Red Hat Decision Manager 7.13

Getting started with Red Hat Decision Manager
Abstract

This document describes how to get started with decision services and planning solutions in Red Hat Decision Manager.
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PREFACE

As a developer of business decisions, you can use Red Hat Decision Manager to develop decision services using a variety of available assets. You can also use Red Hat build of OptaPlanner to find the optimal solution to planning problems based on a set of limited resources and under specific constraints.
MAKING OPEN SOURCE MORE INCLUSIVE

Red Hat is committed to replacing problematic language in our code, documentation, and web properties. We are beginning with these four terms: master, slave, blacklist, and whitelist. Because of the enormity of this endeavor, these changes will be implemented gradually over several upcoming releases. For more details, see our CTO Chris Wright’s message.
PART I. GETTING STARTED WITH DECISION SERVICES IN RED HAT PROCESS AUTOMATION MANAGER
As a business rules developer, you can use Business Central in Red Hat Decision Manager or the Red Hat Decision Manager DMN modeler in VS Code to design a variety of decision services. Red Hat Decision Manager provides example projects with example business assets directly in Business Central as a reference. This document describes how to create and test an example traffic violation project based on the Traffic_Violation sample project included in Business Central. This sample project uses a Decision Model and Notation (DMN) model to define driver penalty and suspension rules in a traffic violation decision service. You can follow the steps in this document to create the project and the assets it contains, or open and review the existing Traffic_Violation sample project.
For more information about the DMN components and implementation in Red Hat Decision Manager, see Designing a decision service using DMN models.

Prerequisites
- Red Hat JBoss Enterprise Application Platform 7.4 is installed. For installation information, see Red Hat JBoss Enterprise Application Platform 7.4 Installation Guide.
- Red Hat Process Automation Manager is installed and configured with KIE Server. For more information see Installing and configuring Red Hat Decision Manager on Red Hat JBoss EAP 7.4.
- Red Hat Decision Manager is running and you can log in to Business Central with the developer role. For more information, see Planning a Red Hat Decision Manager installation.
CHAPTER 1. SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL

Business Central contains sample projects with business assets that you can use as a reference for the rules or other assets that you create in your own Red Hat Decision Manager projects. Each sample project is designed differently to demonstrate decision management or business optimization assets and logic in Red Hat Decision Manager.

NOTE

Red Hat does not provide support for the sample code included in the Red Hat Decision Manager distribution.

The following sample projects are available in Business Central:

- **Course_Scheduling**: (Business optimization) Course scheduling and curriculum decision process. Assigns lectures to rooms and determines a student’s curriculum based on factors such as course conflicts and classroom capacity.

- **Dinner_Party**: (Business optimization) Guest seating optimization using guided decision tables. Assigns guest seating based on each guest’s job type, political beliefs, and known relationships.

- **Employee_Rostering**: (Business optimization) Employee rostering optimization using decision and solver assets. Assigns employees to shifts based on skills.


- **IT_Orders**: (Process automation and case management) Ordering case using business process and case management assets. Places an IT hardware order based on needs and approvals.

- **Mortgages**: (Decision management with rules) Loan approval process using rule-based decision assets. Determines loan eligibility based on applicant data and qualifications.

- **Mortgage_Process**: (Process automation) Loan approval process using business process and decision assets. Determines loan eligibility based on applicant data and qualifications.

- **OptaCloud**: (Business optimization) Resource allocation optimization using decision and solver assets. Assigns processes to computers with limited resources.

- **Traffic_Violation**: (Decision management with DMN) Traffic violation decision service using a Decision Model and Notation (DMN) model. Determines driver penalty and suspension based on traffic violations.

1.1. ACCESSING SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL

You can use the sample projects in Business Central to explore business assets as a reference for the rules or other assets that you create in your own Red Hat Decision Manager projects.

Prerequisites

- Business Central is installed and running. For installation options, see *Planning a Red Hat Decision Manager installation*. 
Procedure

1. In Business Central, go to **Menu** → **Design** → **Projects**. If there are existing projects, you can access the samples by clicking the MySpace default space and selecting **Try Samples** from the Add Project drop-down menu. If there are no existing projects, click **Try samples**.

2. Review the descriptions for each sample project to determine which project you want to explore. Each sample project is designed differently to demonstrate decision management or business optimization assets and logic in Red Hat Decision Manager.

3. Select one or more sample projects and click **Ok** to add the projects to your space.

4. In the **Projects** page of your space, select one of the sample projects to view the assets for that project.

5. Select each asset to explore how the project is designed to achieve the specified goal or workflow. Some of the sample projects contain more than one page of assets. Click the left or right arrows in the upper-right corner to view the full asset list.

   **Figure 1.1. Asset page selection**

   

   ![1-15 of 21](<1 of 2)

6. In the upper-right corner of the project **Assets** page, click **Build** to build the sample project or **Deploy** to build the project and then deploy it to KIE Server.

   **NOTE**

   You can also select the **Build & Install** option to build the project and publish the KJAR file to the configured Maven repository without deploying to a KIE Server. In a development environment, you can click **Deploy** to deploy the built KJAR file to a KIE Server without stopping any running instances (if applicable), or click **Redeploy** to deploy the built KJAR file and replace all instances. The next time you deploy or redeploy the built KJAR, the previous deployment unit (KIE container) is automatically updated in the same target KIE Server. In a production environment, the **Redeploy** option is disabled and you can click **Deploy** only to deploy the built KJAR file to a new deployment unit (KIE container) on a KIE Server.

   To configure the KIE Server environment mode, set the `org.kie.server.mode` system property to `org.kie.server.mode=development` or `org.kie.server.mode=production`. To configure the deployment behavior for a corresponding project in Business Central, go to project **Settings** → **General Settings** → **Version**, toggle the **Development Mode** option, and click **Save**. By default, KIE Server and all new projects in Business Central are in development mode. You cannot deploy a project with **Development Mode** turned on or with a manually added `SNAPSHOT` version suffix to a KIE Server that is in production mode.

   To review project deployment details, click **View deployment details** in the deployment banner at the top of the screen or in the **Deploy** drop-down menu. This option directs you to the **Menu** → **Deploy** → **Execution Servers** page.
CHAPTER 2. RED HAT DECISION MANAGER BPMN AND DMN MODELERS

Red Hat Decision Manager provides the following extensions or applications that you can use to design Business Process Model and Notation (BPMN) process models and Decision Model and Notation (DMN) decision models using graphical modelers.

- **Business Central**: Enables you to view and design BPMN models, DMN models, and test scenario files in a related embedded designer. To use Business Central, you can set up a development environment containing a Business Central to design business rules and processes, and a KIE Server to execute and test the created business rules and processes.

- **Red Hat Decision Manager VS Code extension**: Enables you to view and design BPMN models, DMN models, and test scenario files in Visual Studio Code (VS Code). The VS Code extension requires VS Code 1.46.0 or later. To install the Red Hat Decision Manager VS Code extension, select the Extensions menu option in VS Code and search for and install the Red Hat Business Automation Bundle extension.

- **Standalone BPMN and DMN editors**: Enable you to view and design BPMN and DMN models embedded in your web applications. To download the necessary files, you can either use the NPM artifacts from the NPM registry or download the JavaScript files directly for the DMN standalone editor library at https://<YOUR_PAGE>/dmn/index.js and for the BPMN standalone editor library at https://<YOUR_PAGE>/bpmn/index.js.

2.1. INSTALLING THE RED HAT DECISION MANAGER VS CODE EXTENSION BUNDLE

Red Hat Decision Manager provides a Red Hat Business Automation Bundle VS Code extension that enables you to design Decision Model and Notation (DMN) decision models, Business Process Model and Notation (BPMN) 2.0 business processes, and test scenarios directly in VS Code. VS Code is the preferred integrated development environment (IDE) for developing new business applications. Red Hat Decision Manager also provides individual DMN Editor and BPMN Editor VS Code extensions for DMN or BPMN support only, if needed.

**IMPORTANT**

The editors in the VS Code are partially compatible with the editors in the Business Central, and several Business Central features are not supported in the VS Code.

Prerequisites

- The latest stable version of VS Code is installed.

Procedure

1. In your VS Code IDE, select the Extensions menu option and search for Red Hat Business Automation Bundle for DMN, BPMN, and test scenario file support. For DMN or BPMN file support only, you can also search for the individual DMN Editor or BPMN Editor extensions.

2. When the Red Hat Business Automation Bundle extension appears in VS Code, select it and click Install.
3. For optimal VS Code editor behavior, after the extension installation is complete, reload or close and re-launch your instance of VS Code.

After you install the VS Code extension bundle, any .dmn, .bpmn, or .bpmn2 files that you open or create in VS Code are automatically displayed as graphical models. Additionally, any .scesim files that you open or create are automatically displayed as tabular test scenario models for testing the functionality of your business decisions.

If the DMN, BPMN, or test scenario modelers open only the XML source of a DMN, BPMN, or test scenario file and displays an error message, review the reported errors and the model file to ensure that all elements are correctly defined.

NOTE

For new DMN or BPMN models, you can also enter dmn.new or bpmn.new in a web browser to design your DMN or BPMN model in the online modeler. When you finish creating your model, you can click Download in the online modeler page to import your DMN or BPMN file into your Red Hat Decision Manager project in VS Code.

2.2. CONFIGURING THE RED HAT DECISION MANAGER STANDALONE EDITORS

Red Hat Decision Manager provides standalone editors that are distributed in a self-contained library providing an all-in-one JavaScript file for each editor. The JavaScript file uses a comprehensive API to set and control the editor.

You can install the standalone editors using the following methods:

- Download each JavaScript file manually
- Use the NPM package

Procedure

1. Install the standalone editors using one of the following methods:
   Download each JavaScript file manually For this method, follow these steps:
   a. Download the JavaScript files.
   b. Add the downloaded Javascript files to your hosted application.
   c. Add the following <script> tag to your HTML page:

   ```
   Script tag for your HTML page for the DMN editor
   
   <script src="https://<YOUR_PAGE>/dmn/index.js"></script>
   
   Script tag for your HTML page for the BPMN editor
   
   <script src="https://<YOUR_PAGE>/bpmn/index.js"></script>
   ```

   Use the NPM package: For this method, follow these steps:
   a. Add the NPM package to your package.json file:
Adding the NPM package

```
  npm install @kie-tools/kie-editors-standalone
```

b. Import each editor library to your **TypeScript** file:

**Importing each editor**

```
import * as DmnEditor from "@kie-tools/kie-editors-standalone/dist/dmn"
import * as BpmnEditor from "@kie-tools/kie-editors-standalone/dist/bpmn"
```

2. After you install the standalone editors, open the required editor by using the provided editor API, as shown in the following example for opening a DMN editor. The API is the same for each editor.

**Opening the DMN standalone editor**

```javascript
const editor = DmnEditor.open({
  container: document.getElementById("dmn-editor-container"),
  initialContent: Promise.resolve(""),
  readOnly: false,
  origin: "",
  resources: new Map([
    ["MyIncludedModel.dmn",
      {
        contentType: "text",
        content: Promise.resolve(""
      }
    ]
  ])
});
```

Use the following parameters with the editor API:

**Table 2.1. Example parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>container</td>
<td>HTML element in which the editor is appended.</td>
</tr>
<tr>
<td>initialContent</td>
<td>Promise to a DMN model content. This parameter can be empty, as shown in the following examples:</td>
</tr>
<tr>
<td></td>
<td>- Promise.resolve(&quot;&quot;&quot;)</td>
</tr>
<tr>
<td></td>
<td>- Promise.resolve(&quot;&lt;DIAGRAM_CONTENT_DIRECTLY_HERE&gt;&quot;)</td>
</tr>
<tr>
<td></td>
<td>- fetch(&quot;MyDmnModel.dmn&quot;).then(content =&gt; content.text())</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>readOnly</strong> (Optional)</td>
<td>Enables you to allow changes in the editor. Set to <strong>false</strong> (default) to allow content editing and <strong>true</strong> for read-only mode in editor.</td>
</tr>
<tr>
<td><strong>origin</strong> (Optional)</td>
<td>Origin of the repository. The default value is <code>window.location.origin</code>.</td>
</tr>
<tr>
<td><strong>resources</strong> (Optional)</td>
<td>Map of resources for the editor. For example, this parameter is used to provide included models for the DMN editor or work item definitions for the BPMN editor. Each entry in the map contains a resource name and an object that consists of <strong>content-type</strong> (<strong>text</strong> or <strong>binary</strong>) and <strong>content</strong> (similar to the <strong>initialContent</strong> parameter).</td>
</tr>
</tbody>
</table>

The returned object contains the methods that are required to manipulate the editor.

**Table 2.2. Returned object methods**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>getContent(): Promise&lt;string&gt;</strong></td>
<td>Returns a promise containing the editor content.</td>
</tr>
<tr>
<td><strong>setContent(path: string, content: string): void</strong></td>
<td>Sets the content of the editor.</td>
</tr>
<tr>
<td><strong>getPreview(): Promise&lt;string&gt;</strong></td>
<td>Returns a promise containing an SVG string of the current diagram.</td>
</tr>
<tr>
<td><strong>subscribeToContentChanges(callback: (isDirty: boolean) ⇒ void): (isDirty: boolean) ⇒ void</strong></td>
<td>Sets a callback to be called when the content changes in the editor and returns the same callback to be used for unsubscription.</td>
</tr>
<tr>
<td><strong>unsubscribeToContentChanges(callback: (isDirty: boolean) ⇒ void): void</strong></td>
<td>Unsubscribes the passed callback when the content changes in the editor.</td>
</tr>
<tr>
<td><strong>markAsSaved(): void</strong></td>
<td>Resets the editor state that indicates that the content in the editor is saved. Also, it activates the subscribed callbacks related to content change.</td>
</tr>
<tr>
<td><strong>undo(): void</strong></td>
<td>Undoes the last change in the editor. Also, it activates the subscribed callbacks related to content change.</td>
</tr>
<tr>
<td><strong>redo(): void</strong></td>
<td>Redoes the last undone change in the editor. Also, it activates the subscribed callbacks related to content change.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>close(): void</td>
<td>Closes the editor.</td>
</tr>
<tr>
<td>getElementPosition(selector: string): Promise&lt;Rect&gt;</td>
<td>Provides an alternative to extend the standard query selector when an element lives inside a canvas or a video component. The selector parameter must follow the (&lt;\text{PROVIDER}&gt;::&lt;\text{SELECT}&gt;) format, such as Canvas:::MySquare or Video:::PresenterHand. This method returns a Rect representing the element position.</td>
</tr>
<tr>
<td>envelopeApi: MessageBusClientApi&lt;KogitoEditorEnvelopeApi&gt;</td>
<td>This is an advanced editor API. For more information about advanced editor API, see MessageBusClientApi and KogitoEditorEnvelopeApi.</td>
</tr>
</tbody>
</table>
CHAPTER 3. CREATING AND EXECUTING DMN AND BPMN MODELS USING MAVEN

You can use Maven archetypes to develop DMN and BPMN models in VS Code using the Red Hat Decision Manager VS Code extension instead of Business Central. You can then integrate your archetypes with your Red Hat Decision Manager decision and process services in Business Central as needed. This method of developing DMN and BPMN models is helpful for building new business applications using the Red Hat Decision Manager VS Code extension.

Procedure

1. In a command terminal, navigate to a local folder where you want to store the new Red Hat Decision Manager project.

2. Enter the following command to use a Maven archetype to generate a project within a defined folder:

   Generating a project using Maven archetype

```
mvn archetype:generate \
   -DarchetypeGroupId=org.kie \
   -DarchetypeArtifactId=kie-kjar-archetype \
   -DarchetypeVersion=7.67.0.Final-redhat-00024
```

   This command generates a Maven project with required dependencies and generates required directories and files to build your business application. You can use the Git version control system (recommended) when developing a project.

   If you want to generate multiple projects in the same directory, specify the `artifactId` and `groupId` of the generated business application by adding `-DgroupId=<groupid> -DartifactId=<artifactId>` to the previous command.

3. In your VS Code IDE, click File, select Open Folder, and navigate to the folder that is generated using the previous command.

4. Before creating the first asset, set a package for your business application, for example, `org.kie.businessapp`, and create respective directories in the following paths:

   - `PROJECT_HOME/src/main/java`
   - `PROJECT_HOME/src/main/resources`
   - `PROJECT_HOME/src/test/resources`

   For example, you can create `PROJECT_HOME/src/main/java/org/kie/businessapp` for `org.kie.businessapp` package.

5. Use VS Code to create assets for your business application. You can create the assets supported by Red Hat Decision Manager VS Code extension using the following ways:

   - To create a business process, create a new file with `.bpmn` or `.bpmn2` in `PROJECT_HOME/src/main/resources/org/kie/businessapp` directory, such as `Process.bpmn`.
To create a DMN model, create a new file with .dmn in
PROJECT_HOME/src/main/resources/org/kie/businessapp directory, such as AgeDecision.dmn.

To create a test scenario simulation model, create a new file with .scesim in
PROJECT_HOME/src/test/resources/org/kie/businessapp directory, such as TestAgeScenario.scesim.

6. After you create the assets in your Maven archetype, navigate to the root directory (contains pom.xml) of the project in the command line and run the following command to build the knowledge JAR (KJAR) of your project:

```
mvn clean install
```

If the build fails, address any problems described in the command line error messages and try again to validate the project until the build is successful. However, if the build is successful, you can find the artifact of your business application in PROJECT_HOME/target directory.

**NOTE**

Use `mvn clean install` command often to validate your project after each major change during development.

You can deploy the generated knowledge JAR (KJAR) of your business application on a running KIE Server using the REST API. For more information about using REST API, see *Interacting with Red Hat Decision Manager using KIE APIs*. 
CHAPTER 4. CREATING THE TRAFFIC VIOLATIONS PROJECT IN BUSINESS CENTRAL

For this example, create a new project called traffic-violation. A project is a container for assets such as data objects, DMN assets, and test scenarios. This example project that you are creating is similar to the existing Traffic_Violation sample project in Business Central.

Procedure

1. In Business Central, go to **Menu → Design → Projects**. Red Hat Decision Manager provides a default space called **MySpace**. You can use the default space to create and test example projects.

