# COPD MANAGEMENT CLINICAL DECISION SUPPORT SYSTEM: technical documentation

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# General Information

## System Overview

The COPD-CDS system is a cloud-based system that enables users to request support when managing the COPD of a patient via an electronic health record (EHR) system. Notifications for decision support comply with HL7 CDS Hooks specifications. Results from COPD-CDS are HL7-FHIR compliant.

The COPD-CDS system supports COPD management in two stages: first, the system assesses the COPD severity of the patient using the context data which is part of the client’s request call under hook with Id ‘copd-assess’. Next, the system reviews the patient’s COPD treatment and provides a collection of care plan proposals to update the patient’s COPD treatment pathway. This is done as part of hook ‘copd-careplan-review’.

The COPD-CDS system is composed of a collection of microservices to handle the context data included in an EHR system request for support, to enact computer-interpretable guidelines (CIGs), and to identify potential conflicting interactions among recommendations within a CIG (which it may be composed of one or more parts of distinct CIGs). Additionally, there is an argumentation-based mitigation service to convert a (possibly merged) CIG into a set of safe care plan proposals along with the rationale for including each recommendation as part of the care plan (personalised care planning).

## Authorised Use Permission

This document and the corresponding COPD-CDS system are part of ROAD2H: Resource Optimisation, Argumentation, Decision Support and Knowledge Transfer to create Value via Learning Health Systems (<https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/P029558/1>). Access to the CDS system is limited and permission must be sought before making copies. Please contact the relevant department for more information.

## Points of contact

### Information

|  |  |  |
| --- | --- | --- |
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### Coordination

All queries regarding installation or use of the COPD-CDS system should be addressed to:

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## Acronyms and Abbreviations

|  |  |
| --- | --- |
| CDS | Clinical Decision Support |
| CDS-HsM | CDS Hooks Manager microservice |
| CDS-SsM | CDS Services Manager microservice |
| EHR | Electronic Health Records |
| COPD | Chronic Obstructive Pulmonary Disease |
| GOLD | Chronic Obstructive Pulmonary Disease |
| CIG | Computer-Interpretable Guideline |

# System Concepts

This section describes the features of the COPD-CDS system, and the technologies used to build it.

## Available CDS Services

* **Hook `copd-assess`:** this hook is triggered when the pulmonologist has completed the airflow limitation severity assessment on the current patient with COPD. The hook context contains pairs of COPD measurements for CAT and mMRC dyspnoea scale scores, one pair taken from the patient record from a previous COPD assessment visit (if a previous visit exists) and another of measurements taken on the current encounter. Similarly for the number of COPD exacerbations. Additionally, the context includes information on whether asthma is present in the patient as well as the COPD diagnosis from the previous COPD visit (if such visit exists), that is, the identified COPD group and active COPD treatment. The result suggests a GOLD 2017 COPD group (that is, A, B, C, or D) and a list of preferentially ordered COPD treatments, both outcomes are personalised for the COPD patient at hand.
* **Hook `copd-careplan-review`:** this hook is triggered when the pulmonologist has assessed the COPD severity of the patient, by assigning/confirming a GOLD 2017 COPD group as well as selecting one or more COPD treatments for care planning decision support. The hook context contains the GOLD 20017 COPD group selected by the clinician, along with two collections of COPD drug types, or drug type combinations, one collection includes the treatments proposed by the pulmonologist alongside the patient; the other collection includes the treatment preferences as suggested by the COPD-CDS system as a response to hook `copd-assess` on the active patient. Additionally, there is some lifestyle and demographics information, and comorbidities and immunization status data. The response of the COPD-CDS system is composed of a collection of personalised care plan proposals, based on GOLD 2017, where each proposal contains non-conflictive clinical recommendations that have been selected taking into account the pulmonologist/patient preferences on COPD treatments, as well as other factors such as immunization, lifestyle -e.g., smoking status- and active comorbidities present in the patient's record, in particular cardiovascular and chronic kidney diseases, which could potentially interfere with some COPD treatments.

## System Specification

The technologies used to construct the COPD-CDS system are

* Node.js v16.17
* Docker v4.13.0
* MongoDB v6.0
* SWI-Prolog v8.4.3
* Apache Jena-Fuseki v4.6.1
* SPARQL v1.1
* HL7 CDS Hooks v2.0
* HL7 FHIR v4.3.0
* SNOWSTORM by SNOMED International v7.11.0
* Python v3.4.0

# Getting Started

## System Requirements

Most of the system -excluding the mitigation service which it is currently live, running at a Heroku server address- has been dockerised (the process of packing, deploying, and running an application using Docker containers) so that there is no specific requirement for distinct operating systems. The software can run on machines with potentially any operating system installed, assuming the Docker desktop app is available for download for said operating system.

