient outcomes by considering the completion degrees, potential risks and costs of the small services that constitutes the MSPrM under the assumption that all services above are executed acceptably. The patient outcomes above are desirable ones.
2. Pick up small events or activities that are not easy to complete with no potential risk and no high cost. Thus, add the undesirable outcomes that are caused by the failure of such small events and/or activities.

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In the case of open abdominal surgery of stomach cancer, one may obtain undesirable patient outcomes including the following outcomes:

i. Tumor excision with a certain level of bleeding,
ii. Tumor excision with surgical site infection,
iii. Tumor excision with light damage to abdominal organs,
iv. Excessive tumor excision,
v. Deficient tumor excision and
vi. Failure of tumor excision by severe damage to abdominal organs or blood vessel.

V. DESIGN OF QUALITY INDICATORS BASED ON MSAMS

In this section, we explain the way to design quality indicators based on given MSAMs that are obtained in the previous section. As well as the previous section, we consider "open abdominal surgery of stomach cancer" as a conclusive medical service. Thus, we will explain how to design quality indicators to assess the quality of the conclusive medical service above in the following subsections.

A. *Design of QIs based on MSPM*

By virtue of the MSPM that is obtained in Section 4.1, one can clarify significant medical staff, instruments and facilities of the given conclusive medical service. Thus, quality indicators can be defined to be what indicate the status of the resources above.

For example, it is valuable for assessment of the conclusive medical service quality to calculate quality indicators that indicate acceptance situations of medical staff "radiologist", "cancer physician" and "anesthetist", instruments "MRI" and "CT" and a facility "operation room", which are shown as exclusive resources in the MSPM (Fig. 7).

B. *Design of QIs based on PM*

By virtue of the PM obtained in Section 4.2, target patients of the given conclusive medical service can be figured out. In the case of "stomach cancer patients", quality indicators can be defined to be what indicate acceptance number of patients who are characterized by instances in the PM above.

C. *Design of QIs based on MSPrM and POM*

By virtue of the POM that is obtained in Section 4.4, one can clarify remarkable patient outcomes, especially, undesirable ones (i, …, vi in Section 4.4). Thus, it is valuable to define quality indicators that indicate frequency of the undesirable patient outcomes above.

For example, the number of surgeries that need a certain amount of blood transfusion or time-lengths reflects the frequency of the undesirable outcomes i and iii. On the other hand, the number of surgeries that need certain lengths of hospital stays reflects the frequency of the outcome that force patients to bear the burden such as the outcomes iii and iv. The rate of SSI is directly related to the outcome ii. Finally, the rate of hospital readmissions and re-surgeries reflect the frequency of the outcomes v and vi.

Finally, we explain how to design quality indicators that correspond to the third step in MSADPs by using MSPrM and POM in Sections 4.3 and 4.4. Through the two models above, one can associate remarkable undesirable outcomes i, ...,vi and small events and/or activities in the MSPrM. Thus, quality indicators that indicate level of skill of such services are important ones of the third pattern of MSADPs.

For example, degree of conformance of scales of tumors in diagnoses before surgeries to scales of tumors that surgery doctors actually excised is related to frequency of the outcomes iv and v in Section 4.4. Thus, the degree of the conformance above may be an important indicator of surgery doctors' skills.

Moreover, the executing rate of additional activities or small events that prevent the outcomes i,...,vi are also important quality indicators of the third pattern of MSADPs

D. *Comparison of QID-FW and TDD-FW*

The designing framework of quality indicators explained in the previous sections, which we call QI-designing-FW or QID-FW, can be regarded as an analogy of a test-driven development framework (TDD-FW) of information systems. The following table shows correspondence relationships of components of QIDFW and TDD-FW.

TABLE I. COMPARISON OF QID-FW AND TDD-FW

	QID-FW	TDD-FW
1	Medical staff	System users
2	Patients	Data
3	Medical instruments and facilities	Information systems
4	Medical services	Accumulation of data through information systems
5	Medical service provider models	Use case diagrams
6	Patient models	Data models
7	Medical service process models	Business process models
8	Patient outcome models	Models obtained by integration of use case scenarios
9	The model constituting a patient outcome models	Use case scenarios
10	Quality indicators	Tests

The 1st to 3rd items in Table 1 are components that exist initially in working places, while the 5th to 9th items are models or specifications. From the viewpoint of medical informatics, medical services can be regarded as creation and/or modification of patients' data. Thus, the 1st to 3rd components of QID-FW can be regarded as the same components of TDD-FW in Table 1. Therefore, medical service provider models in QID-FW correspond to use case diagrams in TDD-FW, which show relationships between

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users and information systems. Moreover, patient models can be considered to be data models (more properly, master data models), while medical service process models can be considered to be business process models that shows workflows with information systems. Though there do not exist well-known models in TDD-FW that directly correspond to patient outcome models, components of a POM, which show outcomes of activities in a medical service, can be represented by use case scenarios.

On the other hand, a test in the TDD-FW plays the role of a criterion of an information system or a service with the system. So, quality indicators can be regarded as tests in the TDD-FW.

In TDD-FW, developers create efficient tests (or test cases) systematically based on requirement specifications that consists of the 5th to 9th models of TDD-FW in Table 1. Thus, the methodology in QID-FW to design quality indicators, which is based on the idea of tests (test cases) designing in TDD-FW, can be considered to be at least partially reasonable and systematical way to design a set of quality indicators.