2. Click **Add Project**.

3. Enter **traffic-violation** in the **Name** field.

4. Click **Add**.

   ![Figure 4.1. Add Project window](image)

   The **Assets** view of the project opens.
Decision Model and Notation (DMN) is a standard established by the Object Management Group (OMG) for describing and modeling operational decisions. DMN defines an XML schema that enables DMN models to be shared between DMN-compliant platforms and across organizations so that business analysts and business rules developers can collaborate in designing and implementing DMN decision services. The DMN standard is similar to and can be used together with the Business Process Model and Notation (BPMN) standard for designing and modeling business processes.

For more information about the background and applications of DMN, see the OMG Decision Model and Notation specification.

### 5.1. CREATING THE TRAFFIC VIOLATIONS DMN DECISION REQUIREMENTS DIAGRAM (DRD)

A decision requirements diagram (DRD) is a visual representation of your DMN model. Use the DMN designer in Business Central to design the DRD for the traffic violations project and to define the decision logic of the DRD components.

**Figure 5.1. DRD for the Traffic Violations example**

**Prerequisites**
• You have created the traffic violations project in Business Central.

Procedure

1. On the traffic-violation project’s home page, click Add Asset.

2. On the Add Asset page, click DMN. The Create new DMN window is opened.
   a. In the Create new DMN window, enter Traffic Violation in the DMN name field.
   b. From the Package list, select com.myspace.traffic_violation.
   c. Click Ok. The DMN asset in the DMN designer is opened.

3. In the DMN designer canvas, drag two DMN Input Data input nodes onto the canvas.

   Figure 5.2. DMN Input Data nodes

4. In the upper-right corner, click the icon.

5. Double-click the input nodes and rename one to Driver and the other to Violation.

6. Drag a DMN Decision decision node onto the canvas.

7. Double-click the decision node and rename it to Fine.

8. Click the Violation input node, select the Create DMN Information Requirement icon and click the Fine decision node to link the two nodes.
9. Drag a **DMN Decision** decision node onto the canvas.

10. Double-click the decision node and rename it to **Should the driver be suspended?**.

11. Click the **Driver** input node, select the **Create DMN Information Requirement** icon and click the **Should the driver be suspended?** decision node to link the two nodes.

12. Click the **Fine** decision node, select the **Create DMN Information Requirement** icon, and select the **Should the driver be suspended?** decision node.

13. Click **Save**.

**NOTE**

As you periodically save a DRD, the DMN designer performs a static validation of the DMN model and might produce error messages until the model is defined completely. After you finish defining the DMN model completely, if any errors remain, troubleshoot the specified problems accordingly.

### 5.2. Creating the Traffic Violations DMN Custom Data Types

DMN data types determine the structure of the data that you use within a table, column, or field in a DMN boxed expression for defining decision logic. You can use default DMN data types (such as string, number, or boolean) or you can create custom data types to specify additional fields and constraints that you want to implement for the boxed expression values. Use the DMN designer’s **Data Types** tab in Business Central to define the custom data types for the traffic violations project.
The following tables list the **tDriver**, **tViolation**, and **tFine** custom data types that you will create for this project.

### Table 5.1. tDriver custom data type

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>tDriver</td>
<td>Structure</td>
</tr>
<tr>
<td>Name</td>
<td>string</td>
</tr>
<tr>
<td>Age</td>
<td>number</td>
</tr>
<tr>
<td>State</td>
<td>string</td>
</tr>
<tr>
<td>City</td>
<td>string</td>
</tr>
<tr>
<td>Points</td>
<td>number</td>
</tr>
</tbody>
</table>

### Table 5.2. tViolation custom data type

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>tViolation</td>
<td>Structure</td>
</tr>
<tr>
<td>Code</td>
<td>string</td>
</tr>
<tr>
<td>Date</td>
<td>date</td>
</tr>
<tr>
<td>Type</td>
<td>string</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>number</td>
</tr>
</tbody>
</table>
Table 5.3. tFine custom data type

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>tFine</td>
<td>Structure</td>
</tr>
<tr>
<td>Amount</td>
<td>number</td>
</tr>
<tr>
<td>Points</td>
<td>number</td>
</tr>
</tbody>
</table>

Prerequisites

- You created the traffic violations DMN decision requirements diagram (DRDs) in Business Central.

Procedure

1. To create the tDriver custom data type, click Add a custom Data Type on the Data Types tab, enter tDriver in the Name field, and select Structure from the Type list.

2. Click the check mark to the right of the new data type to save your changes.

3. Add each of the following nested data types to the tDriver structured data type by clicking the plus sign next to tDriver for each new nested data type. Click the check mark to the right of each new data type to save your changes.
   - Name (string)
- **Age** (number)
- **State** (string)
- **City** (string)
- **Points** (number)

4. To create the `tViolation` custom data type, click **New Data Type**, enter `tViolation` in the **Name** field, and select **Structure** from the **Type** list.

5. Click the check mark to the right of the new data type to save your changes.

**Figure 5.6. The tViolation custom data type**

![Custom Data Types](image)

6. Add each of the following nested data types to the `tViolation` structured data type by clicking the plus sign next to `tViolation` for each new nested data type. Click the check mark to the right of each new data type to save your changes.

   - **Code** (string)
   - **Date** (date)
   - **Type** (string)
   - **Speed Limit** (number)
   - **Actual Speed** (number)

7. To add the following constraints to the **Type** nested data type, click the edit icon, click **Add Constraints**, and select **Enumeration** from the **Select constraint type** drop-down menu.

   - speed
   - parking
   - driving under the influence
8. Click OK, then click the check mark to the right of the Type data type to save your changes.

9. To create the tFine custom data type, click New Data Type, enter tFine in the Name field, select Structure from the Type list, and click Save.

Figure 5.7. The tFine custom data type

10. Add each of the following nested data types to the tFine structured data type by clicking the plus sign next to tFine for each new nested data type. Click the check mark to the right of each new data type to save your changes.

   - Amount (number)
   - Points (number)

11. Click Save.

5.3. ASSIGNING CUSTOM DATA TYPES TO THE DRD INPUT AND DECISION NODES

After you create the DMN custom data types, assign them to the appropriate DMN Input Data and DMN Decision nodes in the traffic violations DRD.

Prerequisites

- You have created the traffic violations DMN custom data types in Business Central.

Procedure

1. Click the Model tab on the DMN designer and click the Properties icon in the upper-right corner of the DMN designer to expose the DRD properties.

2. In the DRD, select the Driver input data node and in the Properties panel, select tDriver from the Data type drop-down menu.

3. Select the Violation input data node and select tViolation from the Data type drop-down menu.

4. Select the Fine decision node and select tFine from the Data type drop-down menu.
5. Select the **Should the driver be suspended?** decision node and set the following properties:
   - Data type: string
   - Question: Should the driver be suspended due to points on his driver license?
   - Allowed Answers: Yes, No

6. Click **Save**.

You have assigned the custom data types to your DRD’s input and decision nodes.

### 5.4. DEFINING THE TRAFFIC VIOLATIONS DMN DECISION LOGIC

To calculate the fine and to decide whether the driver is to be suspended or not, you can define the traffic violations DMN decision logic using a DMN decision table and context boxed expression.

**Figure 5.8. Fine expression**

![Fine Expression Table]

**Figure 5.9. Should the driver be suspended expression**

![Should the driver be suspended? Context]

**Prerequisites**

- You have assigned the DMN custom data types to the appropriate decision and input nodes in the traffic violations DRD in Business Central.

**Procedure**
1. To calculate the fine, in the DMN designer canvas, select the **Fine** decision node and click the **Edit** icon to open the DMN boxed expression designer.

![Figure 5.10. Decision node edit icon](image)

2. Click **Select expression → Decision Table**.

![Figure 5.11. Select Decision Table logic type](image)

3. For the **Violation.Date**, **Violation.Code**, and **Violation.Speed Limit** columns, right-click and select **Delete** for each field.

4. Click the **Violation.Actual Speed** column header and enter the expression `Violation.Actual Speed - Violation.Speed Limit` in the **Expression** field.

5. Enter the following values in the first row of the decision table:
   - **Violation.Type**: "speed"
   - **Violation.Actual Speed - Violation.Speed Limit**: [10..30)
   - **Amount**: 500
   - **Points**: 3
     - Right-click the first row and select **Insert below** to add another row.

6. Enter the following values in the second row of the decision table:
   - **Violation.Type**: "speed"
   - **Violation.Actual Speed - Violation.Speed Limit >= 30**
- Amount: 1000
- Points: 7
  Right-click the second row and select **Insert below** to add another row.

7. Enter the following values in the third row of the decision table:
- Violation.Type: "parking"
- Violation.Actual Speed - Violation.Speed Limit -
- Amount: 100
- Points: 1
  Right-click the third row and select **Insert below** to add another row.

8. Enter the following values in the fourth row of the decision table:
- Violation.Type: "driving under the influence"
- Violation.Actual Speed - Violation.Speed Limit -
- Amount: 1000
- Points: 5

9. Click **Save**.

10. To define the driver suspension rule, return to the DMN designer canvas, select the **Should the driver be suspended?** decision node, and click the **Edit** icon to open the DMN boxed expression designer.

11. Click **Select expression → Context**.

12. Click **ContextEntry-1**, enter **Total Points** as the **Name**, and select **number** from the **Data Type** drop-down menu.

13. Click the cell next to **Total Points**, select **Literal expression** from the context menu, and enter **Driver.Points + Fine.Points** as the expression.

14. In the cell below **Driver.Points + Fine.Points** select **Literal Expression** from the context menu, and enter **if Total Points >= 20 then "Yes" else "No"**.

15. Click **Save**.

You have defined how to calculate the fine and the context for deciding when to suspend the driver. You can navigate to the traffic-violation project page and click **Build** to build the example project and address any errors noted in the **Alerts** panel.
CHAPTER 6. TEST SCENARIOS

Test scenarios in Red Hat Decision Manager enable you to validate the functionality of business rules and business rule data (for rules-based test scenarios) or of DMN models (for DMN-based test scenarios) before deploying them into a production environment. With a test scenario, you use data from your project to set given conditions and expected results based on one or more defined business rules. When you run the scenario, the expected results and actual results of the rule instance are compared. If the expected results match the actual results, the test is successful. If the expected results do not match the actual results, then the test fails.

Red Hat Decision Manager includes both the new **Test Scenarios** designer and the former **Test Scenarios (Legacy)** designer. The default designer is the new test scenarios designer, which supports the testing of both rules and DMN models and provides an enhanced overall user experience with test scenarios. If required, you can continue to use the legacy test scenarios designer, which supports rule-based test scenarios only.

**IMPORTANT**

The legacy test scenarios designer is deprecated from Red Hat Decision Manager version 7.3.0. It will be removed in a future Red Hat Decision Manager release. Use the new test scenarios designer instead.

You can run the defined test scenarios in a number of ways, for example, you can run available test scenarios at the project level or inside a specific test scenario asset. Test scenarios are independent and cannot affect or modify other test scenarios. You can run test scenarios at any time during project development in Business Central. You do not have to compile or deploy your decision service to run test scenarios.

You can import data objects from different packages to the same project package as the test scenario. Assets in the same package are imported by default. After you create the necessary data objects and the test scenario, you can use the **Data Objects** tab of the test scenarios designer to verify that all required data objects are listed or to import other existing data objects by adding a **New item**.

**IMPORTANT**

Throughout the test scenarios documentation, all references to **test scenarios** and the **test scenarios designer** are for the new version, unless explicitly noted as the legacy version.

6.1. TESTING THE TRAFFIC VIOLATIONS USING TEST SCENARIOS

Use the test scenarios designer in Business Central to test the DMN decision requirements diagrams (DRDs) and define decision logic for the traffic violations project.

Figure 6.1. Test scenario for the traffic violations example
Prerequisites

- You have successfully built the traffic violations project in Business Central.

Procedure

1. On the traffic-violation project’s home screen, click Add Asset to open the Add Asset screen.

2. Click Test Scenario to open the Create new Test Scenario dialog.
   a. Enter Violation Scenarios in the Test Scenario field.
   b. From the Package list, select com.myspace.traffic_violation.
   c. Select DMN as the Source type.
   d. From the Choose a DMN asset list, select the path to the DMN asset.
   e. Click Ok to open the Violation Scenarios test scenario in the Test Scenarios designer.

3. Under Driver column sub-header, right-click the State, City, Age, and Name value cells and select Delete column from the context menu options to remove them.

4. Under Violation column sub-header, right-click the Date and Code value cells and select Delete column to remove them.

5. Enter the following information in the first row of the test scenarios:
   - Scenario description: Above speed limit: 10km/h and 30 km/h
   - Points (under Given column header): 10
   - Type: "speed"
   - Speed Limit: 100
   - Actual Speed: 120
   - Points: 3
   - Amount: 500
   - Should the driver be suspended? "No"
     Right-click the first row and select Insert row below to add another row.

6. Enter the following information in the second row of the test scenarios:
   - Scenario description: Above speed limit: more than 30 km/h
   - Points (under Given column header): 10
   - Type: "speed"
   - Speed Limit: 100
   - Actual Speed: 150
   - Points: 7
• Amount: 1000
• Should the driver be suspended? "No"
  Right-click the second row and select Insert row below to add another row.

7. Enter the following information in the third row of the test scenarios:

• Scenario description: Parking violation
• Points (under Given column header): 10
• Type: "parking"
• Speed Limit: leave blank
• Actual Speed: leave blank
• Points: 1
• Amount: 100
• Should the driver be suspended? "No"
  Right-click the third row and select Insert row below to add another row.

8. Enter the following information in the fourth row of the test scenarios:

• Scenario description: DUI violation
• Points (under Given column header): 10
• Type: "driving under the influence"
• Speed Limit: leave blank
• Actual Speed: leave blank
• Points: 5
• Amount: 1000
• Should the driver be suspended? "No"
  Right-click the fourth row and select Insert row below to add another row.

9. Enter the following information in the fifth row of the test scenarios:

• Scenario description: Driver suspended
• Points (under Given column header): 15
• Type: "speed"
• Speed Limit: 100
• Actual Speed: 140
• Points: 7
• Amount: 1000
Should the driver be suspended? "Yes"

10. Click **Save**.

11. Click the **Play** icon to check whether the test scenarios pass or fail.

**Figure 6.2. Test scenario execution result for the traffic violations example**

In case of failure, correct the errors and run the test scenarios again.
CHAPTER 7. DMN MODEL EXECUTION

You can create or import DMN files in your Red Hat Decision Manager project using Business Central or package the DMN files as part of your project knowledge JAR (KJAR) file without Business Central. After you implement your DMN files in your Red Hat Decision Manager project, you can execute the DMN decision service by deploying the KIE container that contains it to KIE Server for remote access and interacting with the container using the KIE Server REST API.

For information about including external DMN assets with your project packaging and deployment method, see Packaging and deploying an Red Hat Decision Manager project.

7.1. EXECUTING A DMN SERVICE USING THE KIE SERVER REST API

Directly interacting with the REST endpoints of KIE Server provides the most separation between the calling code and the decision logic definition. The calling code is completely free of direct dependencies, and you can implement it in an entirely different development platform such as Node.js or .NET. The examples in this section demonstrate Nix-style curl commands but provide relevant information to adapt to any REST client.

When you use a REST endpoint of KIE Server, the best practice is to define a domain object POJO Java class, annotated with standard KIE Server marshalling annotations. For example, the following code is using a domain object Person class that is annotated properly:

Example POJO Java class

```java
@javax.xml.bind.annotation.XmlAccessorType(javax.xml.bind.annotation.XmlAccessType.FIELD)
public class Person implements java.io.Serializable {

    static final long serialVersionUID = 1L;

    private java.lang.String id;
    private java.lang.String name;

    @javax.xml.bind.annotation.adapters.XmlJavaTypeAdapter(org.kie.internal.jaxb.LocalDateXmlAdapter.class)
    private java.time.LocalDate dojoining;

    public Person() {
    }

    public java.lang.String getId() {
        return this.id;
    }

    public void setId(java.lang.String id) {
        this.id = id;
    }

    public java.lang.String getName() {
        return this.name;
    }

    public void setName(java.lang.String name) {
        this.name = name;
    }
}
```
For more information about the KIE Server REST API, see Interacting with Red Hat Decision Manager using KIE APIs.

Prerequisites

- KIE Server is installed and configured, including a known user name and credentials for a user with the kie-server role. For installation options, see Planning a Red Hat Decision Manager installation.

- You have built the DMN project as a KJAR artifact and deployed it to KIE Server:

  mvn clean install

  For more information about project packaging and deployment and executable models, see Packaging and deploying an Red Hat Decision Manager project.

- You have the ID of the KIE container containing the DMN model. If more than one model is present, you must also know the model namespace and model name of the relevant model.

Procedure

1. Determine the base URL for accessing the KIE Server REST API endpoints. This requires knowing the following values (with the default local deployment values as an example):

   - Host (localhost)
   - Port (8080)
   - Root context (kie-server)
   - Base REST path (services/rest/)

   Example base URL in local deployment for the traffic violations project:

   http://localhost:8080/kie-server/services/rest/server/containers/traffic-violation_1.0.0-SNAPSHOT

2. Determine user authentication requirements.
When users are defined directly in the KIE Server configuration, HTTP Basic authentication is used and requires the user name and password. Successful requests require that the user have the **kie-server** role.