* Docker desktop can be downloaded here: <https://www.docker.com/products/docker-desktop/> .
* To simulate API request calls to the COPD-CDS system, download Postman v10 or higher here: <https://www.postman.com/>.
* To clone the source code from the Github repository, download git here: <https://git-scm.com/>.
* The COPD-CDS system repository is available here: <https://github.com/susoDominguez/COPD-CDS>
* The CDS-HsM repository is available here: <https://github.com/susoDominguez/cds-services-manager>
* The TMR-based CDS-SsM repository is available here: <https://github.com/susoDominguez/cds_hooks_manager>
* The TMR-based authoring tool, that is, the Interaction, Store and Reasoner microservices, is available here <https://github.com/susoDominguez/TMRWebX>
* The argumentation-based conflict resolution service is available here: <https://github.com/susoDominguez/ABAPlusG>
* The mapping from TMR terms (and `copd-assess` structured results, since there is no CIG involved) to FHIR instances is available here: <https://github.com/susoDominguez/TMR2FHIRconverter>
* The TMR ontologies and COPD CIG file are available here: <https://github.com/susoDominguez/TMR-CIG-COPD>
* The CDS hooks specifications, with examples, for `copd-assess` and `copd-careplan-review` are available here: <https://github.com/susoDominguez/ROAD2H-hooks>
* The MongoDB-based hook processing documents for `copd-assess` and `copd-careplan-review` are available here: <https://github.com/susoDominguez/mongodb-hook-processing-collections.git>
* The SNOMED CT server installation can be found here: <https://github.com/IHTSDO/snowstorm>. We access it using their FHIR API.

## Installation

1. Download and Install Docker and Git.
2. Clone the COPD-CDS repository to your computer. This repository contains a docker-compose file to automate the build and running of the applications involved in the system.

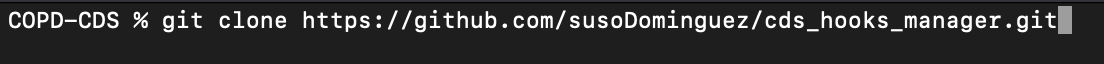


(Other cloning options are available from git)

1. change to the COPD-CDS directory
2. Inside the COPD-CDS folder do
   1. Clone the TMR-based authoring tool



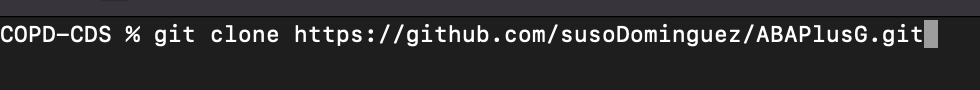
* 1. Clone the CDS-HsM repository



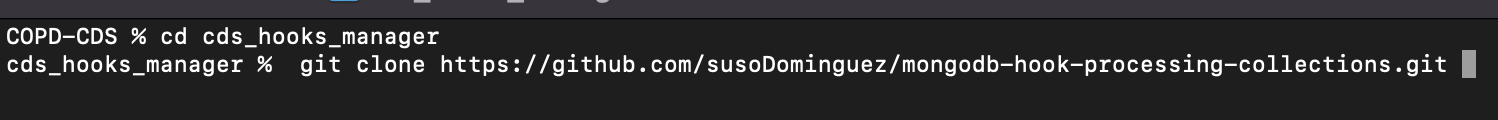
* 1. Clone the CDS-SsM repository



* 1. Clone the ABA+G repository



1. Let’s add the CDS Hooks processing documents to the CDS-HsM
   1. Go to the CDS-HsM directory
   2. Clone the processing documents repository into CDS-HsM

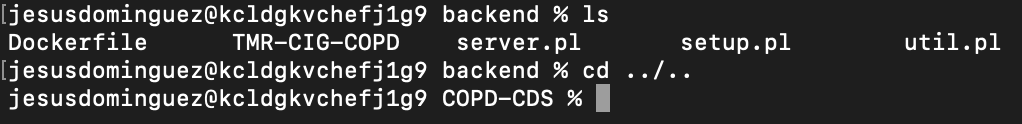


1. Let’s add the TMR schema and ontologies to the TMR-based authoring tool.
   1. Go back to the main folder of COPD-CDS
   2. Go to the reasoner microservice directory (/TMRWebX/backend/)
   3. Clone the TMR ontology

Text

Description automatically generated

* 1. Go back to the COPD-CDS directory



1. Next, let’s add the TMR to FHIR converter repository to the CDS-SsM
   1. Go to the FHIR\_converter\_module folder within the CDS-SsM.
   2. Clone the TMR2FHIRconverter repository.

Text

Description automatically generated

* 1. Return to the COPD-CDS directory to launch the application

Graphical user interface, text

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1. Now we are ready to build and launch the COPD-DSS.

## Configuration

The collection of microservices is built automatically using an environment file within the COPD-CDS directory. Below, we provide the set of variables, and default values, that must be added to the environment file. Values can be changed by the user if required. A brief description of the semantics of each variable can be found after the assignment of values to variables.

