Custom FHIR Resources Definition of Detailed Radiation Information for Dose Management Systems

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Abstract: Medical diagnostic imaging dose management systems aggregate and calculate irradiation dose generated by acquisition modalities, collected through standardized methods such as DICOM®, HL7® or proprietary interfaces. Irradiation dose information is valuable to multiple stakeholders, such as, general practitioners (GP), nationalized dose registries, patient facing applications, and information systems, such as, the Radiology Information System (RIS) or Electronic Health Record (EHR). For Medical Physicists, the radiation data is used to perform patient cohort and statistical analysis as part of a dose management program. However, there is no standardized, lightweight method to exchange the collected dose information with third party applications, through RESTful APIs. In this paper, we define a methodology to expose the content of the Radiation Dose DICOM® SR data models as custom HL7® FHIR® resources. This methodology leverages the strength of FHIR® in defining and exchanging resources, and the strength of the DICOM® SR data models, as their structure is implemented, maintained, and tested by dozens of modality providers.

1 INTRODUCTION

In recent years, dose management systems have played an increasingly important role within the fleet of applications inside hospitals, assisting in compliance with regional and national regulations, and improving the safety of irradiated patients (R. Loose, 2020). Dose management systems gather technical information from modalities and demographic and clinical observation data from other various facility applications. Some dose management systems provide functionalities for the enhancement of dose information through calculations and analyzes, such as effective dose calculation, organ dose, size specific dose estimation (SSDE), etc. Where IHE profiles and DICOM® specifications have been established to normalize the exchange between modalities and dose management systems (IHE, 2020b) (IHE, 2016), there has been no standardization exposing the dose information from the dose management systems to third party applications through RESTful APIs. Such exposure should include both the collected and enhanced data. In this paper, we first describe the problem and the need for "API-zation" of dose information exposure. Then, we detail the methodology for taking advantage of the rising HL7® FHIR® standard (Fast Healthcare Interoperability Resources) (HL7, 2019). Finally, we perform a comparison between the described methodology and another possible solution.

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2 PROBLEM

The dose irradiation information is collected from multiple sources. The most standardized structure is the DICOM® Radiation Dose Structured Report (RDSR) based structures. There are four RDSR structures allowing to expose the dose information and defined in PS3.16 of the DICOM® standard (DICOM, 2020c):

- X-Ray Radiation Dose SR
- CT Radiation Dose SR
- Radiopharmaceutical Radiation Dose SR
- Cone-beam CT Radiation Dose SR (WIP)

Each of these structures define a complete structured report of irradiation events. Radiation exposure information can be collected from other kinds of messages, as well. For instance, some modalities share the dose information through MPPS messages.

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Also, some DICOM® images contain relevant dose information, like nuclear medicine images (R. Loose, 2020). The most structured definition of radiation exposure information are RDSR DICOM® objects.

The IHE Radiology domain defined two IHE integration profiles: REM (Radiation Exposure Monitoring) (IHE, 2020b), and REM-NM (Radiation Exposure Monitoring for Nuclear Medicine) (IHE, 2016). The aim of these profiles is to define the actors intervening in patient radiation exposure process, their roles and the different transactions performed between them. REM profiles the X-Ray Radiation Dose SR and the CT Radiation Dose SR; and REM-NM profiles the Radiopharmaceutical Radiation Dose SR. The aim of both integration profiles is to describe how the dose information transits between modalities or radiopharmaceutical activity suppliers and the dose registry actors. During the process of sharing the dose information with the dose registry, the dose consuming actors may enhance the dose content with calculated information, like the effective dose, the organ dose, or the size specific dose estimation methods.

Once the original and the enhanced dose information are stored in the dose registry, which could be a hospital based registry or a regional/national based registry (IHE, 2020a), there is a need to expose the radiation information to third parties in a lightweight manner. Exposing the complete RDSR is useless for most of the use cases:

- Most of the display applications need only few parts of the RDSR
- Many third party applications are specialized in specific dose information like the effective dose, the organ dose, or the size specific dose estimation. However, these applications cannot access such specific dose information without retrieving the entire RDSR.
- Backend applications performing cohort search and measures need efficient data structures to query information within the RDSR

Partial exposure of the RDSR contents is needed. However, there is no lightweight methodology facilitating access to the dose information content within the RDSR from the dose management system to the third party applications.