The following example demonstrates how to add credentials to a curl request:

```bash
curl -u username:password <request>
```

If KIE Server is configured with Red Hat Single Sign-On, the request must include a bearer token:

```bash
curl -H "Authorization: bearer $TOKEN" <request>
```

3. Specify the format of the request and response. The REST API endpoints work with both JSON and XML formats and are set using request headers:

**JSON**

```bash
curl -H "accept: application/json" -H "content-type: application/json"
```

**XML**

```bash
curl -H "accept: application/xml" -H "content-type: application/xml"
```

4. Optional: Query the container for a list of deployed decision models:

```
[GET] server/containers/{containerId}/dmn
```

Example curl request:

```bash
curl -u wbadmin:wbadmin -H "accept: application/xml" -X GET "http://localhost:8080/kie-server/services/rest/server/containers/traffic-violation_1.0.0-SNAPSHOT/dmn"
```

Sample XML output:

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<response type="SUCCESS" msg="Ok models successfully retrieved from container 'traffic-violation_1.0.0-SNAPSHOT'">
  <dmn-model-info-list>
    <model>
      <model-namespace>https://kiegroup.org/dmn/_60b01f4d-e407-43f7-848e-258723b5fac8</model-namespace>
      <model-name>Traffic Violation</model-name>
      <model-id>_2CD7D1AA-BD84-4B43-AD21-B0342ADE655A</model-id>
      <decisions>
        <dmn-decision-info>
          <decision-id>_23428EE8-DC8B-4067-8E67-9D7C53EC975F</decision-id>
          <decision-name>Fine</decision-name>
        </dmn-decision-info>
        <dmn-decision-info>
          <decision-id>_B5EE2B1-915C-44DC-BE43-C244DC066FD8</decision-id>
          <decision-name>Should the driver be suspended?</decision-name>
        </dmn-decision-info>
      </decisions>
    </model>
  </dmn-model-info-list>
</response>
```
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CHAPTER 7. DMN MODEL EXECUTION

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Sample JSON output:

```json
{
  "type": "SUCCESS",
  "msg": "OK models successfully retrieved from container 'Traffic-Violation_1.0.0-SNAPSHOT'",
  "result": {
    "dmn-model-info-list": {
      "models": [
        {
          "model-namespace": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
          "model-name": "Traffic Violation",
          "model-id": "_2CD7D1AA-BD84-4B43-AD21-B0342ADE655A",
          "decisions": []
        }
      ]
    }
  }
}
```
"decision-name": "Fine"
},
"inputs": [
    {
        "inputdata-id": "_CEB959CD-3638-4A87-93BA-03CD0FB63AE3",
        "inputdata-name": "Violation",
        "inputdata-typeRef": {
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            "local-part": "tViolation",
            "prefix": ""
        }
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    {
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        "inputdata-name": "Driver",
        "inputdata-typeRef": {
            "namespace-uri": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
            "local-part": "tDriver",
            "prefix": ""
        }
    }
],
"itemDefinitions": [
    {
        "itemdefinition-id": "_13C7EFD8-B85C-43BF-94D3-14FABE39A4A0",
        "itemdefinition-name": "tDriver",
        "itemdefinition-typeRef": null,
        "itemdefinition-itemComponent": [
            {
                "itemdefinition-id": "_EC11744C-4160-4549-9610-2C757F40DFE8",
                "itemdefinition-name": "Name",
                "itemdefinition-typeRef": {
                    "namespace-uri": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
                    "local-part": "string",
                    "prefix": ""
                }
            },
            {
                "itemdefinition-id": "_E95BE3DB-4A51-4658-A166-02493EAAC9D2",
                "itemdefinition-name": "Age",
                "itemdefinition-typeRef": {
                    "namespace-uri": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
                    "local-part": "number",
                    "prefix": ""
                }
            },
            {
                "itemdefinition-id": "_7B3023E2-BC44-4BF3-BF7E-773C240FB9AD",
                "itemdefinition-name": "State",
                "itemdefinition-typeRef": {
                    "namespace-uri": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
                    "local-part": "State",
                    "prefix": ""
                }
            }
        ],
        "itemdefinition-isCollection": false
    }
]
"local-part" : "string",
"prefix" : ""
},
"itemdefinition-itemComponent" : [ ],
"itemdefinition-isCollection" : false
};
{
"itemdefinition-id" : "._3D4B49DD-700C-4925-99A7-3B2B873F7800",
"itemdefinition-name" : "City",
"itemdefinition-typeRef" : {
   "namespace-uri" : "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
   "local-part" : "string",
   "prefix" : ""
},
"itemdefinition-itemComponent" : [ ],
"itemdefinition-isCollection" : false
},
{
"itemdefinition-id" : "._B37C49E8-B0D9-4B20-9DC6-D655BB1CA7B1",
"itemdefinition-name" : "Points",
"itemdefinition-typeRef" : {
   "namespace-uri" : "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
   "local-part" : "number",
   "prefix" : ""
},
"itemdefinition-itemComponent" : [ ],
"itemdefinition-isCollection" : false
},
{
"itemdefinition-id" : "._A4077C7E-B57A-4DEE-9C65-7769636316F3",
"itemdefinition-name" : "tFine",
"itemdefinition-typeRef" : null,
"itemdefinition-itemComponent" : [ {
   "itemdefinition-id" : "._79B152A8-DE83-4001-B88B-52DFF0D73B2D",
   "itemdefinition-name" : "Amount",
   "itemdefinition-typeRef" : {
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      "local-part" : "number",
      "prefix" : ""
   },
   "itemdefinition-itemComponent" : [ ],
   "itemdefinition-isCollection" : false
}
],
"itemdefinition-isCollection" : false
},
{
"itemdefinition-id" : "._D7CB5F9C-9D55-48C2-83EE-D47045EC90D0",
"itemdefinition-name" : "Points",
"itemdefinition-typeRef" : {
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   "local-part" : "number",
   "prefix" : ""
},
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"itemdefinition-isCollection" : false
} ],
"itemdefinition-isCollection": false,
},
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"itemdefinition-name": "tViolation",
"itemdefinition-typeRef": null,
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    "itemdefinition-name": "Code",
    "itemdefinition-typeRef": {
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      "local-part": "string",
      "prefix": ""
    },
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    "itemdefinition-isCollection": false
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    "itemdefinition-name": "Date",
    "itemdefinition-typeRef": {
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      "local-part": "date",
      "prefix": ""
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    "itemdefinition-itemComponent": [],
    "itemdefinition-isCollection": false
  },
  {
    "itemdefinition-id": "_8961969A-8A80-4F12-B568-346920C0F038",
    "itemdefinition-name": "Type",
    "itemdefinition-typeRef": {
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      "local-part": "string",
      "prefix": ""
    },
    "itemdefinition-itemComponent": [],
    "itemdefinition-isCollection": false
  },
  {
    "itemdefinition-id": "_7450F12A-3E95-4D5E-8DCE-2CB1FAC2BDD4",
    "itemdefinition-name": "Speed Limit",
    "itemdefinition-typeRef": {
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      "prefix": ""
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    "itemdefinition-itemComponent": [],
    "itemdefinition-isCollection": false
  },
  {
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    "itemdefinition-typeRef": {
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      "local-part": "number",
      "prefix": ""
    },
    "itemdefinition-itemComponent": [],
    "itemdefinition-isCollection": false
  }
]
Execute the model:

```
[POST] server/containers/{containerId}/dmn
```

**NOTE**

The attribute `model-namespace` is automatically generated and is different for every user. Ensure that the `model-namespace` and `model-name` attributes that you use match those of the deployed model.

Example curl request:

```
```

Example JSON request:

```
{
  "model-namespace": "https://kiegroup.org/dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
  "model-name": "Traffic Violation",
  "dmn-context": {
    "Driver": {
      "Points": 15
    },
    "Violation": {
      "Type": "speed",
      "Actual Speed": 135,
      "Speed Limit": 100
    }
  }
}
```

Example XML request (JAXB format):

```xml
```

Example XML request (JAXB format):
NOTE

Regardless of the request format, the request requires the following elements:

- Model namespace
- Model name
- Context object containing input values

Example JSON response:

```json
{
    "type": "SUCCESS",
    "msg": "OK from container 'Traffic-Violation_1.0.0-SNAPSHOT'",
    "result": {
        "dmn-evaluation-result": {
            "messages": [],
            "model-namespace": "https://kiegroup.org/dmn/_7D8116DE-ADF5-4560-A116-FE1A2EAFFF48",
            "model-name": "Traffic Violation",
```
"decision-name": [],
"dmn-context": {
  "Violation": {
    "Type": "speed",
    "Speed Limit": 100,
    "Actual Speed": 135
  },
  "Should Driver be Suspended?": "Yes",
  "Driver": {
    "Points": 15
  },
  "Fine": {
    "Points": 7,
    "Amount": 1000
  }
},
"decision-results": {
  "_E1AF5AC2-E259-455C-96E4-596E30D3BC86": {
    "messages": [],
    "decision-id": "_E1AF5AC2-E259-455C-96E4-596E30D3BC86",
    "decision-name": "Should the Driver be Suspended?",
    "result": "Yes",
    "status": "SUCCEEDED"
  },
  "_D7F02CE0-AF50-4505-AB80-C7D6DE257920": {
    "messages": [],
    "decision-id": "_D7F02CE0-AF50-4505-AB80-C7D6DE257920",
    "decision-name": "Fine",
    "result": {
      "Points": 7,
      "Amount": 1000
    },
    "status": "SUCCEEDED"
  }
}

Example XML (JAXB format) response:

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<response type="SUCCESS" msg="OK from container 'Traffic_1.0.0-SNAPSHOT'">
  <dmn-evaluation-result>
    <model-name>Traffic Violation</model-name>
    <dmn-context xsi:type="jaxbListWrapper"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
      <MAP xsi:type="jaxbStringObjectPair" key="Violation">
        <value xsi:type="jaxbListWrapper" xsi:type="xs:string">
          speed</value>
```
<element xsi:type="jaxbStringObjectPair" key="Speed Limit">
  <value xsi:type="xs:decimal">
    100
  </value>
</element>

<element xsi:type="jaxbStringObjectPair" key="Actual Speed">
  <value xsi:type="xs:decimal">
    135
  </value>
</element>

<element xsi:type="jaxbStringObjectPair" key="Driver">
  <value xsi:type="jaxbListWrapper">
    <type>MAP</type>
    <element xsi:type="jaxbStringObjectPair" key="Points">
      <value xsi:type="xs:decimal">
        15
      </value>
    </element>
    <element xsi:type="jaxbStringObjectPair" key="Fine">
      <value xsi:type="jaxbListWrapper">
        <type>MAP</type>
        <element xsi:type="jaxbStringObjectPair" key="Points">
          <value xsi:type="xs:decimal">
            7
          </value>
        </element>
        <element xsi:type="jaxbStringObjectPair" key="Amount">
          <value xsi:type="xs:decimal">
            1000
          </value>
        </element>
      </value>
    </element>
    <element xsi:type="jaxbStringObjectPair" key="Should the driver be suspended?">
      <value xsi:type="xs:string">
        Yes
      </value>
    </element>
  </value>
</element>
<result>
  <messages/>
  <status>SUCCEEDED</status>
</value>
</entry>
<entry>
  <key>_8A408366-D8E9-4626-ABF3-5F69AA01F880</key>
  <value>
    <decision-id>_8A408366-D8E9-4626-ABF3-5F69AA01F880</decision-id>
    <decision-name>Should the driver be suspended?</decision-name>
    <result xsi:type="xs:string" xmlns:xs="http://www.w3.org/2001/XMLSchema"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">Yes</result>
  <messages/>
  <status>SUCCEEDED</status>
</value>
</entry>
</decisionResults>
</dmn-evaluation-result>
</response>
CHAPTER 8. ADDITIONAL RESOURCES

- Designing a decision service using DMN models
- Testing a decision service using test scenarios
- Managing projects in Business Central
- Interacting with Red Hat Decision Manager using KIE APIs
PART II. GETTING STARTED WITH RED HAT BUILD OF OPTAPlANNER

As a business rules developer, you can use Red Hat build of OptaPlanner to find the optimal solution to planning problems based on a set of limited resources and under specific constraints.

Use this document to start developing solvers with OptaPlanner.
CHAPTER 9. INTRODUCTION TO RED HAT BUILD OF OPTAPLANNER

OptaPlanner is a lightweight, embeddable planning engine that optimizes planning problems. It helps normal Java programmers solve planning problems efficiently, and it combines optimization heuristics and metaheuristics with very efficient score calculations.

For example, OptaPlanner helps solve various use cases:

- **Employee/Patient Rosters**: It helps create timetables for nurses and keeps track of patient bed management.
- **Educational Timetables**: It helps schedule lessons, courses, exams, and conference presentations.
- **Shop Schedules**: It tracks car assembly lines, machine queue planning, and workforce task planning.
- **Cutting Stock**: It minimizes waste by reducing the consumption of resources such as paper and steel.

Every organization faces planning problems; that is, they provide products and services with a limited set of constrained resources (employees, assets, time, and money).

OptaPlanner is open source software under the Apache Software License 2.0. It is 100% pure Java and runs on most Java virtual machines (JVMs).

9.1. PLANNING PROBLEMS

A planning problem has an optimal goal, based on limited resources and under specific constraints. Optimal goals can be any number of things, such as:

- Maximized profits - the optimal goal results in the highest possible profit.
- Minimized ecological footprint - the optimal goal has the least amount of environmental impact.
- Maximized satisfaction for employees or customers - the optimal goal prioritizes the needs of employees or customers.

The ability to achieve these goals relies on the number of resources available. For example, the following resources might be limited:

- Number of people
- Amount of time
- Budget
- Physical assets, for example, machinery, vehicles, computers, buildings

You must also take into account the specific constraints related to these resources, such as the number of hours a person works, their ability to use certain machines, or compatibility between pieces of equipment.

Red Hat build of OptaPlanner helps Java programmers solve constraint satisfaction problems efficiently. It combines optimization heuristics and metaheuristics with efficient score calculation.
9.2. NP-COMPLETENESS IN PLANNING PROBLEMS

The provided use cases are probably NP-complete or NP-hard, which means the following statements apply:

- It is easy to verify a specific solution to a problem in reasonable time.
- There is no simple way to find the optimal solution of a problem in reasonable time.

The implication is that solving your problem is probably harder than you anticipated, because the two common techniques do not suffice:

- A brute force algorithm (even a more advanced variant) takes too long.
- A quick algorithm, for example in the bin packing problem, putting in the largest items first returns a solution that is far from optimal.

By using advanced optimization algorithms, OptaPlanner finds a good solution in reasonable time for such planning problems.

9.3. SOLUTIONS TO PLANNING PROBLEMS

A planning problem has a number of solutions.

Several categories of solutions are:

- **Possible solution**
  A possible solution is any solution, whether or not it breaks any number of constraints. Planning problems often have an incredibly large number of possible solutions. Many of those solutions are not useful.

- **Feasible solution**
  A feasible solution is a solution that does not break any (negative) hard constraints. The number of feasible solutions are relative to the number of possible solutions. Sometimes there are no feasible solutions. Every feasible solution is a possible solution.

- **Optimal solution**
  Optimal solutions are the solutions with the highest scores. Planning problems usually have a few optimal solutions. They always have at least one optimal solution, even in the case that there are no feasible solutions and the optimal solution is not feasible.

- **Best solution found**
  The best solution is the solution with the highest score found by an implementation in a specified amount of time. The best solution found is likely to be feasible and, given enough time, it’s an optimal solution.

Counterintuitively, the number of possible solutions is huge (if calculated correctly), even with a small data set.

In the examples provided in the planner-engine distribution folder, most instances have a large number of possible solutions. As there is no guaranteed way to find the optimal solution, any implementation is forced to evaluate at least a subset of all those possible solutions.

OptaPlanner supports several optimization algorithms to efficiently wade through that incredibly large number of possible solutions.
Depending on the use case, some optimization algorithms perform better than others, but it is impossible to know in advance. Using OptaPlanner, you can switch the optimization algorithm by changing the solver configuration in a few lines of XML or code.

9.4. CONSTRAINTS ON PLANNING PROBLEMS

Usually, a planning problem has minimum two levels of constraints:

- A *(negative) hard constraint* must not be broken.
  For example, one teacher can not teach two different lessons at the same time.

- A *(negative) soft constraint* should not be broken if it can be avoided.
  For example, Teacher A does not like to teach on Friday afternoons.

Some problems also have positive constraints:

- A *positive soft constraint (or reward)* should be fulfilled if possible.
  For example, Teacher B likes to teach on Monday mornings.

Some basic problems only have hard constraints. Some problems have three or more levels of constraints, for example, hard, medium, and soft constraints.

These constraints define the *score calculation* (otherwise known as the *fitness function*) of a planning problem. Each solution of a planning problem is graded with a score. With OptaPlanner, score constraints are written in an object oriented language such as Java, or in Drools rules.

This type of code is flexible and scalable.

9.5. EXAMPLES PROVIDED WITH RED HAT BUILD OF OPTAPLANNER

Several Red Hat build of OptaPlanner examples are shipped with Red Hat Decision Manager. You can review the code for examples and modify it as necessary to suit your needs.

**NOTE**

Red Hat does not provide support for the example code included in the Red Hat Decision Manager distribution.

Some of the OptaPlanner examples solve problems that are presented in academic contests. The *Contest* column in the following table lists the contests. It also identifies an example as being either *realistic* or *unrealistic* for the purpose of a contest. A *realistic contest* is an official, independent contest that meets the following standards:

- Clearly defined real-world use cases
- Real-world constraints
- Multiple real-world datasets
- Reproducible results within a specific time limit on specific hardware
- Serious participation from the academic and/or enterprise Operations Research community.