**MONGODB\_PORT=**27017

**CDS\_HM\_PORT=**3001

**CDS\_SM\_PORT=**3010

**SNOMEDCT\_FHIR\_SRVR\_URL=**snowstorm-fhir.snomedtools.org

**CDS\_SM\_LOGS=**cds\_sm\_logs

**CDS\_HM\_LOGS=**cds\_hm\_logs

**CIG\_INTERACTION\_PORT=**8888

**CIG\_STORE\_PWD=**road2h

**CIG\_STORE\_PORT=**3030

**ARGUMENTATION\_PORT=**5000

* **MONGODB\_PORT:** port number of the MongoDB server
* **CDS\_HM\_PORT:** port number of the CDS-HsM
* **CDS\_SM\_PORT** port number of the CDS-SsM
* **SNOMEDCT\_FHIR\_SRVR\_URL:** URL of the SNOMED CT FHIR API server. For testing purposes, we have provided the sandbox offered by the team at SNOWSTORM. If you would like to install your own SNOMED CT server and add its FHIR API URL instead, follow the instructions at <https://github.com/IHTSDO/snowstorm>
* **CDS\_SM\_LOGS:** name of the MongoDB collection to store CDS-SsM logs
* **CDS\_HM\_LOGS:** name of the MongoDB collection to store CDS-HsM logs
* **CIG\_INTERACTION\_PORT:** port number of the CIG Interaction microservice
* **CIG\_STORE\_PWD:** password to access the Jena/Fuseki server with ADMIN rights as part of the STORE microservice
* **CIG\_STORE\_PORT:** port number of the Jena/Fuseki database
* **ARGUMENTATION\_PORT:** port number of the conflict resolution service

Now, create the environment file with name **.env** and use your favourite text editor to add the set of variables and corresponding values into the folder of COPD-CDS.

Graphical user interface, text

Description automatically generated

Finally, launch the COPD-CDS system:

Text

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Then, all the services should be up and running.



Figure . Illustration depicting the collection of microservices, and conflict resolution service involved in the COPD-CDS system.

## Loading TMR Knowledge into the Store microservice

The final step is to load the TMR ontologies into the Store microservice. To do that, in your browser go to <http://localhost:3030/>. When asked for credentials, the username is **admin** and the password is the one given to variable **CIG\_STORE\_PWD.** You will find the server with 4 empty datasets:

Graphical user interface, application

Description automatically generated

* In the row with dataset name **/CIG-COPD,** click on *add data* button then on *select files* button in the next page. The file is in *COPD-CDS/TMRWebX/backend/TMR-CIG-COPD/ontologies/guidelines/CIG-COPD.trig.* Open the file, then select *upload all* button.
* Similarly for dataset **/beliefs**, which has its corresponding file in *COPD-CDS/TMRWebX/backend/TMR-CIG-COPD/ontologies/beliefs\_shorten.trig.*
* Similarly for dataset **/*careActions***, which has its corresponding file in *COPD-CDS/TMRWebX/backend/TMR-CIG-COPD/ontologies/careActions.trig.*
* Similarly for dataset **/transitions**, which has its corresponding file in *COPD-CDS/TMRWebX/backend/TMR-CIG-COPD/ontologies/transitions.trig.*

The system installation is now finished.

We have provided an additional microservice, mongo-express web server, that is linked to the MongoDB database and can be used to view/modify the collection of CDS hooks processing documents applied to both hooks. The web server is located by default in <http://localhost:8081/>.

# Using the COPD-CDS System

To request support from the COPD-CDS system, a notification must be sent using the CDS hooks specifications for hooks `copd-assess’ and `copd-careplan-review`.

CDS hooks specifications, with examples, for both hook contexts with Ids `copd-assess’ and `copd-careplan-review` alongside JSON-based input files for each of the use cases and hooks can be found here: <https://github.com/susoDominguez/ROAD2H-hooks>.

Next, we demonstrate how to launch each of the hooks with the JSON-based input files taken from the repository stated above.

## LAunch

### Hook ‘copd-assess’

To invoke CDS for hook with Id ‘copd-assess’ and clinical workflow context from use case 1, we must make a request call as follows:

curl --location --request POST '127.0.0.1:3001/cds-services/copd-assess' \

--header 'Content-Type: application/json' \

--data-raw 'useCase\_1.json'

where *useCase\_1.json* is the file with the JSON document to be used as input for the COPD severity assessment of the first use case. The document is excessive in length to have it added on this document, but it is stored in the ROAD2H-hooks repository, in directory `ROAD2H use cases/copd-assess hook contexts`.

The response from the COPD-CDS system is a CDS suggestion card with the following (abbreviated) information:

{

"cards": [{

"summary": "Assessment of COPD",

"indicator": "info",

"source": {

"label": "GOLD 2017 COPD assessment"

},

"suggestions": [{

"label": "COPD assessment decision support",

"uuid": "00000001677163",

"actions": [{

"type": "update",

"description": "Update COPD assessment interface",

"resource": {

"resourceType": "Parameters",

"id": "copdAssessParameters",

"parameter": [{

"name": "patient",

"valueId": "1677163"

},

{

"name": "medicationBundle",

"resource": {

"resourceType": "Bundle",

"id": "medicationBundle",

"type": "collection",

"entry": [{

"resource": {

"resourceType": "Medication",

"id": "DrugCatLabaLama",

"code": {

"coding": [{

"code": "LabaLama",

"display": "medication containing a combination of LABA and LAMA"

}]

}

}

},{…},{…},{…},{…},{…},{…},

{

"resource": {

"resourceType": "Medication",

"id": "DrugCatLabaLamaIcs",

"code": {

"coding": [{

"code": "LabaLamaIcs",

"display": "medication containing a combination of LABA, LAMA and ICS"

}]

}

}

}

]