Many healthcare systems can benefit from the exposure of dose details from the dose registry/repository actors:

- Mobile applications: new dose related mobile applications may benefit from the exposure of the information in the dose management systems. Such applications could follow accumulated patient dose exposure in a multi-facility enterprise.

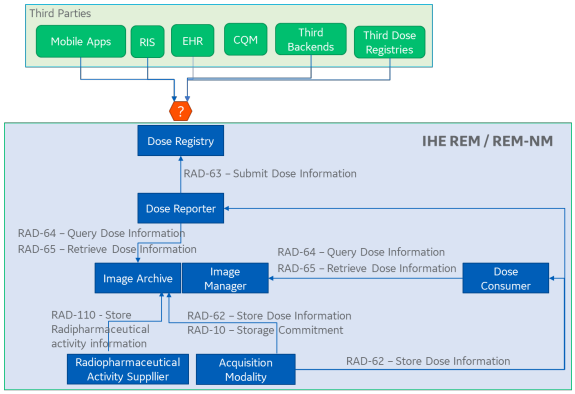

Figure 1: IHE REM/REM-NM profiles description.

- RIS: Radiology Information Systems may benefit by retrieving dose data for inclusion in the final imaging report, as mandated by multiple national/regional regulations promoting the sharing of dose information (IHE, 2020a).
- EHR: Electronic Health Record systems can benefit from sharing dose information, as some utilize manual entry of dose, and many do not support the ingestion and analysis of DICOM® objects, especially SR objects. A REST based API allows simple integration of dose information within the EHR system. Dose information can be provided to practitioners for appropriate procedure selection during a diagnostic encounter.
- CQMS: Clinical Quality Management Systems can benefit from lightweight exposure of dose information, in order to provide different metrics for a multitude of stakeholders. These metrics can be used to compare facilities, patient cohorts, or even, regional practices as part of a comprehensive quality control program.
- Third party application backends: some third party applications may use the exposed dose information for other uses. For example, technical exposure factors of previously performed exams for a specific patient can be used by the modality operator to set parameters of the current exam.
- Third party dose registries: API based exposure can facilitate reconciliation between multiple dose registries implementing the same API.

The most widely used standard for exposing APIs and resources in healthcare domain is FHIR®, which fits our problem well.

3 STATE OF THE ART

3.1 Dose Summary on FHIR

An ongoing work item within the DICOM® WG-20 and the HL7® O&O (Orders and Observations) group analyses the specification and the profiling of the Dose Summary on FHIR® (DICOM, 2020a). The aim of this working item is to describe the minimal required dose information within a normative resource (likely the Observation resource), allowing communication of the accumulated dose information from the performed procedure step, to provide a summary overview of the patient dose exposure. This working item will involve several activities, like the identification of the minimal dose information from various national regulations and recommendations, and the profiling of the Observation resource in order to integrate the minimal dose information. The scope of the Dose Summary on FHIR® is to share a summary of dose information by exam through FHIR®, which is different than the scope of this analysis: sharing details of the radiation administration, and sharing of the enhanced data like SSDE and effective dose to third party applications.

3.2 DICOM SR to FHIR Mapping

Another ongoing work item is a mapping between DICOM® SR and FHIR® resources (DICOM, 2020b). The scope of this work item is to map key SR templates and content into FHIR® resources. At the time of this paper, the work item was concentrated in the mapping of measurement TIDs (Template IDs: TID1410, TID1411, and TID1420). There are two explored solutions: Observation based solution, and a CDA® based solution. The first solution is describing all elements inside the TIDs using the ”hasMember” and ”component” attributes. The second solution is to translate the SR into CDA®, following DICOM® PS3.20 (DICOM, 2020d). After CDA® mapping, a translation between CDA® and FHIR® can be performed using custom resources, following the project Clinical Document Architecture V2.1 (HL7, 2020a). The methodology is very interesting, as it allows the direct mapping from SR templates to custom FHIR® resources. However, this is less relevant for DICOM® Radiation SR templates. In fact, in PS3.20, there is only one CDA® section defined, summarizing the patient dose exposure. This section is useful for the Dose Summary on FHIR® work item; however, it is not useful for a detailed mapping between DICOM® RDSRs and FHIR® resources.