Realistic contests provide an objective comparison of OptaPlanner with competitive software and academic research.
<table>
<thead>
<tr>
<th>Example</th>
<th>Domain</th>
<th>Size</th>
<th>Contest</th>
<th>Directory name</th>
</tr>
</thead>
</table>
| **N queens**           | 1 entity class  | Entity $\Leftarrow 256$  
Value $\Leftarrow 256$  
Search space $\Leftarrow 10^{616}$ | Pointless (cheatable)       | **nqueens**         |
| **Cloud balancing**    | 1 entity class  | Entity $\Leftarrow 2400$  
Value $\Leftarrow 800$  
Search space $\Leftarrow 10^{6967}$ | No (Defined by us)         | **cloudbalancing**|
| **Traveling salesman** | 1 entity class  | Entity $\Leftarrow 980$  
Value $\Leftarrow 980$  
Search space $\Leftarrow 10^{2504}$ | Unrealistic TSP web        | **tsp**           |
| **Tennis club scheduling** | 1 entity class | Entity $\Leftarrow 72$  
Value $\Leftarrow 7$  
Search space $\Leftarrow 10^{60}$ | No (Defined by us)         | **tennis**        |
| **Meeting scheduling** | 1 entity class  | Entity $\Leftarrow 10$  
Value $\Leftarrow 320$ and $\Leftarrow 5$  
Search space $\Leftarrow 10^{320}$ | No (Defined by us)         | **meetingscheduling**|
| **Course timetabling** | 1 entity class  | Entity $\Leftarrow 434$  
Value $\Leftarrow 25$ and $\Leftarrow 20$  
Search space $\Leftarrow 10^{1171}$ | Realistic ITC 2007 track 3 | **curriculumCourse** |
| **Machine reassignment** | 1 entity class | Entity $\Leftarrow 50000$  
Value $\Leftarrow 5000$  
Search space $\Leftarrow 10^{184948}$ | Nearly realistic ROADEF 2012 | **machineReassignment** |
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<tr>
<th>Example</th>
<th>Domain</th>
<th>Size</th>
<th>Contest</th>
<th>Directory name</th>
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</thead>
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<td>Vehicle routing</td>
<td>1 entity class (1 chained variable)</td>
<td>Entity $\Leftarrow 2740$</td>
<td>Unrealistic VRP web</td>
<td>vehiclerouting</td>
</tr>
<tr>
<td></td>
<td>1 shadow entity class (1 automatic shadow variable)</td>
<td>Value $\Leftarrow 2795$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\Leftarrow 10^{8380}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All of Vehicle routing (1 shadow variable)</td>
<td>Entity $\Leftarrow 2740$</td>
<td>Unrealistic VRP web</td>
<td>vehiclerouting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value $\Leftarrow 2795$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\Leftarrow 10^{8380}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project job scheduling</td>
<td>1 entity class (2 variables) (1 shadow variable)</td>
<td>Entity $\Leftarrow 640$</td>
<td>Nearly realistic MISTA 2013</td>
<td>projectjobscheduling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value $\Leftarrow ?$ and $\Leftarrow ?$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\Leftarrow ?$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task assigning</td>
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<td>Entity $\Leftarrow 500$</td>
<td>No Defined by us</td>
<td>taskassigning</td>
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<td></td>
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<td></td>
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<td></td>
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<td>Exam timetabling</td>
<td>2 entity classes (same hierarchy) (2 variables)</td>
<td>Entity $\Leftarrow 1096$</td>
<td>Realistic ITC 2007 track 1</td>
<td>examination</td>
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<td></td>
<td></td>
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<td>nurserostering</td>
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</tr>
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<td></td>
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<td></td>
<td>Search space $\Leftarrow 10^{2301}$</td>
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</tr>
</tbody>
</table>
9.6. N QUEENS

Place \( n \) number of queens on an \( n \) sized chessboard so that no two queens can attack each other. The most common \( n \) queens puzzle is the eight queens puzzle, with \( n = 8 \):
Constraints:

- Use a chessboard of $n$ columns and $n$ rows.
- Place $n$ queens on the chessboard.
- No two queens can attack each other. A queen can attack any other queen on the same horizontal, vertical, or diagonal line.

This documentation heavily uses the four queens puzzle as the primary example.

A proposed solution could be:

**Figure 9.1. A wrong solution for the four queens puzzle**
The above solution is wrong because queens A1 and B0 can attack each other (so can queens B0 and D0). Removing queen B0 would respect the “no two queens can attack each other” constraint, but would break the “place n queens” constraint.

Below is a correct solution:

Figure 9.2. A correct solution for the Four queens puzzle

![Correct Solution](image)

All the constraints have been met, so the solution is correct.

Note that most n queens puzzles have multiple correct solutions. We will focus on finding a single correct solution for a specific n, not on finding the number of possible correct solutions for a specific n.

Problem size

<table>
<thead>
<tr>
<th>n</th>
<th># Queens</th>
<th>Search Space</th>
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<td>4</td>
<td>256</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>$10^7$</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
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<td>32</td>
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<td>64</td>
<td>$10^{115}$</td>
</tr>
<tr>
<td>256</td>
<td>256</td>
<td>$10^{616}$</td>
</tr>
</tbody>
</table>

The implementation of the n queens example has not been optimized because it functions as a beginner example. Nevertheless, it can easily handle 64 queens. With a few changes it has been shown to easily handle 5000 queens and more.

9.6.1. Domain model for N queens

This example uses the domain model to solve the four queens problem.

- Creating a Domain Model
  
  A good domain model will make it easier to understand and solve your planning problem.

  This is the domain model for the n queens example:

  ```java
  public class Column {
      private int index;
      // ... getters and setters
  }

  public class Row {
  ```
Calculating the Search Space.
A Queen instance has a Column (for example: 0 is column A, 1 is column B, ...) and a Row (its row, for example: 0 is row 0, 1 is row 1, ...).

The ascending diagonal line and the descending diagonal line can be calculated based on the column and the row.

The column and row indexes start from the upper left corner of the chessboard.

Finding the Solution
A single NQueens instance contains a list of all Queen instances. It is the Solution implementation which will be supplied to, solved by, and retrieved from the Solver.

Notice that in the four queens example, the NQueens getN() method will always return four.
Figure 9.3. A solution for Four Queens

Table 9.2. Details of the solution in the domain model

<table>
<thead>
<tr>
<th>columnIndex</th>
<th>rowIndex</th>
<th>ascendingDiagonalIndex (columnIndex + rowIndex)</th>
<th>descendingDiagonalIndex (columnIndex - rowIndex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0</td>
<td>1(**)</td>
<td>-1</td>
</tr>
<tr>
<td>B0</td>
<td>1</td>
<td>0 (*)</td>
<td>1(**)</td>
</tr>
<tr>
<td>C2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>D0</td>
<td>3</td>
<td>0 (*)</td>
<td>3</td>
</tr>
</tbody>
</table>

When two queens share the same column, row or diagonal line, such as (*) and (**) , they can attack each other.

9.7. CLOUD BALANCING

For information about this example, see Red Hat build of OptaPlanner quick start guides.

9.8. TRAVELING SALESMAN (TSP - TRAVELING SALESMAN PROBLEM)

Given a list of cities, find the shortest tour for a salesman that visits each city exactly once.

The problem is defined by Wikipedia. It is one of the most intensively studied problems in computational mathematics. Yet, in the real world, it is often only part of a planning problem, along with other constraints, such as employee shift rostering constraints.

Problem size

dj38 has 38 cities with a search space of 10^43.
europe40 has 40 cities with a search space of 10^46.
st70 has 70 cities with a search space of 10^98.
pcb442 has 442 cities with a search space of 10^976.
lu980 has 980 cities with a search space of 10^2504.

Problem difficulty
Despite TSP’s simple definition, the problem is surprisingly hard to solve. Because it is an NP-hard problem (like most planning problems), the optimal solution for a specific problem dataset can change a lot when that problem dataset is slightly altered:

9.9. TENNIS CLUB SCHEDULING

Every week the tennis club has four teams playing round robin against each other. Assign those four spots to the teams fairly.

Hard constraints:

- Conflict: A team can only play once per day.
- Unavailability: Some teams are unavailable on some dates.

Medium constraints:

- Fair assignment: All teams should play an (almost) equal number of times.

Soft constraints:

- Evenly confrontation: Each team should play against every other team an equal number of times.

Problem size
munich-7teams has 7 teams, 18 days, 12 unavailability penalties and 72 team assignments with a search space of $10^{60}$.

Figure 9.4. Domain model

### Tennis class diagram

- **Day**: 1
- **Team**: 1
- **UnavailabilityPenalty**: *
- **@PlanningVariable**: @PlanningEntity
- **@PlanningEntityCollectionProperty**: @PlanningSolution
- **TeamAssignment**: *

### 9.10. MEETING SCHEDULING

Assign each meeting to a starting time and a room. Meetings have different durations.

**Hard constraints:**

- Room conflict: Two meetings must not use the same room at the same time.
- Required attendance: A person cannot have two required meetings at the same time.
- Required room capacity: A meeting must not be in a room that doesn’t fit all of the meeting’s attendees.
- Start and end on same day: A meeting shouldn’t be scheduled over multiple days.

**Medium constraints:**

- Preferred attendance: A person cannot have two preferred meetings at the same time, nor a preferred and a required meeting at the same time.

**Soft constraints:**

- Sooner rather than later: Schedule all meetings as soon as possible.
• A break between meetings: Any two meetings should have at least one time grain break between them.

• Overlapping meetings: To minimize the number of meetings in parallel so people don’t have to choose one meeting over the other.

• Assign larger rooms first: If a larger room is available any meeting should be assigned to that room in order to accommodate as many people as possible even if they haven’t signed up to that meeting.

• Room stability: If a person has two consecutive meetings with two or less time grains break between them they better be in the same room.

**Problem size**

- 50meetings-160timegrains-5rooms has 50 meetings, 160 timeGrains and 5 rooms with a search space of $10^{145}$.
- 100meetings-320timegrains-5rooms has 100 meetings, 320 timeGrains and 5 rooms with a search space of $10^{320}$.
- 200meetings-640timegrains-5rooms has 200 meetings, 640 timeGrains and 5 rooms with a search space of $10^{701}$.
- 400meetings-1280timegrains-5rooms has 400 meetings, 1280 timeGrains and 5 rooms with a search space of $10^{1522}$.
- 800meetings-2560timegrains-5rooms has 800 meetings, 2560 timeGrains and 5 rooms with a search space of $10^{3285}$.

**9.11. COURSE TIMETABLING (ITC 2007 TRACK 3 - CURRICULUM COURSE SCHEDULING)**

Schedule each lecture into a timeslot and into a room.

Hard constraints:

• Teacher conflict: A teacher must not have two lectures in the same period.

• Curriculum conflict: A curriculum must not have two lectures in the same period.

• Room occupancy: Two lectures must not be in the same room in the same period.

• Unavailable period (specified per dataset): A specific lecture must not be assigned to a specific period.

Soft constraints:

• Room capacity: A room’s capacity should not be less than the number of students in its lecture.

• Minimum working days: Lectures of the same course should be spread out into a minimum number of days.

• Curriculum compactness: Lectures belonging to the same curriculum should be adjacent to each other (so in consecutive periods).

• Room stability: Lectures of the same course should be assigned to the same room.

The problem is defined by the International Timetabling Competition 2007 track 3.
Problem size

comp01 has 24 teachers, 14 curricula, 30 courses, 160 lectures, 30 periods, 6 rooms and 53 unavailable period constraints with a search space of $10^{360}$.

comp02 has 71 teachers, 70 curricula, 82 courses, 283 lectures, 25 periods, 16 rooms and 513 unavailable period constraints with a search space of $10^{736}$.

comp03 has 61 teachers, 68 curricula, 72 courses, 251 lectures, 25 periods, 16 rooms and 382 unavailable period constraints with a search space of $10^{653}$.

comp04 has 70 teachers, 57 curricula, 79 courses, 286 lectures, 25 periods, 18 rooms and 396 unavailable period constraints with a search space of $10^{758}$.

comp05 has 47 teachers, 139 curricula, 54 courses, 152 lectures, 36 periods, 9 rooms and 771 unavailable period constraints with a search space of $10^{381}$.

comp06 has 87 teachers, 70 curricula, 108 courses, 361 lectures, 25 periods, 18 rooms and 632 unavailable period constraints with a search space of $10^{957}$.

comp07 has 99 teachers, 77 curricula, 131 courses, 434 lectures, 25 periods, 20 rooms and 667 unavailable period constraints with a search space of $10^{1171}$.

comp08 has 76 teachers, 61 curricula, 86 courses, 324 lectures, 25 periods, 18 rooms and 478 unavailable period constraints with a search space of $10^{859}$.

comp09 has 68 teachers, 75 curricula, 76 courses, 279 lectures, 25 periods, 18 rooms and 405 unavailable period constraints with a search space of $10^{740}$.

comp10 has 88 teachers, 67 curricula, 115 courses, 370 lectures, 25 periods, 18 rooms and 694 unavailable period constraints with a search space of $10^{981}$.

comp11 has 24 teachers, 13 curricula, 30 courses, 162 lectures, 45 periods, 5 rooms and 94 unavailable period constraints with a search space of $10^{381}$.

comp12 has 74 teachers, 150 curricula, 88 courses, 218 lectures, 36 periods, 11 rooms and 1368 unavailable period constraints with a search space of $10^{566}$.

comp13 has 77 teachers, 66 curricula, 82 courses, 308 lectures, 25 periods, 19 rooms and 468 unavailable period constraints with a search space of $10^{824}$.

comp14 has 68 teachers, 60 curricula, 85 courses, 275 lectures, 25 periods, 17 rooms and 486 unavailable period constraints with a search space of $10^{722}$. 
Assign each process to a machine. All processes already have an original (unoptimized) assignment. Each process requires an amount of each resource (such as CPU or RAM). This is a more complex version of the Cloud Balancing example.

**Hard constraints:**

- **Maximum capacity:** The maximum capacity for each resource for each machine must not be exceeded.
- **Conflict:** Processes of the same service must run on distinct machines.
- **Spread:** Processes of the same service must be spread out across locations.
- **Dependency:** The processes of a service depending on another service must run in the neighborhood of a process of the other service.
- **Transient usage:** Some resources are transient and count towards the maximum capacity of both the original machine as the newly assigned machine.

**Soft constraints:**

- **Load:** The safety capacity for each resource for each machine should not be exceeded.
- Balance: Leave room for future assignments by balancing the available resources on each machine.
- Process move cost: A process has a move cost.
- Service move cost: A service has a move cost.
- Machine move cost: Moving a process from machine A to machine B has another A-B specific move cost.

The problem is defined by the Google ROADEF/EURO Challenge 2012.

**Cloud optimization is like Tetris**

![Diagram showing traditional algorithm and OptaPlanner](image)

**Traditional algorithm (Construction Heuristic)**

**OptaPlanner (Construction Heuristic + Local Search)**
Cloud optimization

Assign processes to machines more efficiently.

Problem size

model_a1_1 has 2 resources, 1 neighborhoods, 4 locations, 4 machines, 79 services, 100 processes and 1 balancePenalties with a search space of $10^{60}$.
model_a1_2 has 4 resources, 2 neighborhoods, 4 locations, 100 machines, 980 services, 1000 processes and 0 balancePenalties with a search space of $10^{2000}$.
model_a1_3 has 3 resources, 5 neighborhoods, 25 locations, 100 machines, 216 services, 1000 processes and 0 balancePenalties with a search space of $10^{2000}$.
model_a1_4 has 3 resources, 50 neighborhoods, 50 locations, 50 machines, 142 services, 1000 processes and 1 balancePenalties with a search space of $10^{1698}$.
model_a1_5 has 4 resources, 2 neighborhoods, 4 locations, 12 machines, 981 services, 1000 processes and 1 balancePenalties with a search space of $10^{1079}$.
model_a2_1 has 3 resources, 1 neighborhoods, 1 locations, 100 machines, 1000 services, 1000 processes and 0 balancePenalties with a search space of $10^{2000}$.
model_a2_2 has 12 resources, 5 neighborhoods, 25 locations, 100 machines, 170 services, 1000 processes and 0 balancePenalties with a search space of $10^{2000}$.
model_a2_3 has 12 resources, 5 neighborhoods, 25 locations, 100 machines, 129 services, 1000 processes and 0 balancePenalties with a search space of $10^{2000}$.
model_a2_4 has 12 resources, 5 neighborhoods, 25 locations, 50 machines, 180 services, 1000 processes and 1 balancePenalties with a search space of $10^{1698}$.
model_a2_5 has 12 resources, 5 neighborhoods, 25 locations, 50 machines, 153 services, 1000 processes and 0 balancePenalties with a search space of $10^{1698}$.
model_b_1 has 12 resources, 5 neighborhoods, 10 locations, 100 machines, 2512 services, 5000 processes and 0 balancePenalties with a search space of $10^{10000}$.
model_b_2 has 12 resources, 5 neighborhoods, 10 locations, 100 machines, 2462 services, 5000 processes and 1 balancePenalties with a search space of $10^{10000}$. 

Don't believe us? Run our open benchmarks yourself: http://www.optaplanner.org/code/benchmarks.html
model_b_3 has 6 resources, 5 neighborhoods, 10 locations, 100 machines, 15025 services, 20000 processes and 0 balancePenalties with a search space of \(10^{40000}\).
model_b_4 has 6 resources, 5 neighborhoods, 50 locations, 500 machines, 1732 services, 20000 processes and 1 balancePenalties with a search space of \(10^{53979}\).
model_b_5 has 6 resources, 5 neighborhoods, 10 locations, 100 machines, 35082 services, 40000 processes and 0 balancePenalties with a search space of \(10^{80000}\).
model_b_6 has 6 resources, 5 neighborhoods, 50 locations, 200 machines, 14680 services, 40000 processes and 1 balancePenalties with a search space of \(10^{92041}\).
model_b_7 has 6 resources, 5 neighborhoods, 50 locations, 4000 machines, 15050 services, 40000 processes and 1 balancePenalties with a search space of \(10^{144082}\).
model_b_8 has 3 resources, 5 neighborhoods, 10 locations, 100 machines, 45030 services, 50000 processes and 0 balancePenalties with a search space of \(10^{100000}\).
model_b_9 has 3 resources, 5 neighborhoods, 100 locations, 1000 machines, 4609 services, 50000 processes and 1 balancePenalties with a search space of \(10^{150000}\).
model_b_10 has 3 resources, 5 neighborhoods, 100 locations, 5000 machines, 4896 services, 50000 processes and 1 balancePenalties with a search space of \(10^{184948}\).

Figure 9.7. Domain model

Machine reassignment class diagram

9.13. VEHICLE ROUTING

Using a fleet of vehicles, pick up the objects of each customer and bring them to the depot. Each vehicle can service multiple customers, but it has a limited capacity.
Besides the basic case (CVRP), there is also a variant with time windows (CVRPTW).

Hard constraints:

- Vehicle capacity: a vehicle cannot carry more items than its capacity.
- Time windows (only in CVRPTW):
  - Travel time: Traveling from one location to another takes time.
  - Customer service duration: A vehicle must stay at the customer for the length of the service duration.
  - Customer ready time: A vehicle may arrive before the customer’s ready time, but it must wait until the ready time before servicing.
  - Customer due time: A vehicle must arrive on time, before the customer’s due time.

Soft constraints:

- Total distance: Minimize the total distance driven (fuel consumption) of all vehicles.
The capacitated vehicle routing problem (CVRP) and its time-windowed variant (CVRPTW) are defined by the VRP web.

**Figure 9.8. Value proposition**

### Vehicle routing

Assign the delivery order of vehicles more efficiently.