}

},

{

"name": "assessedCopdStage",

"valueCoding": {

"system": "http://snomed.info/sct",

"code": "1097901000000101"

}

},

{

"name": "copdGroupA",

"part": […]

},

{

"name": "copdGroupB",

"part": […]

},

{

"name": "copdGroupC",

"part": […]

},

{

"name": "copdGroupD",

"part": [{

"name": "code",

"valueCoding": {

"system": "http://snomed.info/sct",

"code": "1097901000000101",

"display": "Global Initiative for Chronic Obstructive Lung Disease 2017 group D"

}

},

{

"name": "medicationPreference\_1",

"resource": {

"resourceType": "List",

"id": "list1",

"status": "current",

"mode": "changes",

"entry": [{

"item": {

"reference": "Medication/DrugCatLabaLama"

}

}]

}

},

{

"name": "medicationPreference\_2",

"resource": {

"resourceType": "List",

"id": "list2",

"status": "current",

"mode": "changes",

"entry": [{

"item": {

"reference": "Medication/DrugCatLabaLamaIcs"

}

}]

}

},

{

"name": "medicationPreference\_3",

"resource": {

"resourceType": "List",

"id": "list3",

"status": "current",

"mode": "changes",

"entry": [{

"item": {

"reference": "Medication/DrugCatLabaIcs"

}

}]

}

},

{

"name": "medicationPreference\_4",

"resource": {

"resourceType": "List",

"id": "list4",

"status": "current",

"mode": "changes",

"entry": [{

"item": {

"reference": "Medication/DrugTLama"

}

}]

}

}

]

}

]

}

}]

}],

"selectionBehaviour": "at-most-one"

}]

}

Observe the card contains parameters to describe the patient identifier, the collection of drug types and drug type combinations for COPD, the personalised GOLD group (labelled as assessedCopdStage), and four parameters denoting each GOLD group (labelled as copdGroupA, copdGroupB, copdGroupC, and copdGroupD for GOLD group A – D, respectively). The personalised GOLD group is the result of the COPD severity symptom assessment using both current and previous measurements taken by the pulmonologist. Each parameter denoting a GOLD group contains the SNOMED CT term that represents said GOLD group and a list of ordered COPD drug types. Drug types have a priority order which follows the GOLD guideline algorithm for selecting suitable COPD treatment pathways for COPD patients. Although parameter with label assessedCopdStage identifies the current GOLD group of the patient, the COPD-CDS system provides a COPD treatment priority order for all four GOLD groups using the same clinical workflow context, to provide all available information to the pulmonologist while they verify/confirm the COPD-CDS system response.

The patient in this use case has been assessed by the COPD-CDS system as belonging to GOLD group D. Parameter copdGroupD contains four COPD treatments pathways, each labelled as medicationPreference\_n where n is the COPD treatment preference level, ranging from 1 -the most preferred- to 4 -the least preferred-. Then, each medicationPreference\_n contains an unordered list of references to FHIR medication instances in this CDS card, under resource labelled as medicationBundle. Accordingly, medicationPreference\_1 has solely one reference, to the FHIR medication denoting a combination of LABA and LAMA bronchodilators; medicationPreference\_2 has also a single reference, to the FHIR medication denoting a combination of LABA and LAMA and ICS bronchodilators; medicationPreference\_3 has a single reference to the FHIR medication denoting a combination of LABA and ICS bronchodilators; and medicationPreference\_4 has a single reference to the FHIR medication denoting a bronchodilator of type LAMA.

### hook ‘copd-careplan-review’

To invoke CDS for hook with Id ‘copd-careplan-review’ and clinical workflow context from use case 1, we must make a request call as follows:

curl --location --request POST

'127.0.0.1:3001/cds-services/copd-careplan-review/cigModel/tmr' \

--header 'Content-Type: application/json' \

--data-raw 'useCase\_1.json'

where *useCase\_1.json* is the file with the JSON document to be used as input for the COPD treatment management of the first use case. The document is excessive in length to have it added on this document, but it is stored in the ROAD2H-hooks repository, in directory `ROAD2H use cases/copd-careplan-review hook contexts`.

The response from the COPD-CDS system is a CDS suggestion card with the following entries:

#### Medication resources

Medication resources in the context of the COPD-CDS system represent the application of care actions and include both the vaccines and the collection of COPD drug types or type combinations which are active in any of the care plan proposals suggested by the COPD-CDS system. For this iteration of the project, clinical terms returned to the CDS client were not identified by structured clinical vocabularies like SNOMED CT, but by the internal codes used by the TMR ontology.

{

"resource": {

"resourceType": "Medication",

"id": "DrugTFluVac",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugTFluVac",

"code": "FluVac",

"display": "administer influenza vaccine"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugTIcs",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugTIcs",

"code": "Ics",

"display": "administer inhaled corticosteroids"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugCatLabaIcs",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugCatLabaIcs",

"code": "LabaIcs",

"display": "administer a combination of LABA and ICS"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugTLama",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugTLama",

"code": "Lama",

"display": "administer LAMA"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugCatLabaLama",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugCatLabaLama",

"code": "LabaLama",

"display": "administer a combination of LABA and LAMA"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugCatBetaAgonist",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugCatBetaAgonist",

"code": "BetaAgonist",

"display": "administer Beta Agonists when cardiovascular disease is present"

}

]

}

}

},

{

"resource": {

"resourceType": "Medication",

"id": "DrugCatLabaLamaIcs",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/DrugCatLabaLamaIcs",

"code": "LabaLamaIcs",

"display": "administer a combination of LABA, LAMA and ICS"

}

]

}

}

}

Medications are referenced by FHIR medicationRequest resources, which we illustrate after introduction other canonical resources that are also included in a medicationRequest.