3.3 DICOM SR and FHIR Representations for Imaging Measurements

An analysis was performed within the 30th Project Week event, in order to convert the TID 1500 - Measurement Report, to FHIR® resources (H. Meine, 2019). The working team concluded that the FHIR® resources should be used to store only the most relevant information, and to keep DICOM® as main storage format. A python based project is shared in a GitHub repository to describe the different samples and code used to generate the FHIR® resources. From the samples provided, the targeted mapping between TID 1500 and FHIR® is based on combination between the resources DiagnosticReport, Observation and ImagingStudy.

4 METHODOLOGY

4.1 Apization of DICOM Radiation SR

The best way to expose detailed radiation information through an API is to combine the strength of FHIR® (HL7, 2019) (T. Benson, 2016), and the stable structure of the RDSRs coming from PS3.16 (DICOM, 2020c). HL7® FHIR® provides a strong API model and capabilities for searching and exposing resources, like indexing and searching operations. The FHIR® community has published numerous open source tools, simplifying any integration with a FHIR® server, and simplifying the creation of FHIR® servers. FHIR® also comes with defined primitive and complex types, ready for use. Comparing to proprietary APIs, FHIR® facilitates conception of custom resources and the profiling of existing resources, which reduces the time to production. In fact, many open source applications exist, facilitating the profiling of FHIR® resources. Examples include FHIR® Shorthand / Sushi (HL7, 2020b), SIMPLIFIER.NET (K. Gopinathan, 2018), and FHIR® IG publisher tool (HL7, 2020d). For custom resources, HL7® provides FHIR® spreadsheet authoring, an Excel or OpenOffice structure for designing FHIR® data types, resources, and profiles (HL7, 2020c).

DICOM® PS3.16 provides a complete definition of each RDSR type, with a clear definition of content items, cardinality, data type, format, and constraints. The structure of the RDSRs have been defined since 2004 and tested hundreds of times during testing events like IHE Connectathons, or directly in production. Their structure has evolved over the years

but can be considered as having a stable structure and content.

Our methodology takes advantage of both standards: we defined FHIR® resources using the elements and the structures defined in PS3.16 of the DICOM® standard. For each defined container in the DICOM® RDSR structure, a custom FHIR® resource is defined. For each container, a list of rules is followed to create the custom resource. A custom resource may also be a subset of a container defining a node with a considerable number of nested levels.

4.2 Mapping between Dose SR and FHIR Resources

Each Dose SR can be described as a tree of different TIDs. Each TID can be a container of elements, or a tree of containers. Each container is described in the defined API as a custom FHIR® resource. For example: TID 10003 (Irradiation Event X-Ray Data) (DICOM, 2020c) describes the container with the identifier EV (113706, DCM, "Irradiation Event X-Ray Data").

For a specific dose container, a custom resource is created. A container is not always described by a TID. In fact, a TID can describe multiple containers as well as a subset of a container. This nuance is important for the definition of the FHIR® custom resources. Let's consider for example the CT Radiation Dose SR IOD Templates. The figure 2 describes the TIDs relationship, and the figure 3 describes the containers relationship, within the same IOD.

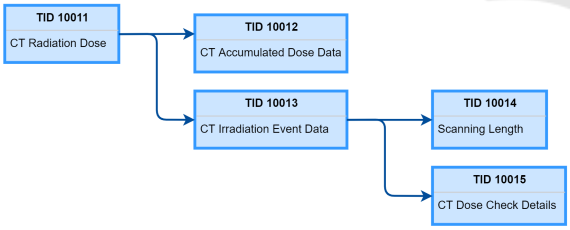

Figure 2: CT Radiation Dose SR IOD TIDs relationship.