### Users

- Supermarkets & retail stores
- Freight transportation
- Buses, taxi’s & airlines
- Technicians on the road

### Problem size

**CVRP instances (without time windows):**

- `belgium-n50-k10` has 1 depots, 10 vehicles and 49 customers with a search space of $10^{74}$.
- `belgium-n100-k10` has 1 depots, 10 vehicles and 99 customers with a search space of $10^{170}$.
- `belgium-n500-k20` has 1 depots, 20 vehicles and 499 customers with a search space of $10^{1168}$.
- `belgium-n1000-k20` has 1 depots, 20 vehicles and 999 customers with a search space of $10^{2607}$.
- `belgium-n2750-k55` has 1 depots, 55 vehicles and 2749 customers with a search space of $10^8380$.
- `belgium-road-km-n50-k10` has 1 depots, 10 vehicles and 49 customers with a search space of $10^{74}$.
- `belgium-road-km-n100-k10` has 1 depots, 10 vehicles and 99 customers with a search space of $10^{170}$.
- `belgium-road-km-n500-k20` has 1 depots, 20 vehicles and 499 customers with a search space of $10^{1168}$.
- `belgium-road-km-n1000-k20` has 1 depots, 20 vehicles and 999 customers with a search space of $10^{2607}$.
- `belgium-road-km-n2750-k55` has 1 depots, 55 vehicles and 2749 customers with a search space of $10^8380$.
10^8380.

belgium-road-time-n50-k10 has 1 depots, 10 vehicles and 49 customers with a search space of 10^74.
belgium-road-time-n100-k10 has 1 depots, 10 vehicles and 99 customers with a search space of 10^170.
belgium-road-time-n500-k20 has 1 depots, 20 vehicles and 499 customers with a search space of 10^1168.
belgium-road-time-n1000-k20 has 1 depots, 20 vehicles and 999 customers with a search space of 10^2607.
belgium-road-time-n2750-k55 has 1 depots, 55 vehicles and 2749 customers with a search space of 10^8380.
belgium-d2-n50-k10 has 2 depots, 10 vehicles and 48 customers with a search space of 10^74.
belgium-d3-n100-k10 has 3 depots, 10 vehicles and 97 customers with a search space of 10^170.
belgium-d5-n500-k20 has 5 depots, 20 vehicles and 495 customers with a search space of 10^1168.
belgium-d8-n1000-k20 has 8 depots, 20 vehicles and 992 customers with a search space of 10^2607.
belgium-d10-n2750-k55 has 10 depots, 55 vehicles and 2740 customers with a search space of 10^8380.

A-n32-k5 has 1 depots, 5 vehicles and 31 customers with a search space of 10^40.
A-n33-k5 has 1 depots, 5 vehicles and 32 customers with a search space of 10^41.
A-n33-k6 has 1 depots, 6 vehicles and 32 customers with a search space of 10^42.
A-n34-k5 has 1 depots, 5 vehicles and 33 customers with a search space of 10^43.
A-n36-k5 has 1 depots, 5 vehicles and 35 customers with a search space of 10^46.
A-n37-k5 has 1 depots, 5 vehicles and 36 customers with a search space of 10^48.
A-n37-k6 has 1 depots, 6 vehicles and 36 customers with a search space of 10^49.
A-n38-k5 has 1 depots, 5 vehicles and 37 customers with a search space of 10^49.
A-n39-k5 has 1 depots, 5 vehicles and 38 customers with a search space of 10^51.
A-n39-k6 has 1 depots, 6 vehicles and 38 customers with a search space of 10^52.
A-n44-k7 has 1 depots, 7 vehicles and 43 customers with a search space of 10^61.
A-n45-k6 has 1 depots, 6 vehicles and 44 customers with a search space of 10^62.
A-n45-k7 has 1 depots, 7 vehicles and 44 customers with a search space of 10^63.
A-n46-k7 has 1 depots, 7 vehicles and 45 customers with a search space of 10^65.
A-n48-k7 has 1 depots, 7 vehicles and 47 customers with a search space of 10^68.
A-n53-k7 has 1 depots, 7 vehicles and 52 customers with a search space of 10^77.
A-n54-k7 has 1 depots, 7 vehicles and 53 customers with a search space of 10^79.
A-n55-k9 has 1 depots, 9 vehicles and 54 customers with a search space of 10^82.
A-n60-k9 has 1 depots, 9 vehicles and 59 customers with a search space of 10^91.
A-n61-k9 has 1 depots, 9 vehicles and 60 customers with a search space of 10^93.
A-n62-k8 has 1 depots, 8 vehicles and 61 customers with a search space of 10^94.
A-n63-k9 has 1 depots, 9 vehicles and 62 customers with a search space of 10^97.
A-n63-k10 has 1 depots, 10 vehicles and 62 customers with a search space of 10^98.
A-n64-k9 has 1 depots, 9 vehicles and 63 customers with a search space of 10^99.
A-n65-k9 has 1 depots, 9 vehicles and 64 customers with a search space of 10^101.
A-n69-k9 has 1 depots, 9 vehicles and 68 customers with a search space of 10^108.
A-n80-k10 has 1 depots, 10 vehicles and 79 customers with a search space of 10^130.
F-n45-k4 has 1 depots, 4 vehicles and 44 customers with a search space of 10^60.
F-n72-k4 has 1 depots, 4 vehicles and 71 customers with a search space of 10^108.
F-n135-k7 has 1 depots, 7 vehicles and 134 customers with a search space of 10^240.

CVRPTW instances (with time windows):

belgium-tw-d2-n50-k10 has 2 depots, 10 vehicles and 48 customers with a search space of
10^74.

**Belgium-TW-D3**: 3 depots, 10 vehicles and 97 customers with a search space of 10^170.
**Belgium-TW-D5**: 5 depots, 20 vehicles and 495 customers with a search space of 10^1168.
**Belgium-TW-D8**: 8 depots, 20 vehicles and 992 customers with a search space of 10^2607.
**Belgium-TW-D10**: 10 depots, 55 vehicles and 2740 customers with a search space of 10^8380.

**Belgium-TW-N50**: 1 depots, 10 vehicles and 49 customers with a search space of 10^74.
**Belgium-TW-N100**: 1 depots, 10 vehicles and 99 customers with a search space of 10^170.
**Belgium-TW-N500**: 1 depots, 20 vehicles and 499 customers with a search space of 10^1168.
**Belgium-TW-N1000**: 1 depots, 20 vehicles and 999 customers with a search space of 10^2607.
**Belgium-TW-N2750**: 1 depots, 55 vehicles and 2749 customers with a search space of 10^8380.

**Solomon_025_C101**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_025_C201**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_025_R101**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_025_R201**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_025_RC101**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_025_RC201**: 1 depots, 25 vehicles and 25 customers with a search space of 10^40.
**Solomon_100_C101**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.
**Solomon_100_C201**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.
**Solomon_100_R101**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.
**Solomon_100_R201**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.
**Solomon_100_RC101**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.
**Solomon_100_RC201**: 1 depots, 25 vehicles and 100 customers with a search space of 10^185.

**Homberger_0200_C1_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
**Homberger_0200_C2_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
**Homberger_0200_R1_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
**Homberger_0200_R2_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
**Homberger_0200_RC1_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
**Homberger_0200_RC2_2_1**: 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0400_C1_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0400_C2_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0400_R1_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0400_R2_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0400_RC1_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0400_RC2_4_1 has 1 depots, 100 vehicles and 400 customers with a search space of $10^{978}$.

Homberger_0600_C1_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0600_C2_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0600_R1_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0600_R2_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0600_RC1_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0600_RC2_6_1 has 1 depots, 150 vehicles and 600 customers with a search space of $10^{1571}$.

Homberger_0800_C1_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_0800_C2_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_0800_R1_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_0800_R2_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_0800_RC1_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_0800_RC2_8_1 has 1 depots, 200 vehicles and 800 customers with a search space of $10^{2195}$.

Homberger_1000_C110_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

Homberger_1000_C210_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

Homberger_1000_R110_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

Homberger_1000_R210_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

Homberger_1000_RC110_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

Homberger_1000_RC210_1 has 1 depots, 250 vehicles and 1000 customers with a search space of $10^{2840}$.

The vehicle routing with time windows domain model makes heavy use of the shadow variable feature. This allows it to express its constraints more naturally, because properties such as `arrivalTime` and `departureTime`, are directly available on the domain model.

**Road Distances Instead of Air Distances**

In the real world, vehicles cannot follow a straight line from location to location: they have to use roads and highways. From a business point of view, this matters a lot:
For the optimization algorithm, this does not matter much, as long as the distance between two points can be looked up (and are preferably precalculated). The road cost does not even need to be a distance. It can also be travel time, fuel cost, or a weighted function of those. There are several technologies available to precalculate road costs, such as GraphHopper (embeddable, offline Java engine), Open MapQuest (web service) and Google Maps Client API (web service).

Vehicle routing distance type

Can we optimize for air distances, when we need road distances or driving times?

<table>
<thead>
<tr>
<th></th>
<th>Optimized for...</th>
<th>...air distance</th>
<th>...road distance</th>
<th>...driving time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>2 327.32 km</td>
<td>2 243.15 km</td>
<td>2 300.32 km</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>118 632 sec</td>
<td>115 516 sec</td>
<td>114 105 sec</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>3.8% worse</td>
<td>1.2% worse</td>
<td>2.5% worse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.0% worse</td>
<td>best</td>
<td>best</td>
<td></td>
</tr>
</tbody>
</table>

For the optimization algorithm, this does not matter much, as long as the distance between two points can be looked up (and are preferably precalculated). The road cost does not even need to be a distance. It can also be travel time, fuel cost, or a weighted function of those. There are several technologies available to precalculate road costs, such as GraphHopper (embeddable, offline Java engine), Open MapQuest (web service) and Google Maps Client API (web service).
Integration with real maps

Google Maps or GraphHopper (OpenStreetMap) calculate distances, OptaPlanner optimizes the trips.

There are also several technologies to render it, such as Leaflet and Google Maps for developers.
It is even possible to render the actual road routes with GraphHopper or Google Map Directions, but because of route overlaps on highways, it can become harder to see the standstill order:
Take special care that the road costs between two points use the same optimization criteria as the one used in OptaPlanner. For example, GraphHopper will by default return the fastest route, not the shortest route. Don’t use the km (or miles) distances of the fastest GPS routes to optimize the shortest trip in OptaPlanner: this leads to a suboptimal solution as shown below:
Contrary to popular belief, most users do not want the shortest route: they want the fastest route instead. They prefer highways over normal roads. They prefer normal roads over dirt roads. In the real world, the fastest and shortest route are rarely the same.

9.14. PROJECT JOB SCHEDULING

Schedule all jobs in time and execution mode to minimize project delays. Each job is part of a project. A job can be executed in different ways: each way is an execution mode that implies a different duration but also different resource usages. This is a form of flexible job shop scheduling.
Hard constraints:

- Job precedence: a job can only start when all its predecessor jobs are finished.
- Resource capacity: do not use more resources than available.
  - Resources are local (shared between jobs of the same project) or global (shared between all jobs)
  - Resources are renewable (capacity available per day) or nonrenewable (capacity available for all days)

Medium constraints:

- Total project delay: minimize the duration (makespan) of each project.

Soft constraints:

- Total makespan: minimize the duration of the whole multi-project schedule.

The problem is defined by the MISTA 2013 challenge.

Problem size

Schedule A-1 has 2 projects, 24 jobs, 64 execution modes, 7 resources and 150 resource requirements.
Schedule A-2 has 2 projects, 44 jobs, 124 execution modes, 7 resources and 420 resource requirements.
Schedule A-3 has 2 projects, 64 jobs, 184 execution modes, 7 resources and 630 resource requirements.
Schedule A-4 has 5 projects, 60 jobs, 160 execution modes, 16 resources and 390 resource requirements.
Schedule A-5 has 5 projects, 110 jobs, 310 execution modes, 16 resources and 900 resource requirements.
Schedule A-6 has 5 projects, 160 jobs, 460 execution modes, 16 resources and 1440 resource requirements.
Schedule A-7 has 10 projects, 120 jobs, 320 execution modes, 22 resources and 900 resource requirements.
Schedule A-8 has 10 projects, 220 jobs, 620 execution modes, 22 resources and 1860 resource requirements.
Schedule A-9 has 10 projects, 320 jobs, 920 execution modes, 31 resources and 2880 resource requirements.
Schedule A-10 has 10 projects, 320 jobs, 920 execution modes, 31 resources and 2970 resource requirements.

Schedule B-1 has 10 projects, 120 jobs, 320 execution modes, 31 resources and 900 resource requirements.
Schedule B-2 has 10 projects, 220 jobs, 620 execution modes, 22 resources and 1740 resource requirements.
Schedule B-3 has 10 projects, 320 jobs, 920 execution modes, 31 resources and 3060 resource requirements.
Schedule B-4 has 15 projects, 180 jobs, 480 execution modes, 46 resources and 1530 resource requirements.
Schedule B-5 has 15 projects, 330 jobs, 930 execution modes, 46 resources and 2760 resource requirements.
Schedule B-6 has 15 projects, 480 jobs, 1380 execution modes, 46 resources and 4500 resource requirements.
Schedule B-7 has 20 projects, 240 jobs, 640 execution modes, 61 resources and 1710 resource requirements.
Schedule B-8 has 20 projects, 440 jobs, 1240 execution modes, 42 resources and 3180 resource requirements.
Schedule B-9 has 20 projects, 640 jobs, 1840 execution modes, 61 resources and 5940 resource requirements.
Schedule B-10 has 20 projects, 460 jobs, 1300 execution modes, 42 resources and 4260 resource requirements.

9.15. TASK ASSIGNING

Assign each task to a spot in an employee’s queue. Each task has a duration which is affected by the employee’s affinity level with the task’s customer.

Hard constraints:

- Skill: Each task requires one or more skills. The employee must possess all these skills.

Soft level 0 constraints:

- Critical tasks: Complete critical tasks first, sooner than major and minor tasks.

Soft level 1 constraints:

- Minimize makespan: Reduce the time to complete all tasks.
  - Start with the longest working employee first, then the second longest working employee and so forth, to create fairness and load balancing.
Soft level 2 constraints:

- Major tasks: Complete major tasks as soon as possible, sooner than minor tasks.

Soft level 3 constraints:

- Minor tasks: Complete minor tasks as soon as possible.

Figure 9.9. Value proposition

Task assigning

Optimize the task queue of every employee by reassigning and reordering tasks.

Employees

8:00  9:00  10:00  11:00  12:00  13:00  14:00  15:00  16:00  17:00  18:00

Critical priority

Medium priority

Requires French skill

Has health care affinity

Maximize throughput

Lacks affinity, takes longer

Starts between 12:00 and 13:30

Users

Payroll services

Call centers

Tax auditors

Recruitment interviewing

Mortgage approval

Problem size

24tasks-8employees has 24 tasks, 6 skills, 8 employees, 4 task types and 4 customers with a search space of $10^{30}$.

50tasks-5employees has 50 tasks, 5 skills, 5 employees, 10 task types and 10 customers with a search space of $10^{69}$.

100tasks-5employees has 100 tasks, 5 skills, 5 employees, 20 task types and 15 customers with a search space of $10^{164}$.

500tasks-20employees has 500 tasks, 6 skills, 20 employees, 100 task types and 60 customers with a search space of $10^{1168}$. 
9.16. EXAM TIMETABLING (ITC 2007 TRACK 1 - EXAMINATION)

Schedule each exam into a period and into a room. Multiple exams can share the same room during the same period.
Hard constraints:

- Exam conflict: Two exams that share students must not occur in the same period.
- Room capacity: A room’s seating capacity must suffice at all times.
- Period duration: A period’s duration must suffice for all of its exams.
- Period related hard constraints (specified per dataset):
  - Coincidence: Two specified exams must use the same period (but possibly another room).
  - Exclusion: Two specified exams must not use the same period.
  - After: A specified exam must occur in a period after another specified exam’s period.
- Room related hard constraints (specified per dataset):
  - Exclusive: One specified exam should not have to share its room with any other exam.

Soft constraints (each of which has a parametrized penalty):

- The same student should not have two exams in a row.
- The same student should not have two exams on the same day.
- Period spread: Two exams that share students should be a number of periods apart.
- Mixed durations: Two exams that share a room should not have different durations.
- Front load: Large exams should be scheduled earlier in the schedule.
- Period penalty (specified per dataset): Some periods have a penalty when used.
- Room penalty (specified per dataset): Some rooms have a penalty when used.

It uses large test data sets of real-life universities.

The problem is defined by the International Timetabling Competition 2007 track 1. Geoffrey De Smet finished 4th in that competition with a very early version of OptaPlanner. Many improvements have been made since then.

**Problem Size**

<table>
<thead>
<tr>
<th>Exam Set</th>
<th>Students</th>
<th>Exams</th>
<th>Periods</th>
<th>Rooms</th>
<th>Period Constraints</th>
<th>Room Constraints</th>
<th>Search Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>exam_comp_set1</td>
<td>7883</td>
<td>607</td>
<td>54</td>
<td>7</td>
<td>12</td>
<td>0</td>
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</tr>
<tr>
<td>exam_comp_set2</td>
<td>12484</td>
<td>870</td>
<td>40</td>
<td>49</td>
<td>12</td>
<td>2</td>
<td>$10^{2864}$</td>
</tr>
<tr>
<td>exam_comp_set3</td>
<td>16365</td>
<td>934</td>
<td>36</td>
<td>48</td>
<td>12</td>
<td>15</td>
<td>$10^{3023}$</td>
</tr>
<tr>
<td>exam_comp_set4</td>
<td>4421</td>
<td>273</td>
<td>21</td>
<td>1</td>
<td>40</td>
<td>0</td>
<td>$10^{360}$</td>
</tr>
<tr>
<td>exam_comp_set5</td>
<td>8719</td>
<td>1018</td>
<td>42</td>
<td>3</td>
<td>27</td>
<td>0</td>
<td>$10^{2138}$</td>
</tr>
<tr>
<td>exam_comp_set6</td>
<td>7909</td>
<td>242</td>
<td>16</td>
<td>8</td>
<td>22</td>
<td>0</td>
<td>$10^{509}$</td>
</tr>
<tr>
<td>exam_comp_set7</td>
<td>13795</td>
<td>1096</td>
<td>80</td>
<td>15</td>
<td>28</td>
<td>0</td>
<td>$10^{3374}$</td>
</tr>
<tr>
<td>exam_comp_set8</td>
<td>7718</td>
<td>598</td>
<td>80</td>
<td>8</td>
<td>20</td>
<td>1</td>
<td>$10^{1678}$</td>
</tr>
</tbody>
</table>

9.16.1. Domain model for exam timetabling

The following diagram shows the main examination domain classes:
Figure 9.11. Examination domain class diagram

Notice that we’ve split up the exam concept into an Exam class and a Topic class. The Exam instances change during solving (this is the planning entity class), when their period or room property changes. The Topic, Period and Room instances never change during solving (these are problem facts, just like some other classes).