Next, we introduce the collection of FHIR condition entries shown in the CDS card response.

#### condition resources

Condition resources that are not included directly within another resource (such as FHIR forecastEffect, a TMR-specialised FHIR type which it is introduced below) represent initial states, or situations, of a TMR transition, that is, the state in which the measured clinical property is found prior application of a care action. In this CDS card, we have the following entries:

{

"resource": {

"resourceType": "Condition",

"id": "SitHghRskFlu",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitHghRskFlu",

"code": "SitHghRskFlu",

"display": "having a high risk of contracting influenza disease"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "Condition",

"id": "SitPrQol",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitPrQol",

"code": "SitPrQol",

"display": "having a poor quality of life"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "Condition",

"id": "SitLwRskPneumn",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitLwRskPneumn",

"code": "SitLwRskPneumn",

"display": "having a low risk of contracting pneumonia"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "Condition",

"id": "SitVerySevAls",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitVerySevAls",

"code": "SitVerySevAls",

"display": "having a very severe airflow limitation severity"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "Condition",

"id": "SitPrLngHlth",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitPrLngHlth",

"code": "SitPrLngHlth",

"display": "having a poor pulmonary health"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "Condition",

"id": "SitLwRskCrd",

"code": {

"coding": [

{

"system": "http://anonymous.org/data/SitLwRskCrd",

"code": "SitLwRskCrd",

"display": "low risk of having cardiac rhythm disturbances"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

}

Condition resources are referenced by forecastEffect resources, which we introduce next.

#### Forecasteffect resources

FHIR forecastEffect was designed to represent a TMR causation belief term, that is, the expected main, and possibly secondary, effects of administering a care action to a patient to change the state of a clinical property. The definition of FHIR forecastEffect can be found in <https://github.com/susoDominguez/ROAD2H-hooks>. A descriptive example is given next, after introducing the collection of forecastEffect entries which are part of the CDS card response.

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitHghRskFlu2SitLwRskFluMp",

"typeOfEffect": "main-effect",

"typeOfEvent": "therapeutic-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "MedicationRequest/RecCOPD-FluVacDecPropRskFluShould"

}

],

"conditionAddressed": {

"reference": "Condition/SitHghRskFlu"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitLwRskFlu",

"code": "SitLwRskFlu",

"display": "having a low risk of contracting influenza disease"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropRskFlu",

"code": "PropRskFlu",

"display": "risk of contracting influenza disease"

}

]

},

"degreeOfChange": "decrease"

},

"probability": "always",

"evidence": "high"

}

},

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitPrQol2SitNrmQolMp",

"typeOfEffect": "main-effect",

"typeOfEvent": "therapeutic-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "ServiceRequest/RecCOPD-SmokeThrpyIncPropQolShould"

}

],

"conditionAddressed": {

"reference": "Condition/SitPrQol"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitNrmQol",

"code": "SitNrmQol",

"display": "having a standard quality of life"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropQol",

"code": "PropQol",

"display": "quality of life"

}

]

},

"degreeOfChange": "increase"

},

"probability": "always",

"evidence": "high"

}

},

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitLwRskPneumn2SitHghRskPneumnMn",

"typeOfEffect": "main-effect",

"typeOfEvent": "adverse-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "MedicationRequest/RecCOPD-IcsIncPropRskPneumnShouldnot"

}

],

"conditionAddressed": {

"reference": "Condition/SitLwRskPneumn"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitHghRskPneumn",

"code": "SitHghRskPneumn",

"display": "having a high risk of contracting pneumonia"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropRskPneumn",

"code": "PropRskPneumn",

"display": "risk of pneumonia"

}

]

},

"degreeOfChange": "increase"

},

"probability": "always",

"evidence": "high"

}

},

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitVerySevAls2SitSevAlsMp",

"typeOfEffect": "main-effect",

"typeOfEvent": "therapeutic-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "MedicationRequest/RecCOPD-LabaIcsDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaIcsDecVerySevPropAlsShould"

}

],

"conditionAddressed": {

"reference": "Condition/SitVerySevAls"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitSevAls",

"code": "SitSevAls",

"display": "having a severe airflow limitation severity"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropAls",

"code": "PropAls",

"display": "airflow limitation severity"

}

]

},

"degreeOfChange": "decrease"

},

"probability": "always",

"evidence": "high"

}

},

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitPrLngHlth2SitNrmLngHlthMp",

"typeOfEffect": "main-effect",

"typeOfEvent": "therapeutic-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "ServiceRequest/RecCOPD-LngRehabIncPropLngHlthShould"

}

],

"conditionAddressed": {

"reference": "Condition/SitPrLngHlth"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitNrmLngHlth",