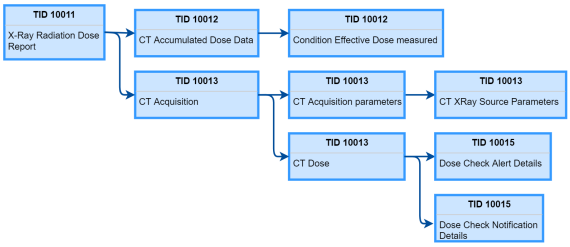

Figure 3: CT Radiation Dose SR IOD containers relationship.

We note that the tree of containment is not the same. Containers relationship is better suited as unit for FHIR® resources definition than the DICOM® TIDs. In fact, the containers have a better granularity than TIDs and can be shared independently from the rest of the structured report. Example: in TID 10013, CT Acquisition parameters may be shared between multiple RDSRs generated by the same modality.

The figure 4 describes the workflow used to define custom resources based on the identified container.

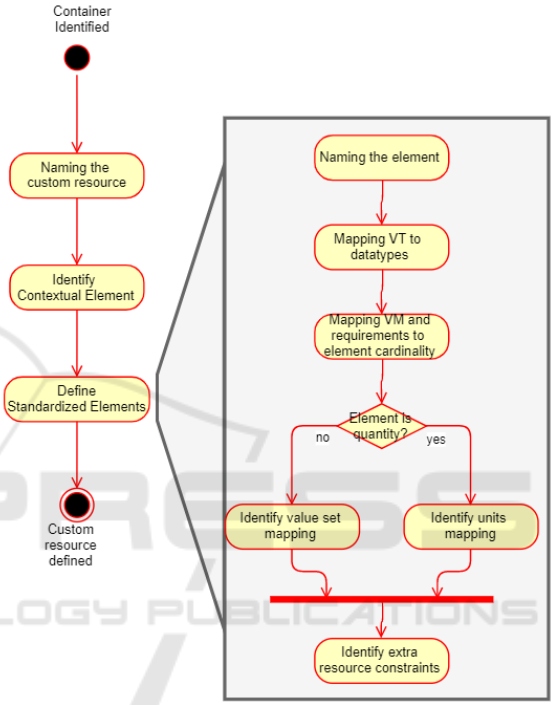

Figure 4: Workflow to define custom FHIR® resources from Radiation DICOM® templates.

The first step is to name the custom resource. The name is based on the code used to identify the container. Each custom resource contains two kinds of elements: contextual elements and standardized elements. The second step is to define contextual elements. They are defined based on the contextual usage of the resource. Contextual elements describe the context of the resource, such as encounter information, patient identification, performed exam identification, exam description, and exam date.

The third step is to identify the standardized elements, their cardinalities, datatypes, and constraints. For each content item in the TIDs, an element or a sub-element in the FHIR® custom resource is created. We applied the following rules:

- The concept name defines the name of the FHIR® element, using the name of the attribute in lower camel case. Example: the content item with the

value EV (113764, DCM, ”Acquisition Plane”) is transformed into element with the name ”acquisitionPlane”.

- The level of the content item is respected, i.e. the Nesting Level (NL) in the parent container is the same as in the custom FHIR® resource.
- The relationship with parent is ignored.
- The VT (Value Type) is mapped with its corresponding primitive or complex types. Table 1 describes the mapping between VT types and FHIR® datatypes.
- The Value Multiplicity (VM) and Requirement Type (Req Type) define the cardinality of the element in the defined custom resource. The cardinality of the FHIR® elements is based on the combination of the values of both VM and requirement type. The table 2 describes the mapping to FHIR® cardinalities as identified by our analysis. This table was partially described in PS3.16, paragraph ”6.1.7 - Requirement Type” (DICOM, 2020c).
- The value set constraints can define:
  - The list of supported value sets if the element is a CodeableConcept
  - The unit of the element if it is of type quantity
- The Condition column defines the constraints related to the custom resource elements

Table 1: Mapping between VT values and FHIR® Datatypes.

VT values	FHIR® Datatypes
CODE	CodeableConcept
UIDREF	string
TEXT	string
DATETIME	dateTime
NUM	integer ‖ decimal ‖ quantity
IMAGE	string

Table 2: Mapping between VM and Req type values, and FHIR® Cardinalities.