9.17. NURSE ROSTERING (INRC 2010)

For each shift, assign a nurse to work that shift.
Employee shift rostering

Populate each work shift with a nurse.

## Hard constraints:

- **No unassigned shifts** (built-in): Every shift need to be assigned to an employee.
- **Shift conflict**: An employee can have only one shift per day.

## Soft constraints:

- Contract obligations. The business frequently violates these, so they decided to define these as soft constraints instead of hard constraints.
  - **Minimum and maximum assignments**: Each employee needs to work more than x shifts and less than y shifts (depending on their contract).
  - **Minimum and maximum consecutive working days**: Each employee needs to work between x and y days in a row (depending on their contract).
  - **Minimum and maximum consecutive free days**: Each employee needs to be free between x and y days in a row (depending on their contract).
  - **Minimum and maximum consecutive working weekends**: Each employee needs to work between x and y weekends in a row (depending on their contract).
  - **Complete weekends**: Each employee needs to work every day in a weekend or not at all.
  - **Identical shift types during weekend**: Each weekend shift for the same weekend of the same employee must be the same shift type.

### Largest staff first

<table>
<thead>
<tr>
<th></th>
<th>Maternity nurses</th>
<th>Emergency nurses</th>
<th>Basic nurses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sat</td>
<td>1 2</td>
<td>2 1</td>
<td>1 2</td>
</tr>
<tr>
<td>Sun</td>
<td>1 1</td>
<td>1 1</td>
<td>1 1</td>
</tr>
<tr>
<td>Mon</td>
<td>2 1</td>
<td>A C</td>
<td>2 1</td>
</tr>
</tbody>
</table>

### OptaPlanner

<table>
<thead>
<tr>
<th></th>
<th>Maternity nurses</th>
<th>Emergency nurses</th>
<th>Basic nurses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sat</td>
<td>1 2</td>
<td>2 1</td>
<td>1 2</td>
</tr>
<tr>
<td>Sun</td>
<td>1 1</td>
<td>1 1</td>
<td>1 1</td>
</tr>
<tr>
<td>Mon</td>
<td>2 1</td>
<td>A C</td>
<td>2 1</td>
</tr>
</tbody>
</table>

### Identical shift types during weekend

- Each weekend shift for the same weekend of the same employee must be the same shift type.
- **Unwanted patterns**: A combination of unwanted shift types in a row, for example a late shift followed by an early shift followed by a late shift.

  - **Employee wishes**:
    - **Day on request**: An employee wants to work on a specific day.
    - **Day off request**: An employee does not want to work on a specific day.
    - **Shift on request**: An employee wants to be assigned to a specific shift.
    - **Shift off request**: An employee does not want to be assigned to a specific shift.

  - **Alternative skill**: An employee assigned to a skill should have a proficiency in every skill required by that shift.

The problem is defined by the *International Nurse Rostering Competition 2010*.

Figure 9.12. Value proposition

---

**Employee rostering**

Assign shifts to employees more efficiently.

<table>
<thead>
<tr>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>14</td>
<td>22</td>
<td>6</td>
<td>14</td>
<td>22</td>
<td>6</td>
</tr>
</tbody>
</table>

- **Employees**
  - 1 shift per day
  - ≥ 10 hours forward rotation (enough time to sleep)
  - ≤ 5 consecutive shifts
  - Free day off request
  - ≥ 48 hours rest
  - Free no weekend work

- **Users**
  - Hospitals
  - Security guard firms
  - Call centers
  - Police and fire department

**NurseRostering benchmark**

**Employee well-being**

OptaPlanner versus traditional algorithm with domain knowledge

<table>
<thead>
<tr>
<th>Average</th>
<th>Min/Max</th>
<th># datasets</th>
<th>Biggest dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>+53%</td>
<td>+19%</td>
<td>26</td>
<td>752 assignments</td>
</tr>
</tbody>
</table>

Don't believe us? Run our open benchmarks yourself: [https://www.optaplanner.org/code/benchmarks.html](https://www.optaplanner.org/code/benchmarks.html)

**Problem size**

There are three dataset types:

- **Sprint**: must be solved in seconds.
- **Medium**: must be solved in minutes.
- **Long**: must be solved in hours.
toy1 has 1 skills, 3 shiftTypes, 2 patterns, 1 contracts, 6 employees, 7 shiftDates, 35 shiftAssignments and 0 requests with a search space of $10^{27}$.

toy2 has 1 skills, 3 shiftTypes, 3 patterns, 2 contracts, 20 employees, 28 shiftDates, 180 shiftAssignments and 140 requests with a search space of $10^{234}$.

sprint01 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint02 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint03 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint04 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint05 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint06 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint07 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint08 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint09 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint10 has 1 skills, 4 shiftTypes, 3 patterns, 4 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_hint01 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_hint02 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_hint03 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late01 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late02 has 1 skills, 4 shiftTypes, 4 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 139 requests with a search space of $10^{144}$.

sprint_late03 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 160 shiftAssignments and 150 requests with a search space of $10^{160}$.

sprint_late04 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 160 shiftAssignments and 150 requests with a search space of $10^{160}$.

sprint_late05 has 1 skills, 4 shiftTypes, 8 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late06 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late07 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late08 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 0 requests with a search space of $10^{152}$.

sprint_late09 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 0 requests with a search space of $10^{152}$.

sprint_late10 has 1 skills, 4 shiftTypes, 0 patterns, 3 contracts, 10 employees, 28 shiftDates, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

medium01 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 31 employees, 28 shiftDates, 608 shiftAssignments and 403 requests with a search space of $10^{906}$.

medium02 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 31 employees, 28 shiftDates, 608 shiftAssignments and 403 requests with a search space of $10^{906}$. 
medium03 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 31 employees, 28 shiftDates, 608 shiftAssignments and 403 requests with a search space of $10^{906}$.

medium04 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 31 employees, 28 shiftDates, 608 shiftAssignments and 403 requests with a search space of $10^{906}$.

medium05 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 31 employees, 28 shiftDates, 608 shiftAssignments and 403 requests with a search space of $10^{906}$.

medium_hint01 has 1 skills, 4 shiftTypes, 7 patterns, 4 contracts, 30 employees, 28 shiftDates, 428 shiftAssignments and 390 requests with a search space of $10^{632}$.

medium_hint02 has 1 skills, 4 shiftTypes, 7 patterns, 3 contracts, 30 employees, 28 shiftDates, 428 shiftAssignments and 390 requests with a search space of $10^{632}$.

medium_hint03 has 1 skills, 4 shiftTypes, 7 patterns, 4 contracts, 30 employees, 28 shiftDates, 428 shiftAssignments and 390 requests with a search space of $10^{632}$.

medium_late01 has 1 skills, 4 shiftTypes, 7 patterns, 4 contracts, 30 employees, 28 shiftDates, 424 shiftAssignments and 390 requests with a search space of $10^{626}$.

medium_late02 has 1 skills, 4 shiftTypes, 7 patterns, 3 contracts, 30 employees, 28 shiftDates, 428 shiftAssignments and 390 requests with a search space of $10^{632}$.

medium_late03 has 1 skills, 4 shiftTypes, 0 patterns, 4 contracts, 30 employees, 28 shiftDates, 428 shiftAssignments and 390 requests with a search space of $10^{632}$.

medium_late04 has 1 skills, 4 shiftTypes, 7 patterns, 3 contracts, 30 employees, 28 shiftDates, 416 shiftAssignments and 390 requests with a search space of $10^{614}$.

medium_late05 has 2 skills, 5 shiftTypes, 7 patterns, 4 contracts, 30 employees, 28 shiftDates, 452 shiftAssignments and 390 requests with a search space of $10^{667}$.

long01 has 2 skills, 5 shiftTypes, 3 patterns, 3 contracts, 49 employees, 28 shiftDates, 740 shiftAssignments and 735 requests with a search space of $10^{1250}$.

long02 has 2 skills, 5 shiftTypes, 3 patterns, 3 contracts, 49 employees, 28 shiftDates, 740 shiftAssignments and 735 requests with a search space of $10^{1250}$.

long03 has 2 skills, 5 shiftTypes, 3 patterns, 3 contracts, 49 employees, 28 shiftDates, 740 shiftAssignments and 735 requests with a search space of $10^{1250}$.

long04 has 2 skills, 5 shiftTypes, 3 patterns, 3 contracts, 49 employees, 28 shiftDates, 740 shiftAssignments and 735 requests with a search space of $10^{1250}$.

long05 has 2 skills, 5 shiftTypes, 3 patterns, 3 contracts, 49 employees, 28 shiftDates, 740 shiftAssignments and 735 requests with a search space of $10^{1250}$.

long_hint01 has 2 skills, 5 shiftTypes, 9 patterns, 3 contracts, 50 employees, 28 shiftDates, 740 shiftAssignments and 0 requests with a search space of $10^{1257}$.

long_hint02 has 2 skills, 5 shiftTypes, 7 patterns, 3 contracts, 50 employees, 28 shiftDates, 740 shiftAssignments and 0 requests with a search space of $10^{1257}$.

long_hint03 has 2 skills, 5 shiftTypes, 7 patterns, 3 contracts, 50 employees, 28 shiftDates, 740 shiftAssignments and 0 requests with a search space of $10^{1257}$.

long_late01 has 2 skills, 5 shiftTypes, 9 patterns, 3 contracts, 50 employees, 28 shiftDates, 752 shiftAssignments and 0 requests with a search space of $10^{1277}$.

long_late02 has 2 skills, 5 shiftTypes, 9 patterns, 4 contracts, 50 employees, 28 shiftDates, 752 shiftAssignments and 0 requests with a search space of $10^{1277}$.

long_late03 has 2 skills, 5 shiftTypes, 9 patterns, 3 contracts, 50 employees, 28 shiftDates, 752 shiftAssignments and 0 requests with a search space of $10^{1277}$.

long_late04 has 2 skills, 5 shiftTypes, 9 patterns, 4 contracts, 50 employees, 28 shiftDates, 752 shiftAssignments and 0 requests with a search space of $10^{1277}$.

long_late05 has 2 skills, 5 shiftTypes, 9 patterns, 3 contracts, 50 employees, 28 shiftDates, 740 shiftAssignments and 0 requests with a search space of $10^{1257}$.
9.18. TRAVELING TOURNAMENT PROBLEM (TTP)

Schedule matches between \( n \) number of teams.
**Hard constraints:**

- Each team plays twice against every other team: once home and once away.
- Each team has exactly one match on each timeslot.
- No team must have more than three consecutive home or three consecutive away matches.
- No repeaters: no two consecutive matches of the same two opposing teams.

**Soft constraints:**

- Minimize the total distance traveled by all teams.

The problem is defined on [Michael Trick’s website (which contains the world records too)](http://www.princeton.edu/~murphy1/tour/)

**Problem size**

- 1-nl04 has 6 days, 4 teams and 12 matches with a search space of $10^5$.
- 1-nl06 has 10 days, 6 teams and 30 matches with a search space of $10^{19}$.
- 1-nl08 has 14 days, 8 teams and 56 matches with a search space of $10^{43}$.
- 1-nl10 has 18 days, 10 teams and 90 matches with a search space of $10^{79}$.
- 1-nl12 has 22 days, 12 teams and 132 matches with a search space of $10^{126}$.
- 1-nl14 has 26 days, 14 teams and 182 matches with a search space of $10^{186}$.
- 1-nl16 has 30 days, 16 teams and 240 matches with a search space of $10^{259}$.
- 2-bra24 has 46 days, 24 teams and 552 matches with a search space of $10^{692}$.
- 3-nfl16 has 30 days, 16 teams and 240 matches with a search space of $10^{259}$.
- 3-nfl18 has 34 days, 18 teams and 306 matches with a search space of $10^{346}$.
3-nfl20 has 38 days, 20 teams and 380 matches with a search space of $10^{447}$.
3-nfl22 has 42 days, 22 teams and 462 matches with a search space of $10^{562}$.
3-nfl24 has 46 days, 24 teams and 552 matches with a search space of $10^{692}$.
3-nfl26 has 50 days, 26 teams and 650 matches with a search space of $10^{838}$.
3-nfl28 has 54 days, 28 teams and 756 matches with a search space of $10^{999}$.
3-nfl30 has 58 days, 30 teams and 870 matches with a search space of $10^{1175}$.
3-nfl32 has 62 days, 32 teams and 992 matches with a search space of $10^{1367}$.
4-super04 has 6 days, 4 teams and 12 matches with a search space of $10^{5}$.
4-super06 has 10 days, 6 teams and 30 matches with a search space of $10^{19}$.
4-super08 has 14 days, 8 teams and 56 matches with a search space of $10^{43}$.
4-super10 has 18 days, 10 teams and 90 matches with a search space of $10^{79}$.
4-super12 has 22 days, 12 teams and 132 matches with a search space of $10^{126}$.
4-super14 has 26 days, 14 teams and 182 matches with a search space of $10^{186}$.
5-galaxy04 has 6 days, 4 teams and 12 matches with a search space of $10^{5}$.
5-galaxy06 has 10 days, 6 teams and 30 matches with a search space of $10^{19}$.
5-galaxy08 has 14 days, 8 teams and 56 matches with a search space of $10^{43}$.
5-galaxy10 has 18 days, 10 teams and 90 matches with a search space of $10^{79}$.
5-galaxy12 has 22 days, 12 teams and 132 matches with a search space of $10^{126}$.
5-galaxy14 has 26 days, 14 teams and 182 matches with a search space of $10^{186}$.
5-galaxy16 has 30 days, 16 teams and 240 matches with a search space of $10^{259}$.
5-galaxy18 has 34 days, 18 teams and 306 matches with a search space of $10^{346}$.
5-galaxy20 has 38 days, 20 teams and 380 matches with a search space of $10^{447}$.
5-galaxy22 has 42 days, 22 teams and 462 matches with a search space of $10^{562}$.
5-galaxy24 has 46 days, 24 teams and 552 matches with a search space of $10^{692}$.
5-galaxy26 has 50 days, 26 teams and 650 matches with a search space of $10^{838}$.
5-galaxy28 has 54 days, 28 teams and 756 matches with a search space of $10^{999}$.
5-galaxy30 has 58 days, 30 teams and 870 matches with a search space of $10^{1175}$.
5-galaxy32 has 62 days, 32 teams and 992 matches with a search space of $10^{1367}$.
5-galaxy34 has 66 days, 34 teams and 1122 matches with a search space of $10^{1576}$.
5-galaxy36 has 70 days, 36 teams and 1260 matches with a search space of $10^{1801}$.
5-galaxy38 has 74 days, 38 teams and 1406 matches with a search space of $10^{2042}$.
5-galaxy40 has 78 days, 40 teams and 1560 matches with a search space of $10^{2301}$.

9.19. CHEAP TIME SCHEDULING

Schedule all tasks in time and on a machine to minimize power cost. Power prices differ in time. This is a form of job shop scheduling.

Hard constraints:

- Start time limits: Each task must start between its earliest start and latest start limit.
- Maximum capacity: The maximum capacity for each resource for each machine must not be exceeded.
- Startup and shutdown: Each machine must be active in the periods during which it has assigned tasks. Between tasks it is allowed to be idle to avoid startup and shutdown costs.

Medium constraints:

- Power cost: Minimize the total power cost of the whole schedule.
  - Machine power cost: Each active or idle machine consumes power, which infers a power cost (depending on the power price during that time).
- Task power cost: Each task consumes power too, which infers a power cost (depending on the power price during its time).

- Machine startup and shutdown cost: Every time a machine starts up or shuts down, an extra cost is incurred.

Soft constraints (addendum to the original problem definition):

- Start early: Prefer starting a task sooner rather than later.

The problem is defined by the ICON challenge.