"code": "SitNrmLngHlth",

"display": "having a standard pulmonary health"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropLngHlth",

"code": "PropLngHlth",

"display": "pulmonary health"

}

]

},

"degreeOfChange": "increase"

},

"probability": "always",

"evidence": "high"

}

},

{

"resource": {

"resourceType": "ForecastEffect",

"id": "SitLwRskCrd2SitHghRskCrdMn",

"typeOfEffect": "main-effect",

"typeOfEvent": "adverse-effect",

"subject": {

"reference": "Patient/1677163"

},

"appliesTo": {

"careActionInstance": [

{

"reference": "MedicationRequest/RecCOPD-BetaAgonistIncPropRskCrdShouldnot"

}

],

"conditionAddressed": {

"reference": "Condition/SitLwRskCrd"

}

},

"expectedOutcomeCode": {

"coding": [

{

"system": "http://anonymous.org/data/SitHghRskCrd",

"code": "SitHghRskCrd",

"display": "high risk of having cardiac rhythm disturbances"

}

]

},

"targetMeasurement": {

"measuredProperty": {

"coding": [

{

"system": "http://anonymous.org/data/PropRskCrd",

"code": "PropRskCrd",

"display": "risk of cardiac rhythm disturbances"

}

]

},

"degreeOfChange": "increase"

},

"probability": "always",

"evidence": "high"

}

}

Let’s go over the forecastEffect instance with id = SitVerySevAls2SitSevAlsMp. In a nutshell, this resource represents the expected effect of administering COPD treatments to a patient with very severe COPD symptoms, that is, a patient assessed to follow treatment pathways from GOLD group D. The type of effect is denoted as main-effect (for this proof-of-concept we did not include side-effects) and the type of event as therapeutical, that is, the effect of the care action, or actions, has a positive result in the overall health of the patient, particularly in *decreasing* (see parameter degreeOfChange) the condition addressed -represented as a reference to one of the condition resources we introduced earlier-: *having a very severe airflow limitation severity*. The expected outcome of this forecastEffect is also represented in the resource: *having a severe airflow limitation severity.* Both the initial state and expected outcome share the same measured property, that is, the property that the user wants to change by administering a care action. In this case, the measured property is the *airflow limitation severity*. Observe that this causation belief, or forecastEffect resource, is shared by more than one care action, in fact, it is share by four care actions, each representing a medicationRequest resource for each of the personalised COPD treatments from GOLD group D suitable for the current patient. MedicationRequest resources are introduced next. Finally, the forecastEffect resource identifies the probability (always) of this effect happening as described, and the level of evidence (high) found in the literature to make such claim. Parameters probability and evidence have fixed values for all forecastEffect resources in this iteration of the project.

#### medicationrequest and servicerequest resources

MedicationRequest and ServiceRequest resources describe the reasons and outcomes of care actions in a patient. The former is applicable to (drug-based) treatments and the latter to therapies.

{

"resource": {

"resourceType": "ServiceRequest",

"id": "RecCOPD-SmokeThrpyIncPropQolShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitPrQol"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitPrQol2SitNrmQolMp"

}

],

"code": {

"coding": [

{

"system": "http://anonymous.org/data/NonDrugTSmokeThrpy",

"code": "SmokeThrpy",

"display": "administer smoking cessation therapy"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "ServiceRequest",

"id": "RecCOPD-LngRehabIncPropLngHlthShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitPrLngHlth"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitPrLngHlth2SitNrmLngHlthMp"

}

],

"code": {

"coding": [

{

"system": "http://anonymous.org/data/NonDrugTLngRehab",

"code": "LngRehab",

"display": "administer pulmonary rehabilitation"

}

]

},

"subject": {

"reference": "Patient/1677163"

}

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-FluVacDecPropRskFluShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitHghRskFlu"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitHghRskFlu2SitLwRskFluMp"

}

],

"medicationReference": {

"reference": "Medication/DrugTFluVac"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": []

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-IcsIncPropRskPneumnShouldnot",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": true,

"reasonReference": [

{

"reference": "Condition/SitLwRskPneumn"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitLwRskPneumn2SitHghRskPneumnMn"

}

],

"medicationReference": {

"reference": "Medication/DrugTIcs"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": [

{

"reference": "DetectedIssue/contradiction2"

},

{

"reference": "DetectedIssue/contradiction3"

}

]

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-LabaIcsDecVerySevPropAlsShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitVerySevAls"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitVerySevAls2SitSevAlsMp"

}

],

"medicationReference": {

"reference": "Medication/DrugCatLabaIcs"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": [

{

"reference": "DetectedIssue/alternative1"

},

{

"reference": "DetectedIssue/contradiction2"

}

]

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-LamaDecVerySevPropAlsShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitVerySevAls"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitVerySevAls2SitSevAlsMp"

}

],

"medicationReference": {

"reference": "Medication/DrugTLama"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": [

{

"reference": "DetectedIssue/repetition0"

},

{

"reference": "DetectedIssue/alternative1"

}

]

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-LabaLamaDecVerySevPropAlsShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitVerySevAls"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitVerySevAls2SitSevAlsMp"