VM	Req Type	FHIR® Card
1	M	1..1
1	U	0..1
1	MC	0..1
1-n	M	1..*
1-n	U	0..*
1-n	MC	0..*

This methodology can be used to generate custom resources for any kind of SR template, not only dose information templates.

5 RESULTS

5.1 Custom Dose Resources Definition

The described methodology allowed the definition of custom resources for the different Dose SRs. The different custom resources are defined using FHIR® spreadsheet authoring structure, allowing generating a Dose Implementation Guide (IG) by leveraging the FHIR® IG publisher tool. The generated IG facilitates communication with third parties as it follows the FHIR® IG publisher style. Let’s take the example of the TID 10011: CT Radiation Dose. Figure 5 describes the structure of this TID as described in the DICOM® standard, PS3.16 (DICOM, 2020c).

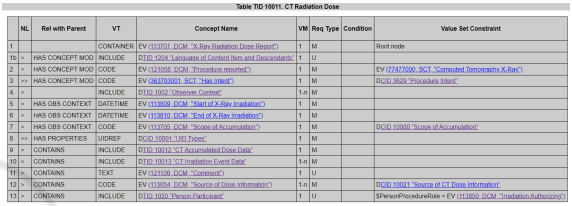

Table TID 10011. CT Radiation Dose

	NL	Rel with Parent	VT	Concept Name	VM	Req Type	Condition	Value Set Constraint
1			CONTAINER	EV (113701, DCM, "X-Ray Radiation Dose Report")	1	M		Root node
1b	>	HAS CONCEPT MOD	INCLUDE	DTID 1204 "Language of Content Item and Descendants"	1	U		
2	>	HAS CONCEPT MOD	CODE	EV (121058, DCM, "Procedure reported")	1	M		EV (77477000, SCT, "Computed Tomography X-Ray")
3	>>	HAS CONCEPT MOD	CODE	EV (363703001, SCT, "Has intent")	1	M		DCID 3629 "Procedure Intent"
4	>		INCLUDE	DTID 1002 "Observer Context"	1-n	M		
5	>	HAS OBS CONTEXT	DATETIME	EV (113809, DCM, "Start of X-Ray Irradiation")	1	M		
6	>	HAS OBS CONTEXT	DATETIME	EV (113810, DCM, "End of X-Ray Irradiation")	1	M		
7	>	HAS OBS CONTEXT	CODE	EV (113705, DCM, "Scope of Accumulation")	1	M		DCID 10000 "Scope of Accumulation"
8	>>	HAS PROPERTIES	UIDREF	DCID 10001 "UID Types"	1	M		
9	>	CONTAINS	INCLUDE	DTID 10012 "CT Accumulated Dose Data"	1	M		
10	>	CONTAINS	INCLUDE	DTID 10013 "CT Irradiation Event Data"	1-n	M		
11	>	CONTAINS	TEXT	EV (121106, DCM, "Comment")	1	U		
12	>	CONTAINS	CODE	EV (113854, DCM, "Source of Dose Information")	1-n	M		DCID 10021 "Source of CT Dose Information"
13	>	CONTAINS	INCLUDE	DTID 1020 "Person Participant"	1	U		$PersonProcedureRole = EV (113850, DCM, "Irradiation Authorizing")

Figure 5: TID 10011 - CT Radiation Dose.

This TID contains a parent container item, which translated then into a custom FHIR® resource. Figure 6 shows the mapping between the TID items and the FHIR® resource elements.

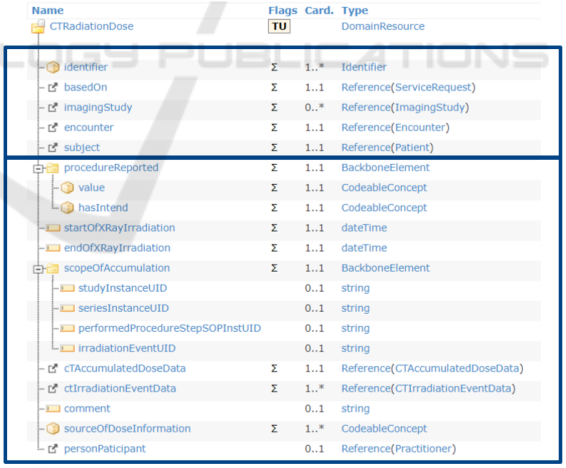

Figure 6: Custom FHIR® resource for the TID 10011 - CT Radiation Dose.