### Problem size

<table>
<thead>
<tr>
<th>Sample/Instance</th>
<th>Resources</th>
<th>Machines</th>
<th>Periods</th>
<th>Tasks</th>
<th>Search Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>sample01</td>
<td>3</td>
<td>2</td>
<td>288</td>
<td>25</td>
<td>$10^{53}$</td>
</tr>
<tr>
<td>sample02</td>
<td>3</td>
<td>2</td>
<td>288</td>
<td>50</td>
<td>$10^{114}$</td>
</tr>
<tr>
<td>sample03</td>
<td>3</td>
<td>2</td>
<td>288</td>
<td>100</td>
<td>$10^{226}$</td>
</tr>
<tr>
<td>sample04</td>
<td>3</td>
<td>5</td>
<td>288</td>
<td>100</td>
<td>$10^{266}$</td>
</tr>
<tr>
<td>sample05</td>
<td>3</td>
<td>2</td>
<td>288</td>
<td>250</td>
<td>$10^{584}$</td>
</tr>
<tr>
<td>sample06</td>
<td>3</td>
<td>5</td>
<td>288</td>
<td>250</td>
<td>$10^{673}$</td>
</tr>
<tr>
<td>sample07</td>
<td>3</td>
<td>2</td>
<td>288</td>
<td>1000</td>
<td>$10^{2388}$</td>
</tr>
<tr>
<td>sample08</td>
<td>3</td>
<td>5</td>
<td>288</td>
<td>1000</td>
<td>$10^{2748}$</td>
</tr>
<tr>
<td>sample09</td>
<td>4</td>
<td>20</td>
<td>288</td>
<td>2000</td>
<td>$10^{6668}$</td>
</tr>
<tr>
<td>instance00</td>
<td>1</td>
<td>10</td>
<td>288</td>
<td>200</td>
<td>$10^{595}$</td>
</tr>
<tr>
<td>instance01</td>
<td>1</td>
<td>10</td>
<td>288</td>
<td>200</td>
<td>$10^{599}$</td>
</tr>
<tr>
<td>instance02</td>
<td>1</td>
<td>10</td>
<td>288</td>
<td>200</td>
<td>$10^{599}$</td>
</tr>
<tr>
<td>instance03</td>
<td>1</td>
<td>10</td>
<td>288</td>
<td>200</td>
<td>$10^{591}$</td>
</tr>
<tr>
<td>instance04</td>
<td>1</td>
<td>10</td>
<td>288</td>
<td>200</td>
<td>$10^{591}$</td>
</tr>
<tr>
<td>instance05</td>
<td>2</td>
<td>25</td>
<td>288</td>
<td>200</td>
<td>$10^{667}$</td>
</tr>
<tr>
<td>instance06</td>
<td>2</td>
<td>25</td>
<td>288</td>
<td>200</td>
<td>$10^{660}$</td>
</tr>
<tr>
<td>instance07</td>
<td>2</td>
<td>25</td>
<td>288</td>
<td>200</td>
<td>$10^{662}$</td>
</tr>
<tr>
<td>instance08</td>
<td>2</td>
<td>25</td>
<td>288</td>
<td>200</td>
<td>$10^{651}$</td>
</tr>
<tr>
<td>instance09</td>
<td>2</td>
<td>25</td>
<td>288</td>
<td>200</td>
<td>$10^{659}$</td>
</tr>
<tr>
<td>instance10</td>
<td>2</td>
<td>20</td>
<td>288</td>
<td>500</td>
<td>$10^{1657}$</td>
</tr>
<tr>
<td>instance11</td>
<td>2</td>
<td>20</td>
<td>288</td>
<td>500</td>
<td>$10^{1644}$</td>
</tr>
</tbody>
</table>
instance12 has 2 resources, 20 machines, 288 periods and 500 tasks with a search space of $10^{1637}$.
instance13 has 2 resources, 20 machines, 288 periods and 500 tasks with a search space of $10^{1659}$.
instance14 has 2 resources, 20 machines, 288 periods and 500 tasks with a search space of $10^{1643}$.
instance15 has 3 resources, 40 machines, 288 periods and 500 tasks with a search space of $10^{1782}$.
instance16 has 3 resources, 40 machines, 288 periods and 500 tasks with a search space of $10^{1778}$.
instance17 has 3 resources, 40 machines, 288 periods and 500 tasks with a search space of $10^{1764}$.
instance18 has 3 resources, 40 machines, 288 periods and 500 tasks with a search space of $10^{1769}$.
instance19 has 3 resources, 40 machines, 288 periods and 500 tasks with a search space of $10^{1778}$.
instance20 has 3 resources, 50 machines, 288 periods and 1000 tasks with a search space of $10^{3689}$.
instance21 has 3 resources, 50 machines, 288 periods and 1000 tasks with a search space of $10^{3678}$.
instance22 has 3 resources, 50 machines, 288 periods and 1000 tasks with a search space of $10^{3706}$.
instance23 has 3 resources, 50 machines, 288 periods and 1000 tasks with a search space of $10^{3676}$.
instance24 has 3 resources, 50 machines, 288 periods and 1000 tasks with a search space of $10^{3681}$.
instance25 has 3 resources, 60 machines, 288 periods and 1000 tasks with a search space of $10^{3774}$.
instance26 has 3 resources, 60 machines, 288 periods and 1000 tasks with a search space of $10^{3737}$.
instance27 has 3 resources, 60 machines, 288 periods and 1000 tasks with a search space of $10^{3744}$.
instance28 has 3 resources, 60 machines, 288 periods and 1000 tasks with a search space of $10^{3731}$.
instance29 has 3 resources, 60 machines, 288 periods and 1000 tasks with a search space of $10^{3746}$.
instance30 has 4 resources, 70 machines, 288 periods and 2000 tasks with a search space of $10^{7718}$.
instance31 has 4 resources, 70 machines, 288 periods and 2000 tasks with a search space of $10^{7740}$.
instance32 has 4 resources, 70 machines, 288 periods and 2000 tasks with a search space of $10^{7686}$.
instance33 has 4 resources, 70 machines, 288 periods and 2000 tasks with a search space of $10^{7672}$.
instance34 has 4 resources, 70 machines, 288 periods and 2000 tasks with a search space of $10^{7695}$.
instance35 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{8078}$.
instance36 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{814}$.
instance37 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7814}$.
instance38 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7764}$.
instance39 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7736}$.
instance40 has 4 resources, 90 machines, 288 periods and 4000 tasks with a search space of \(10^15976\).
instance41 has 4 resources, 90 machines, 288 periods and 4000 tasks with a search space of \(10^15935\).
instance42 has 4 resources, 90 machines, 288 periods and 4000 tasks with a search space of \(10^15887\).
instance43 has 4 resources, 90 machines, 288 periods and 4000 tasks with a search space of \(10^15896\).
instance44 has 4 resources, 90 machines, 288 periods and 4000 tasks with a search space of \(10^15885\).
instance45 has 4 resources, 100 machines, 288 periods and 5000 tasks with a search space of \(10^20173\).
instance46 has 4 resources, 100 machines, 288 periods and 5000 tasks with a search space of \(10^20132\).
instance47 has 4 resources, 100 machines, 288 periods and 5000 tasks with a search space of \(10^20126\).
instance48 has 4 resources, 100 machines, 288 periods and 5000 tasks with a search space of \(10^20110\).
instance49 has 4 resources, 100 machines, 288 periods and 5000 tasks with a search space of \(10^20078\).

9.20. INVESTMENT ASSET CLASS ALLOCATION (PORTFOLIO OPTIMIZATION)

Decide the relative quantity to invest in each asset class.

Hard constraints:

- Risk maximum: the total standard deviation must not be higher than the standard deviation maximum.
  - Total standard deviation calculation takes asset class correlations into account by applying Markowitz Portfolio Theory.
- Region maximum: Each region has a quantity maximum.
- Sector maximum: Each sector has a quantity maximum.

Soft constraints:

- Maximize expected return.

Problem size

de_smet_1 has 1 regions, 3 sectors and 11 asset classes with a search space of \(10^4\).
irrinki_1 has 2 regions, 3 sectors and 6 asset classes with a search space of \(10^3\).

Larger datasets have not been created or tested yet, but should not pose a problem. A good source of data is this Asset Correlation website.

9.21. CONFERENCE SCHEDULING

Assign each conference talk to a timeslot and a room. Timeslots can overlap. Read and write to and from an *.xlsx file that can be edited with LibreOffice or Excel.
Hard constraints:

- Talk type of timeslot: The type of a talk must match the timeslot’s talk type.
- Room unavailable timeslots: A talk’s room must be available during the talk’s timeslot.
- Room conflict: Two talks can’t use the same room during overlapping timeslots.
- Speaker unavailable timeslots: Every talk’s speaker must be available during the talk’s timeslot.
- Speaker conflict: Two talks can’t share a speaker during overlapping timeslots.
- Generic purpose timeslot and room tags:
  - Speaker required timeslot tag: If a speaker has a required timeslot tag, then all of his or her talks must be assigned to a timeslot with that tag.
  - Speaker prohibited timeslot tag: If a speaker has a prohibited timeslot tag, then all of his or her talks cannot be assigned to a timeslot with that tag.
  - Talk required timeslot tag: If a talk has a required timeslot tag, then it must be assigned to a timeslot with that tag.
  - Talk prohibited timeslot tag: If a talk has a prohibited timeslot tag, then it cannot be assigned to a timeslot with that tag.
  - Speaker required room tag: If a speaker has a required room tag, then all of his or her talks must be assigned to a room with that tag.
  - Speaker prohibited room tag: If a speaker has a prohibited room tag, then all of his or her talks cannot be assigned to a room with that tag.
  - Talk required room tag: If a talk has a required room tag, then it must be assigned to a room with that tag.
  - Talk prohibited room tag: If a talk has a prohibited room tag, then it cannot be assigned to a room with that tag.
- Talk mutually-exclusive-talks tag: Talks that share such a tag must not be scheduled in overlapping timeslots.
- Talk prerequisite talks: A talk must be scheduled after all its prerequisite talks.

Soft constraints:

- Theme track conflict: Minimize the number of talks that share a theme tag during overlapping timeslots.
- Sector conflict: Minimize the number of talks that share a same sector tag during overlapping timeslots.
- Content audience level flow violation: For every content tag, schedule the introductory talks before the advanced talks.
- Audience level diversity: For every timeslot, maximize the number of talks with a different audience level.
- Language diversity: For every timeslot, maximize the number of talks with a different language.
• Generic purpose timeslot and room tags:
  ○ Speaker preferred timeslot tag: If a speaker has a preferred timeslot tag, then all of his or her talks should be assigned to a timeslot with that tag.
  ○ Speaker undesired timeslot tag: If a speaker has an undesired timeslot tag, then none of his or her talks should be assigned to a timeslot with that tag.
  ○ Talk preferred timeslot tag: If a talk has a preferred timeslot tag, then it should be assigned to a timeslot with that tag.
  ○ Talk undesired timeslot tag: If a talk has an undesired timeslot tag, then it should not be assigned to a timeslot with that tag.
  ○ Speaker preferred room tag: If a speaker has a preferred room tag, then all of his or her talks should be assigned to a room with that tag.
  ○ Speaker undesired room tag: If a speaker has an undesired room tag, then none of his or her talks should be assigned to a room with that tag.
  ○ Talk preferred room tag: If a talk has a preferred room tag, then it should be assigned to a room with that tag.
  ○ Talk undesired room tag: If a talk has an undesired room tag, then it should not be assigned to a room with that tag.

• Same day talks: All talks that share a theme tag or content tag should be scheduled in the minimum number of days (ideally in the same day).
Problem size

18 talks-6 timeslots-5 rooms has 18 talks, 6 timeslots and 5 rooms with a search space of \(10^{26}\).
36 talks-12 timeslots-5 rooms has 36 talks, 12 timeslots and 5 rooms with a search space of \(10^{64}\).
72 talks-12 timeslots-10 rooms has 72 talks, 12 timeslots and 10 rooms with a search space of \(10^{149}\).
108 talks-18 timeslots-10 rooms has 108 talks, 18 timeslots and 10 rooms with a search space of \(10^{243}\).
216 talks-18 timeslots-20 rooms has 216 talks, 18 timeslots and 20 rooms with a search space of \(10^{552}\).

9.22. ROCK TOUR

Drive the rock bank bus from show to show, but schedule shows only on available days.

Hard constraints:

- Schedule every required show.
- Schedule as many shows as possible.

Medium constraints:

- Maximize revenue opportunity.
• Minimize driving time.
• Visit sooner than later.

Soft constraints:
• Avoid long driving times.

Problem size

47 shows has 47 shows with a search space of $10^{59}$.

9.23. FLIGHT CREW SCHEDULING

Assign flights to pilots and flight attendants.

Hard constraints:
• Required skill: each flight assignment has a required skill. For example, flight AB0001 requires 2 pilots and 3 flight attendants.
• Flight conflict: each employee can only attend one flight at the same time
• Transfer between two flights: between two flights, an employee must be able to transfer from the arrival airport to the departure airport. For example, Ann arrives in Brussels at 10:00 and departs in Amsterdam at 15:00.
• Employee unavailability: the employee must be available on the day of the flight. For example, Ann is on PTO on 1-Feb.

Soft constraints:
• First assignment departing from home
• Last assignment arriving at home
• Load balance flight duration total per employee

Problem size

175 flights-7 days-Europe has 2 skills, 50 airports, 150 employees, 175 flights and 875 flight assignments with a search space of $10^{1904}$.
700 flights-28 days-Europe has 2 skills, 50 airports, 150 employees, 700 flights and 3500 flight assignments with a search space of $10^{7616}$.
875 flights-7 days-Europe has 2 skills, 50 airports, 750 employees, 875 flights and 4375 flight assignments with a search space of $10^{12578}$.
175 flights-7 days-US has 2 skills, 48 airports, 150 employees, 175 flights and 875 flight assignments with a search space of $10^{1904}$.
CHAPTER 10. DOWNLOADING RED HAT BUILD OF OPTAPLANNER EXAMPLES

You can download the Red Hat build of OptaPlanner examples as a part of the {PRODUCTPAM} add-ons package available on the Red Hat Customer Portal.

Procedure

1. Navigate to the Software Downloads page in the Red Hat Customer Portal (login required), and select the product and version from the drop-down options:
   - **Product:** Process Automation Manager
   - **Version:** 7.13.5

2. Download Red Hat Process Automation Manager 7.13 Add Ons


4. Extract the *rhpam-7.13.5-planner-engine.zip* file.

Result

The extracted *rhpam-7.13.5-planner-engine* directory contains example source code under the following subdirectories:

- *examples/sources/src/main/java/org/optaplanner/examples*
- *examples/sources/src/main/resources/org/optaplanner/examples*

10.1. RUNNING OPTAPLANNER EXAMPLES

Red Hat build of OptaPlanner includes several examples that demonstrate a variety of planning use cases. Download and use the examples to explore different types of planning solutions.

Prerequisites

- You have downloaded and extracted the examples as described in Chapter 10, Downloading Red Hat build of OptaPlanner examples.

Procedure

1. To run the examples, in the *rhpam-7.13.5-planner-engine/examples* directory enter one of the following commands:
   - **Linux or Mac:**
     ```bash
     $ ./runExamples.sh
     ```
   - **Windows:**
     ```bash
     $ runExamples.bat
     ```

   The OptaPlanner Examples window opens.
2. Select an example to run that example.

NOTE
Red Hat build of OptaPlanner has no GUI dependencies. It runs just as well on a server or a mobile JVM as it does on the desktop.

10.2. RUNNING THE RED HAT BUILD OF OPTAPLANNER EXAMPLES IN AN IDE (INTELLIJ, ECLIPSE, OR NETBEANS)

If you use an integrated development environment (IDE), such as IntelliJ, Eclipse, or Netbeans, you can run your downloaded OptaPlanner examples within your development environment.

Prerequisites

- You have downloaded and extracted the OptaPlanner examples as described in Chapter 10, Downloading Red Hat build of OptaPlanner examples.

Procedure

1. Open the OptaPlanner examples as a new project:
   a. For IntelliJ or Netbeans, open examples/sources/pom.xml as the new project. The Maven integration guides you through the rest of the installation. Skip the rest of the steps in this procedure.
   b. For Eclipse, open a new project for the /examples/binaries directory, located under the rhpam-7.13.5-planner-engine directory.

2. Add all the JAR files that are in the binaries directory to the classpath, except for the examples/binaries/optaplanner-examples-7.67.0.Final-redhat-00024.jar file.

3. Add the Java source directory src/main/java and the Java resources directory src/main/resources, located under the rhpam-7.13.5-planner-engine/examples/sources directory.

4. Create a run configuration:
   - Main class: org.optaplanner.examples.app.OptaPlannerExamplesApp
   - VM parameters (optional): -Xmx512M -server -Dorg.optaplanner.examples.dataDir=examples/sources/data
   - Working directory: examples/sources

5. Run the run configuration.
CHAPTER 11. GETTING STARTED WITH OPTAPLANNER IN BUSINESS CENTRAL: AN EMPLOYEE ROSTERING EXAMPLE

You can build and deploy the employee-rostering sample project in Business Central. The project demonstrates how to create each of the Business Central assets required to solve the shift rostering planning problem and use Red Hat build of OptaPlanner to find the best possible solution.

You can deploy the preconfigured employee-rostering project in Business Central. Alternatively, you can create the project yourself using Business Central.

**NOTE**

The employee-rostering sample project in Business Central does not include a data set. You must supply a data set in XML format using a REST API call.

### 11.1. DEPLOYING THE EMPLOYEE ROSTERING SAMPLE PROJECT IN BUSINESS CENTRAL

Business Central includes a number of sample projects that you can use to get familiar with the product and its features. The employee rostering sample project is designed and created to demonstrate the shift rostering use case for Red Hat build of OptaPlanner. Use the following procedure to deploy and run the employee rostering sample in Business Central.

**Prerequisites**

- Red Hat Decision Manager has been downloaded and installed. For installation options, see Planning a Red Hat Decision Manager installation.
- You have started Red Hat Decision Manager, as described in the installation documentation, and you are logged in to Business Central as a user with admin permissions.

**Procedure**

1. In Business Central, click **Menu → Design → Projects**.
2. In the preconfigured **MySpace** space, click **Try Samples**.
3. Select **employee-rostering** from the list of sample projects and click **Ok** in the upper-right corner to import the project.
4. After the asset list has complied, click **Build & Deploy** to deploy the employee rostering example.

The rest of this document explains each of the project assets and their configuration.

### 11.2. RE-CREATING THE EMPLOYEE ROSTERING SAMPLE PROJECT

The employee rostering sample project is a preconfigured project available in Business Central. You can learn about how to deploy this project in Section 11.1, “Deploying the employee rostering sample project in Business Central”.

You can create the employee rostering example “from scratch”. You can use the workflow in this example to create a similar project of your own in Business Central.
11.2.1. Setting up the employee rostering project

To start developing a solver in Business Central, you must set up the project.

Prerequisites

- Red Hat Decision Manager has been downloaded and installed.
- You have deployed Business Central and logged in with a user that has the admin role.

Procedure

1. Create a new project in Business Central by clicking Menu → Design → Projects → Add Project.

2. In the Add Project window, fill out the following fields:
   - Name: employee-rostering
   - Description (optional): Employee rostering problem optimization using OptaPlanner. Assigns employees to shifts based on their skill.

   Optional: Click Configure Advanced Options to populate the Group ID, Artifact ID, and Version information.
   - Group ID: employee-rostering
   - Artifact ID: employee-rostering
   - Version: 1.0.0-SNAPSHOT

3. Click Add to add the project to the Business Central project repository.

11.2.2. Problem facts and planning entities

Each of the domain classes in the employee rostering planning problem is categorized as one of the following:

- An unrelated class: not used by any of the score constraints. From a planning standpoint, this data is obsolete.

- A problem fact class: used by the score constraints, but does not change during planning (as long as the problem stays the same), for example, Shift and Employee. All the properties of a problem fact class are problem properties.

- A planning entity class: used by the score constraints and changes during planning, for example, ShiftAssignment. The properties that change during planning are planning variables. The other properties are problem properties.

Ask yourself the following questions:

- What class changes during planning?
- Which class has variables that I want the Solver to change?

That class is a planning entity.
A planning entity class needs to be annotated with the `@PlanningEntity` annotation, or defined in Business Central using the Red Hat build of OptaPlanner dock in the domain designer.

Each planning entity class has one or more planning variables, and must also have one or more defining properties.