}

],

"medicationReference": {

"reference": "Medication/DrugCatLabaLama"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": [

{

"reference": "DetectedIssue/repetition0"

},

{

"reference": "DetectedIssue/alternative1"

}

]

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-BetaAgonistIncPropRskCrdShouldnot",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": true,

"reasonReference": [

{

"reference": "Condition/SitLwRskCrd"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitLwRskCrd2SitHghRskCrdMn"

}

],

"medicationReference": {

"reference": "Medication/DrugCatBetaAgonist"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": []

}

},

{

"resource": {

"resourceType": "MedicationRequest",

"id": "RecCOPD-LabaLamaIcsDecVerySevPropAlsShould",

"status": "active",

"intent": "plan",

"instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf",

"doNotPerform": false,

"reasonReference": [

{

"reference": "Condition/SitVerySevAls"

}

],

"forecast-effects": [

{

"reference": "ForecastEffect/SitVerySevAls2SitSevAlsMp"

}

],

"medicationReference": {

"reference": "Medication/DrugCatLabaLamaIcs"

},

"subject": {

"reference": "Patient/1677163"

},

"detectedIssue": [

{

"reference": "DetectedIssue/repetition0"

},

{

"reference": "DetectedIssue/alternative1"

},

{

"reference": "DetectedIssue/contradiction3"

}

]

}

}

MedicationRequest and ServiceRequest resources are intended as part of a care plan ("intent": "plan") and the evidence is taken from the GOLD guideline ("instantiatesUri": "https://goldcopd.org/wp-content/uploads/2016/12/wms-GOLD-2017-Pocket-Guide.pdf"). Each resource references one or more forecastEffect instances (a main-effect and zero or more side-effect instances). For instance, as we demonstrated above, each of the MedicationRequest instances representing a COPD treatment from GOLD group D have the same forecastEffect reference, and, equally, the same condition referencing the initial state (very severe) of the airflow limitation severity. A crucial part of either resource is the parameter "doNotPerform", which can be either true, then the recommendation is to not administer the care action, or false, which implies the recommendation has positive effects and thus it should be applied. Among other parameters, we also have "detectedIssue", which references resources of the same name, and identifies potential interactions that have been previously detected by the logic rules of the TMR framework.

Following the codes and references from each MedicationRequest and ServiceRequest we can deduce the following information (starting at the top of the shown resources):

* A request to administer smoking cessation therapy towards having a standard quality of life.
* A request to administer pulmonary rehabilitation towards having a standard pulmonary health.
* A request to administer the influenza vaccina towards having a low risk of contracting influenza disease.
* A request to NOT administer ICS to avoid having a high risk of contracting pneumonia.
  + A contradiction interaction has been detected regarding this request.
* A request to administer a combination of LABA + ICS towards decreasing airflow limitation severity from very severe to severe.
  + An alternative interaction has been detected regarding this request.
  + A contradiction interaction has been detected regarding this request.
* A request to administer LAMA towards decreasing airflow limitation severity from very severe to severe.
  + A repetition interaction has been detected regarding this request.
  + An alternative interaction has been detected regarding this request.
* A request to administer a combination of LABA + LAMA towards decreasing airflow limitation severity from very severe to severe.
  + A repetition interaction has been detected regarding this request.
  + An alternative interaction has been detected regarding this request.
* A request to NOT administer beta agonists when cardiovascular disease is present to avoid risk of cardiac rhythm disturbances from having a high risk to a low risk.
  + A contradiction interaction has been detected regarding this request.
* A request to administer a combination of LABA + LAMA + ICS towards decreasing airflow limitation severity from very severe to severe.
  + A repetition interaction has been detected regarding this request.
  + An alternative interaction has been detected regarding this request.
  + A contradiction interaction has been detected regarding this request.

We go over FHIR DetectedIssue types next.

#### detectedissue resources

As stated in the FHIR resource types page (<http://www.hl7.org/fhir/detectedissue.html>), DetectedIssue resources indicate an actual or potential clinical issue with or between one or more active or proposed clinical actions for a patient; e.g. Drug-drug interaction, Ineffective treatment frequency, Procedure-condition conflict, etc.

Let’s have a look at the instances shown in the CDS card:

{

"resource": {

"resourceType": "DetectedIssue",

"id": "repetition0",

"status": "preliminary",

"code": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "DUPTHPY",

"display": "Duplicate Therapy Alert"

}

]

},

"implicated": [

{

"reference": "MedicationRequest/RecCOPD-LabaLamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaIcsDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LamaDecVerySevPropAlsShould"

}

],

"mitigation": [

{

"action": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "13",

"display": "Stopped Concurrent Therapy"

}

]

}

}

]

}

},

{

"resource": {

"resourceType": "DetectedIssue",

"id": "alternative1",

"status": "preliminary",

"code": {

"coding": [

{

"system": "http://anonymous.org/CodeSystem/interactions",

"code": "ALTHRPY",

"display": "Alternative Therapies With Same Intended Effect"

}

]

},

"implicated": [

{

"reference": "MedicationRequest/RecCOPD-LabaIcsDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaIcsDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-LamaDecVerySevPropAlsShould"