Note there are two parts: the contextual elements and the standardized elements. In this example, the contextual elements are: identifiers of the resource, serviceRequest, imagingStudy, encounter, and patient. This information defines the context on which the CT radiation dose was defined, and the different related stakeholders.

The second part of the resource is the standard-

ized elements as defined in the DICOM® standard and TID 10011. For example, the sourceOfDoseInformation is taken from the TID 10011, CT Radiation Dose, under the content item number 12 (DICOM, 2020c), and identified by EV (113854, DCM, "Source of Dose Information"). In the DICOM® standard, the related content item has the Value Multiplicity (VM) of 1-n, and the Requirement Type to 'M'; this is translated to a FHIR® cardinality of 1..n in the custom resource, based on the table 2 of mapping of cardinalities. In the Content Item, VT is 'CODE' with a defined value set CID 10021 "Source of CT Dose Information", translated to the CodeableConcept from FHIR® datatypes. Note that the nested levels are respected inside the defined custom resource and the usage of the summary marker in the defined custom resource. This allows summary of the resource and a lightweight query to the dose management system when possible. The identification of elements that need to be part of the summary resource depends on the defined resource.

5.2 Comparison between Custom FHIR Resources and Observation based Solution

In this paper, we adopted a custom FHIR® resources solution; however, there is another possible solution to describe the different containers inside the RDSRs, which is the Observation based solution. This solution is referenced in the DICOM® SR to FHIR® mapping working item from Imaging Integration WG (DICOM, 2020b). To profile dose SR through Observation resource, here are the steps that can be followed:

- When a content item is describing a container, or has nested content items, or has the cardinality 1-n, it shall be described as an independent observation.
- This observation shall follow these rules:
  - Its code element shall follow the code from DICOM® content item definition
  - If it does not have nested content items, it shall have a value element and no components
  - If it has nested content items, it may have "hasMember" and component elements.
    - If a nested content item is translated into Observation, it shall be referenced in the "hasMember" element
    - If the nested content item is not translated into observation resource, a component element needs to be defined, with a slicing using the code identifier of the content item.

Following these rules, an example of profiling the Observation resource to cover the CT Radiation Dose is described in the picture 7. We used FHIR® Shorthand for the profiling process (HL7, 2020b).

Name	Flags	Card.	Type
Observation		0..*	Observation
identifier		1..*	(Slice Definition)
identifier:studyInstanceUID		1..1	Identifier
identifier:radiationSRUID		0..*	Identifier
identifier:accessionNumber		0..1	Identifier
partOf		1..*	(Slice Definition)
partOf:imagingStudyRef		1..1	Reference(MedicationAdministration | MedicationDispense | MedicationStatement | Procedure | Immunization | ImagingStudy)
code			
subject		1..1	Reference(Patient)
performer		0..*	(Slice Definition)
performer:personParticipant		0..1	Reference(Practitioner)
hasMember		4..*	(Slice Definition)
hasMember:procedureReported		1..1	Reference(CTProcedureReported)
hasMember:scopeOfAccumulation		1..1	Reference(CTScopeOfAccumulation)
hasMember:cTAccumulatedDoseData		0..1	Reference(CTAccumulatedDoseData)
hasMember:ctIrradiationEventData		1..*	Reference(CTIrradiationEventData)
hasMember:sourceOfDoseInformation		1..*	Reference(CTSourceOfDoseInformation)
component		0..*	(Slice Definition)
component:startOfXRayIrradiation		0..1	BackboneElement
component:endOfXRayIrradiation		0..1	BackboneElement
component:comment		0..1	BackboneElement

Figure 7: CT Radiation Dose profiled through Observation resources.