VI. RELATED WORK

The paper [4] is one of the representative researches on what quality of medical service is and how to measure medical service quality. Moreover, one can take representative researchers such as Collopy [2], Copnell [3], Mainz [8, 9] and Mainz et al. [10] for development and improvement of quality indicators. These results play significant roles in researches how to express medical service quality as numerical values. This paper introduces a framework based on MSAO and MSAM to effectively employ the methods that the previous researchers have developed in order to obtain ideal standard of medical service quality.

On the other hand, one can take the papers [6] and [7] for instances of development frameworks of ontology for medical information systems. By combining these frameworks and MSAO, one can establish a framework to define ideal quality indicators and to calculate the values of the quality indicators based on data in medical information systems.

VII. CONCLUSION AND FUTURE WORK

In order to design adequate quality indicators for assessment of medial service quality from the patients' viewpoint, and to explain the basis for the design of quality indicators above, this paper provides the following products:

1. A set of semantic patterns of medical service quality assessment, which is called "Medical Service Assessment Description Patterns (MSADPs)".
2. A set of models called "Medical Service Assessment Models (MSAMs)" that help collect adequate quality indicators to assess medical service quality from the patients' viewpoint.
3. An ontology called "Medical Service Assessment Ontology (MSAO)", which is a vocabulary to construct MSAM based on MSADPs.

Moreover, we also briefly explain the way to design quality indicators based on the framework consisting of the three products above (see Section 5).

On the other hand, the method of our framework to construct patient outcome models is still highly dependent on individual skills, and it has not yet been sufficiently systematic. Thus, our next subject will be to develop a more systematic method to construct patient outcome models.

Moreover, it is necessary to make our designing framework easier for users including medical staff to use. To this end, we will be required to develop a tool that assists users to make medical service assessment models, and to evaluate the acceptability of the framework among medical staff.

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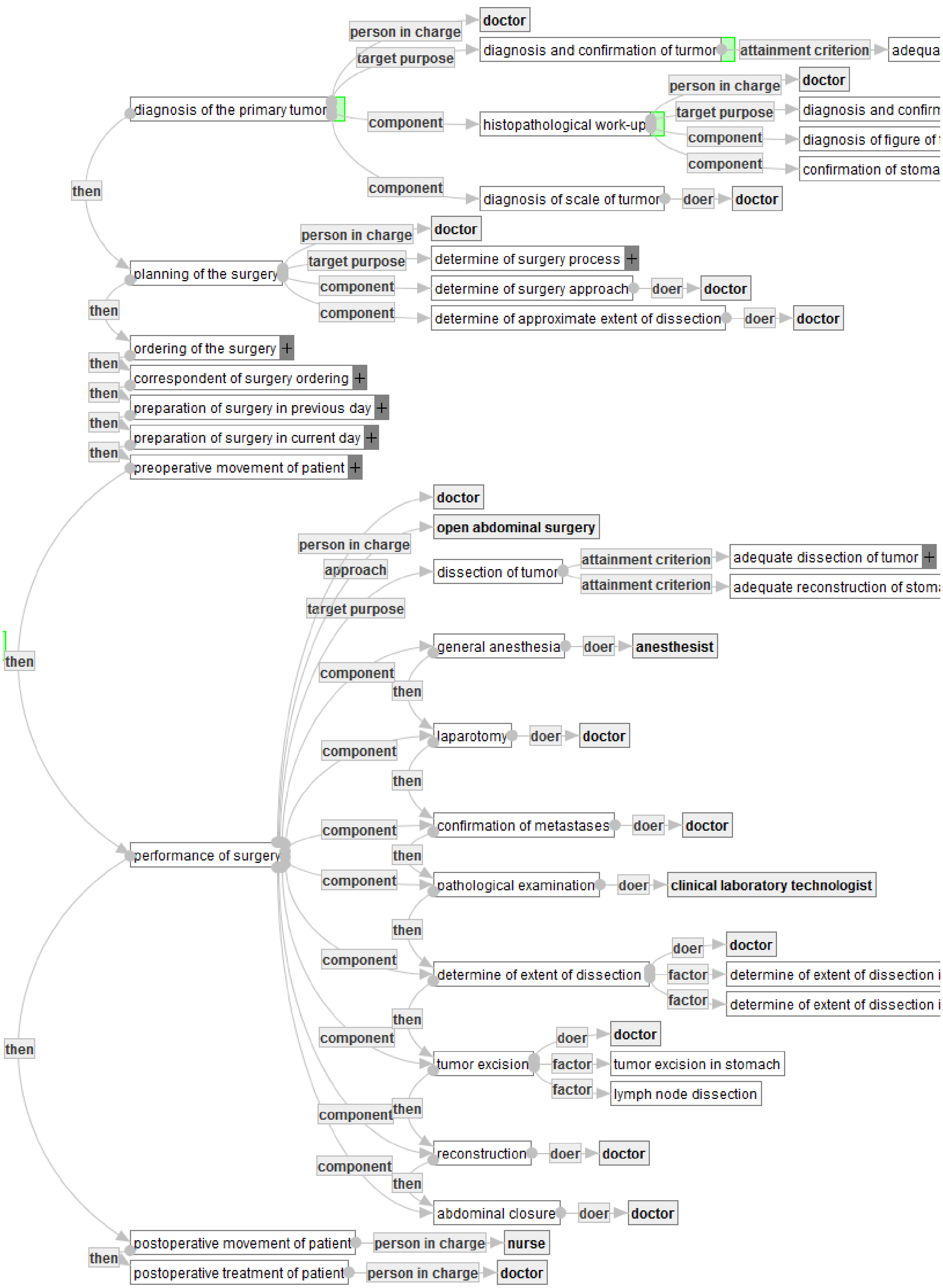

Figure 8. MSPrM of open abdominal surgery of stomach cancer (Partial).