}

],

"mitigation": [

{

"action": {

"coding": [

{

"system": "http://anonymous.org/CodeSystem/interactions",

"code": "NOTREQ",

"display": "Mitigation Not Required"

}

]

}

}

]

}

},

{

"resource": {

"resourceType": "DetectedIssue",

"id": "contradiction2",

"status": "preliminary",

"code": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "DACT",

"display": "Drug Action Detected Issue"

}

]

},

"implicated": [

{

"reference": "MedicationRequest/RecCOPD-IcsIncPropRskPneumnShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-LabaIcsDecVerySevPropAlsShould"

}

],

"mitigation": [

{

"action": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "13",

"display": "Stopped Concurrent Therapy"

}

]

}

}

]

}

},

{

"resource": {

"resourceType": "DetectedIssue",

"id": "contradiction3",

"status": "preliminary",

"code": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "DACT",

"display": "Drug Action Detected Issue"

}

]

},

"implicated": [

{

"reference": "MedicationRequest/RecCOPD-IcsIncPropRskPneumnShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaIcsDecVerySevPropAlsShould"

}

],

"mitigation": [

{

"action": {

"coding": [

{

"system": "http://terminology.hl7.org/CodeSystem/v3-ActCode",

"code": "13",

"display": "Stopped Concurrent Therapy"

}

]

}

}

]

}

}

The DetectedIssue resource identifies the interaction, the implicated FHIR MedicationRequest instances and the mitigation applied by the conflict mitigation service. The instances are self-explanatory hence we move on to the last part, the FHIR carePlan which, with support from the conflict mitigation service, distributes MedicationRequest and ServiceRequest resources into personalised conflict-safe care plan proposals.

#### careplan resources

There are four proposals designed by the COPD-CDS system as COPD management care plans. One for each COPD treatment included.

{

"resource": {

"resourceType": "CarePlan",

"id": "CarePlan0",

"status": "active",

"intent": "plan",

"title": "suggested treatments: LABA + LAMA ",

"subject": {

"reference": "Patient/1677163"

},

"activity": [

{

"reference": "MedicationRequest/RecCOPD-LabaLamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-IcsIncPropRskPneumnShouldnot"

},

{

"reference": "ServiceRequest/RecCOPD-SmokeThrpyIncPropQolShould"

},

{

"reference": "ServiceRequest/RecCOPD-LngRehabIncPropLngHlthShould"

},

{

"reference": "MedicationRequest/RecCOPD-BetaAgonistIncPropRskCrdShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-FluVacDecPropRskFluShould"

}

]

}

},

{

"resource": {

"resourceType": "CarePlan",

"id": "CarePlan1",

"status": "active",

"intent": "plan",

"title": "suggested treatments: LAMA ",

"subject": {

"reference": "Patient/1677163"

},

"activity": [

{

"reference": "MedicationRequest/RecCOPD-LamaDecVerySevPropAlsShould"

},

{

"reference": "MedicationRequest/RecCOPD-IcsIncPropRskPneumnShouldnot"

},

{

"reference": "ServiceRequest/RecCOPD-SmokeThrpyIncPropQolShould"

},

{

"reference": "ServiceRequest/RecCOPD-LngRehabIncPropLngHlthShould"

},

{

"reference": "MedicationRequest/RecCOPD-BetaAgonistIncPropRskCrdShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-FluVacDecPropRskFluShould"

}

]

}

},

{

"resource": {

"resourceType": "CarePlan",

"id": "CarePlan2",

"status": "active",

"intent": "plan",

"title": "suggested treatments: LABA + ICS ",

"subject": {

"reference": "Patient/1677163"

},

"activity": [

{

"reference": "ServiceRequest/RecCOPD-SmokeThrpyIncPropQolShould"

},

{

"reference": "ServiceRequest/RecCOPD-LngRehabIncPropLngHlthShould"

},

{

"reference": "MedicationRequest/RecCOPD-BetaAgonistIncPropRskCrdShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-FluVacDecPropRskFluShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaIcsDecVerySevPropAlsShould"

}

]

}

},

{

"resource": {

"resourceType": "CarePlan",

"id": "CarePlan3",

"status": "active",

"intent": "plan",

"title": "suggested treatments: LABA + LAMA + ICS ",

"subject": {

"reference": "Patient/1677163"

},

"activity": [

{

"reference": "ServiceRequest/RecCOPD-SmokeThrpyIncPropQolShould"

},

{

"reference": "ServiceRequest/RecCOPD-LngRehabIncPropLngHlthShould"

},

{

"reference": "MedicationRequest/RecCOPD-BetaAgonistIncPropRskCrdShouldnot"

},

{

"reference": "MedicationRequest/RecCOPD-FluVacDecPropRskFluShould"

},

{

"reference": "MedicationRequest/RecCOPD-LabaLamaIcsDecVerySevPropAlsShould"

}

]

}

}

For each of the carePlan instances, the main COPD drug type or drug type combination has been identified and added as part of the title, for a quick reference for the user to view. Observe that the carePlan instance is simply a collection of references to FHIR MedicationRequest and ServiceRequest instances that have been introduced above. The carePlan resource is the entry point for the graphical user interface to display information relevant to the current patient and the management of their COPD symptoms.