This profiling allows description of the CT radiation dose contents inside an Observation resource, with three additional nested Observation resources. Even if the same data elements are described in this structure of resource, the complexity of the structure is higher in the Observation based solution compared to the custom resources based solution: four Observation resources are used instead of one custom resource. Also, the use of component instead of custom elements increases the complexity of searching of the data inside the resource. For instance, collecting the endOfXRayIrradiation is less complex in the custom resource than in the Observation based resources. The table 3 compares the characteristics of each solution.

The following metrics describes the improvements between custom resource solution and an observation based solution. A sample of 500 resources were selected, 250 custom resources and 250 Observation resources, describing the same CTRadiationDose data. Four metrics were analyzed:

- The number of characters generated (describing the network footprint)
- The number of lines generated in pretty format (describing the complexity of the structure)
- The response time from the hosting server
- The laps of time to perform a marshalling from JSON to Java

We calculate the average of the metrics for each solution and we divide the value found for custom resources by the value found for Observation resources.

Table 3: Custom resources vs Observation based resources.

	Custom resource solution	Observation based solution
Small network footprint	✓	X
Ease of interpretation by tools	✓	X
Supports "_summary" option	✓	X
Lower processing footprint	✓	X
Human readability	✓	X
Less concepts management	✓	X
Semantic/meaning of the resource	✓	X
Ease of EHR integration	X	✓
Ease of specification	X	✓

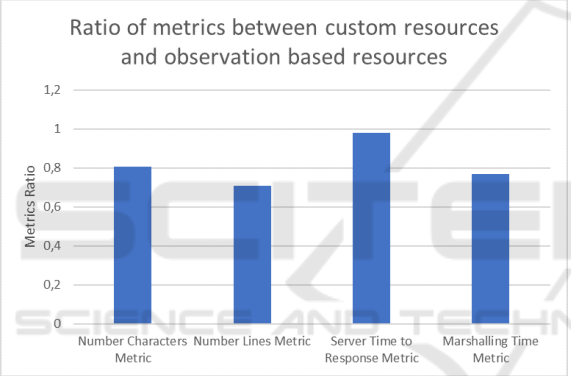

Figure 8: FHIR® custom resources VS Observation based resources performance.

The metrics analysis demonstrates an average of 20% improvement with custom resources compared to the Observation resources. The better network footprint results from a fewer number of exchanged characters compared to the Observation resources. The number of lines is also smaller in custom resources versus Observation resources (an improvement of 30%); this explains the better server response time and marshalling time for custom resources.

Custom resources support the definition of elements as summary elements, which also allows improvement in the network footprint, in some use cases. In custom resources, there is no need to maintain identifying concepts of components and codes of observations. Also, as radiation information is not a typical observation, we estimate that the meaning of the custom resource is more appropriate than in observation based resources.

A major advantage of using the observation based solution is the ease of integration with existing EHRs. In fact, most EHRs supporting FHIR® already include FHIR® server, and integrating a profiled observation resource is much easier than integrating a custom resource, which may need additional effort by the EHR providers. For instance, US Core (HL7, 2020e) is using the Observation resource to profile many healthcare data like patient BMI, heart rate, body temperature, etc.; this profiling simplifies the adoption by EHRs. From specification perspective, FHIR® resources profiling is easier than defining custom resources, as there are many tools allowing to profile FHIR® resources like FHIR® Shorthand (HL7, 2020b) or SIMPLIFIER.NET (K. Gopinathan, 2018).

6 CONCLUSION

In this paper, we described our methodology for detailing dose information through custom FHIR® resources. This methodology takes advantages of both the FHIR® and DICOM® standards: from one, it takes advantage of the normalization of resources exchange, basic datatypes, and existing tooling; from the other, it takes advantage of the stability of structures defined within the RDSR templates. This methodology brings added value to dose management systems, especially through third party applications. The defined methodology opens new perspectives for dose management systems to integrate with hospital ecosystem, as a provider of enhanced dose data, and not simply as a consumer of dose information from modalities. This methodology proves its strengthen in multiple aspects compared to an Observation based solution. The exposition of the dose resources improves the communication by normalizing data exchange between applications, and simplifying the integration with patient facing applications, or business intelligence programs. Although the methodology proved its strengthen and its multiple possible applications, an effort to normalize the different custom resources needs to be performed with a greater level of FHIR® community participation, for standardization and adoption.

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