Most use cases have only one planning entity class, and only one planning variable per planning entity class.

### 11.2.3. Creating the data model for the employee rostering project

Use this section to create the data objects required to run the employee rostering sample project in Business Central.

#### Prerequisites

- You have completed the project setup described in Section 11.2.1, “Setting up the employee rostering project”.

#### Procedure

1. With your new project, either click Data Object in the project perspective, or click Add Asset → Data Object to create a new data object.

2. Name the first data object Timeslot, and select `employeerostering.employeerostering` as the Package. Click Ok.

3. In the Data Objects perspective, click +add field to add fields to the Timeslot data object.

4. In the id field, type endTime.

5. Click the drop-down menu next to Type and select LocalDateTime.

6. Click Create and continue to add another field.

7. Add another field with the id startTime and Type LocalDateTime.

8. Click Create.

9. Click Save in the upper-right corner to save the Timeslot data object.

10. Click the x in the upper-right corner to close the Data Objects perspective and return to the Assets menu.

11. Using the previous steps, create the following data objects and their attributes:

<table>
<thead>
<tr>
<th>Table 11.1. Skill</th>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td></td>
<td>String</td>
</tr>
</tbody>
</table>

Table 11.2. Employee
For more examples of creating data objects, see *Getting started with decision services*.

### 11.2.3.1. Creating the employee roster planning entity

In order to solve the employee rostering planning problem, you must create a planning entity and a solver. The planning entity is defined in the domain designer using the attributes available in the Red Hat build of OptaPlanner dock.

Use the following procedure to define the *ShiftAssignment* data object as the planning entity for the employee rostering example.

**Prerequisites**
• You have created the relevant data objects and planning entity required to run the employee rostering example by completing the procedures in Section 11.2.3, “Creating the data model for the employee rostering project”.

**Procedure**

1. From the project Assets menu, open the *ShiftAssignment* data object.

2. In the *Data Objects* perspective, open the OptaPlanner dock by clicking the on the right.

3. Select *Planning Entity*.

4. Select *employee* from the list of fields under the *ShiftAssignment* data object.

5. In the OptaPlanner dock, select *Planning Variable*.
   In the *Value Range Id* input field, type *employeeRange*. This adds the @ValueRangeProvider annotation to the planning entity, which you can view by clicking the *Source* tab in the designer.

   The value range of a planning variable is defined with the @ValueRangeProvider annotation. A @ValueRangeProvider annotation always has a property *id*, which is referenced by the @PlanningVariable property valueRangeProviderRefs.

6. Close the dock and click *Save* to save the data object.

**11.2.3.2. Creating the employee roster planning solution**

The employee roster problem relies on a defined planning solution. The planning solution is defined in the domain designer using the attributes available in the Red Hat build of OptaPlanner dock.

**Prerequisites**

• You have created the relevant data objects and planning entity required to run the employee rostering example by completing the procedures in Section 11.2.3, “Creating the data model for the employee rostering project” and Section 11.2.3.1, “Creating the employee roster planning entity”.

**Procedure**

1. Create a new data object with the identifier *EmployeeRoster*.

2. Create the following fields:

   **Table 11.6. EmployeeRoster**

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>dayOffRequestList</td>
<td>employeerostering.employeerostering.DayOffRequest[List]</td>
</tr>
<tr>
<td>shiftAssignmentList</td>
<td>employeerostering.employeerostering.ShiftAssignment[List]</td>
</tr>
</tbody>
</table>
3. In the **Data Objects** perspective, open the OptaPlanner dock by clicking the on the right.

4. Select **Planning Solution**.

5. Leave the default **Hard soft score** as the **Solution Score Type**. This automatically generates a **score** field in the **EmployeeRoster** data object with the solution score as the type.

6. Add a new field with the following attributes:

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>shiftList</td>
<td><code>employeerostering.employeerostering.Shift[List]</code></td>
</tr>
<tr>
<td>skillList</td>
<td><code>employeerostering.employeerostering.Skill[List]</code></td>
</tr>
<tr>
<td>timeslotList</td>
<td><code>employeerostering.employeerostering.Timeslot[List]</code></td>
</tr>
</tbody>
</table>

7. With the **employeeList** field selected, open the OptaPlanner dock and select the **Planning Value Range Provider** box.
   
   In the **id** field, type **employeeRange**. Close the dock.

8. Click **Save** in the upper-right corner to save the asset.

### 11.2.4. Employee rostering constraints

Employee rostering is a planning problem. All planning problems include constraints that must be satisfied in order to find an optimal solution.

The employee rostering sample project in Business Central includes the following hard and soft constraints:

**Hard constraint**

- Employees are only assigned one shift per day.
- All shifts that require a particular employee skill are assigned an employee with that particular skill.

**Soft constraints**

- All employees are assigned a shift.
If an employee requests a day off, their shift is reassigned to another employee.

Hard and soft constraints are defined in Business Central using either the free-form DRL designer, or using guided rules.

11.2.4.1. DRL (Drools Rule Language) rules

DRL (Drools Rule Language) rules are business rules that you define directly in .drl text files. These DRL files are the source in which all other rule assets in Business Central are ultimately rendered. You can create and manage DRL files within the Business Central interface, or create them externally as part of a Maven or Java project using Red Hat CodeReady Studio or another integrated development environment (IDE). A DRL file can contain one or more rules that define at a minimum the rule conditions (\texttt{when}) and actions (\texttt{then}). The DRL designer in Business Central provides syntax highlighting for Java, DRL, and XML.

DRL files consist of the following components:

### Components in a DRL file

- **package**
- **import**
- **function**  // Optional
- **query**  // Optional
- **declare**  // Optional
- **global**  // Optional

```
rule "rule name"
  // Attributes
  when
  // Conditions
  then
  // Actions
end

rule "rule2 name"

...
```

The following example DRL rule determines the age limit in a loan application decision service:

### Example rule for loan application age limit

```
rule "Underage"
salience 15
agenda-group "applicationGroup"
when
  $application : LoanApplication()
  Applicant( age < 21 )
then
```
A DRL file can contain single or multiple rules, queries, and functions, and can define resource declarations such as imports, globals, and attributes that are assigned and used by your rules and queries. The DRL package must be listed at the top of a DRL file and the rules are typically listed last. All other DRL components can follow any order.

Each rule must have a unique name within the rule package. If you use the same rule name more than once in any DRL file in the package, the rules fail to compile. Always enclose rule names with double quotation marks (rule "rule name") to prevent possible compilation errors, especially if you use spaces in rule names.

All data objects related to a DRL rule must be in the same project package as the DRL file in Business Central. Assets in the same package are imported by default. Existing assets in other packages can be imported with the DRL rule.

11.2.4.2. Defining constraints for employee rostering using the DRL designer

You can create constraint definitions for the employee rostering example using the free-form DRL designer in Business Central.

Use this procedure to create a hard constraint where no employee is assigned a shift that begins less than 10 hours after their previous shift ended.

Procedure

1. In Business Central, go to Menu → Design → Projects and click the project name.
2. Click Add Asset → DRL file.
3. In the DRL file name field, type ComplexScoreRules.
4. Select the employeerostering.employeerostering package.
5. Click +Ok to create the DRL file.
6. In the Model tab of the DRL designer, define the Employee10HourShiftSpace rule as a DRL file:

```java
package employeerostering.employeerostering;

rule "Employee10HourShiftSpace"
when
   $shiftAssignment : ShiftAssignment( $employee : employee != null, $shiftEndDateTime :
shift.timeslot.endTime) ShiftAssignment( this != $shiftAssignment, $employee == employee, $shiftEndDateTime
<= shift.timeslot.endTime,
   $shiftEndDateTime.until(shift.timeslot.startTime,
   java.time.temporal.ChronoUnit.HOURS) <10)
then
   scoreHolder.addHardConstraintMatch(kcontext, -1);
end
```
7. Click Save to save the DRL file.
For more information about creating DRL files, see *Designing a decision service using DRL rules*.

### 11.2.5. Creating rules for employee rostering using guided rules

You can create rules that define hard and soft constraints for employee rostering using the guided rules designer in Business Central.

#### 11.2.5.1. Guided rules

Guided rules are business rules that you create in a UI-based guided rules designer in Business Central that leads you through the rule-creation process. The guided rules designer provides fields and options for acceptable input based on the data objects for the rule being defined. The guided rules that you define are compiled into Drools Rule Language (DRL) rules as with all other rule assets.

All data objects related to a guided rule must be in the same project package as the guided rule. Assets in the same package are imported by default. After you create the necessary data objects and the guided rule, you can use the Data Objects tab of the guided rules designer to verify that all required data objects are listed or to import other existing data objects by adding a New item.

#### 11.2.5.2. Creating a guided rule to balance employee shift numbers

The `BalanceEmployeesShiftNumber` guided rule creates a soft constraint that ensures shifts are assigned to employees in a way that is balanced as evenly as possible. It does this by creating a score penalty that increases when shift distribution is less even. The score formula, implemented by the rule, incentivizes the Solver to distribute shifts in a more balanced way.

#### Procedure

1. In Business Central, go to **Menu → Design → Projects** and click the project name.

2. Click Add Asset → Guided Rule.

3. Enter `BalanceEmployeesShiftNumber` as the Guided Rule name and select the `employeerostering.employeerostering` Package.

4. Click Ok to create the rule asset.

5. Add a WHEN condition by clicking the + in the WHEN field.

6. Select Employee in the Add a condition to the rule window. Click +Ok.

7. Click the Employee condition to modify the constraints and add the variable name $employee.
8. Add the **WHEN** condition **From Accumulate**.
   a. Above the **From Accumulate** condition, click **click to add pattern** and select **Number** as the fact type from the drop-down list.
   
   b. Add the variable name **$shiftCount** to the **Number** condition.
   
   c. Below the **From Accumulate** condition, click **click to add pattern** and select the **ShiftAssignment** fact type from the drop-down list.
   
   d. Add the variable name **$shiftAssignment** to the **ShiftAssignment** fact type.
   
   e. Click the **ShiftAssignment** condition again and from the **Add a restriction on a field** drop-down list, select **employee**.
   
   f. Select **equal to** from the drop-down list next to the **employee** constraint.
   
   g. Click the **icon** next to the drop-down button to add a variable, and click **Bound variable** in the **Field value** window.
   
   h. Select **$employee** from the drop-down list.
   
   i. In the **Function** box type **count($shiftAssignment)**.

9. Add the **THEN** condition by clicking the **+** in the **THEN** field.

10. Select **Modify Soft Score** in the **Add a new action** window. Click **+Ok**.
   
   a. Type the following expression into the box:
   
   
   \[-(\text{$shiftCount.intValue()} \times \text{$shiftCount.intValue()}\)]
   
   11. Click **Validate** in the upper-right corner to check all rule conditions are valid. If the rule validation fails, address any problems described in the error message, review all components in the rule, and try again to validate the rule until the rule passes.

12. Click **Save** to save the rule.

For more information about creating guided rules, see *Designing a decision service using guided rules*.

**11.2.5.3. Creating a guided rule for no more than one shift per day**

The **OneEmployeeShiftPerDay** guided rule creates a hard constraint that employees are not assigned more than one shift per day. In the employee rostering example, this constraint is created using the guided rule designer.
Procedure

1. In Business Central, go to **Menu → Design → Projects** and click the project name.

2. Click **Add Asset → Guided Rule**.

3. Enter **OneEmployeeShiftPerDay** as the **Guided Rule** name and select the **employeerostering.employeerostering Package**.

4. Click **Ok** to create the rule asset.

5. Add a **WHEN** condition by clicking the + in the **WHEN** field.

6. Select **Free form DRL** from the **Add a condition to the rule** window.

7. In the free form DRL box, type the following condition:

   ```
   $shiftAssignment : ShiftAssignment( employee != null )
   ShiftAssignment( this != $shiftAssignment , employee == $shiftAssignment.employee ,
   shift.timeslot.startTime.toLocalDate() ==
   $shiftAssignment.shift.timeslot.startTime.toLocalDate() )
   ```

   This condition states that a shift cannot be assigned to an employee that already has another shift assignment on the same day.

8. Add the **THEN** condition by clicking the + in the **THEN** field.

9. Select **Add free form DRL** from the **Add a new action** window.

10. In the free form DRL box, type the following condition:

    ```
    scoreHolder.addHardConstraintMatch(kcontext, -1);
    ```

11. Click **Validate** in the upper-right corner to check all rule conditions are valid. If the rule validation fails, address any problems described in the error message, review all components in the rule, and try again to validate the rule until the rule passes.

12. Click **Save** to save the rule.

For more information about creating guided rules, see *Designing a decision service using guided rules*.

11.2.5.4. Creating a guided rule to match skills to shift requirements
The *ShiftRequiredSkillsAreMet* guided rule creates a hard constraint that ensures all shifts are assigned an employee with the correct set of skills. In the employee rostering example, this constraint is created using the guided rule designer.

**Procedure**

1. In Business Central, go to **Menu → Design → Projects** and click the project name.
2. Click **Add Asset → Guided Rule**.
3. Enter *ShiftRequiredSkillsAreMet* as the **Guided Rule** name and select the `employeerostering.employeerostering` Package.
4. Click **Ok** to create the rule asset.
5. Add a **WHEN** condition by clicking the `+` in the **WHEN** field.
6. Select *ShiftAssignment* in the **Add a condition to the rule** window. Click +Ok.
7. Click the *ShiftAssignment* condition, and select **employee** from the **Add a restriction on a field** drop-down list.
8. In the designer, click the drop-down list next to **employee** and select **is not null**.
9. Click the *ShiftAssignment* condition, and click **Expression editor**.
   a. In the designer, click `[not bound]` to open the **Expression editor**, and bind the expression to the variable `$requiredSkill`. Click **Set**.
   b. In the designer, next to `$requiredSkill`, select **shift** from the first drop-down list, then **requiredSkill** from the next drop-down list.
10. Click the *ShiftAssignment* condition, and click **Expression editor**.
    a. In the designer, next to `[not bound]`, select **employee** from the first drop-down list, then **skills** from the next drop-down list.
    b. Leave the next drop-down list as **Choose**.
    c. In the next drop-down box, change **please choose** to **excludes**.
    d. Click the **icon next to excludes**, and in the **Field value** window, click the **New formula** button.
e. Type $requiredSkill into the formula box.

11. Add the THEN condition by clicking the $plus$ in the THEN field.

12. Select Modify Hard Score in the Add a new action window. Click +Ok.

13. Type -1 into the score actions box.

14. Click Validate in the upper-right corner to check all rule conditions are valid. If the rule validation fails, address any problems described in the error message, review all components in the rule, and try again to validate the rule until the rule passes.

15. Click Save to save the rule.

For more information about creating guided rules, see Designing a decision service using guided rules.

11.2.5.5. Creating a guided rule to manage day off requests

The DayOffRequest guided rule creates a soft constraint. This constraint allows a shift to be reassigned to another employee in the event the employee who was originally assigned the shift is no longer able to work that day. In the employee rostering example, this constraint is created using the guided rule designer.

For more information about creating guided rules, see Designing a decision service using guided rules.

### Procedure

1. In Business Central, go to Menu → Design → Projects and click the project name.

2. Click Add Asset → Guided Rule.

3. Enter DayOffRequest as the Guided Rule name and select the employeerostering.employeerostering Package.

4. Click Ok to create the rule asset.

5. Add a WHEN condition by clicking the $plus$ in the WHEN field.

6. Select Free form DRL from the Add a condition to the rule window.

7. In the free form DRL box, type the following condition:

```drl
$dayOffRequest : DayOffRequest( )
ShiftAssignment( employee == $dayOffRequest.employee , shift.timeslot.startTime.toLocalDate() == $dayOffRequest.date )
```

For more information about creating guided rules, see Designing a decision service using guided rules.
This condition states if a shift is assigned to an employee who has made a day off request, the employee can be unassigned the shift on that day.

8. Add the **THEN** condition by clicking the + in the **THEN** field.

9. Select **Add free form DRL** from the **Add a new action** window.

10. In the free form DRL box, type the following condition:

    ```
    scoreHolder.addSoftConstraintMatch(kcontext, -100);
    ```

11. Click **Validate** in the upper-right corner to check all rule conditions are valid. If the rule validation fails, address any problems described in the error message, review all components in the rule, and try again to validate the rule until the rule passes.

12. Click **Save** to save the rule.

For more information about creating guided rules, see *Designing a decision service using guided rules*.

### 11.2.6. Creating a solver configuration for employee rostering

You can create and edit Solver configurations in Business Central. The Solver configuration designer creates a solver configuration that can be run after the project is deployed.

#### Prerequisites

- Red Hat Decision Manager has been downloaded and installed.
- You have created and configured all of the relevant assets for the employee rostering example.

#### Procedure

1. In Business Central, click **Menu** → **Projects**, and click your project to open it.

2. In the **Assets** perspective, click **Add Asset** → **Solver configuration**

3. In the **Create new Solver configuration** window, type the name **EmployeeRosteringSolverConfig** for your Solver and click **Ok**. This opens the **Solver configuration** designer.

4. In the **Score Director Factory** configuration section, define a KIE base that contains scoring rule definitions. The employee rostering sample project uses **defaultKieBase**.
   
   a. Select one of the KIE sessions defined within the KIE base. The employee rostering sample project uses **defaultKieSession**.

5. Click **Validate** in the upper-right corner to check the **Score Director Factory** configuration is correct. If validation fails, address any problems described in the error message, and try again to validate until the configuration passes.

6. Click **Save** to save the Solver configuration.

### 11.2.7. Configuring Solver termination for the employee rostering project

This opens the **Solver configuration** designer.
You can configure the Solver to terminate after a specified amount of time. By default, the planning engine is given an unlimited time period to solve a problem instance.

The employee rostering sample project is set up to run for 30 seconds.

**Prerequisites**

- You have created all relevant assets for the employee rostering project and created the `EmployeeRosteringSolverConfig` solver configuration in Business Central as described in Section 11.2.6, “Creating a solver configuration for employee rostering”.

**Procedure**

1. Open the `EmployeeRosteringSolverConfig` from the Assets perspective. This will open the Solver configuration designer.
2. In the Termination section, click Add to create new termination element within the selected logical group.
3. Select the Time spent termination type from the drop-down list. This is added as an input field in the termination configuration.
4. Use the arrows next to the time elements to adjust the amount of time spent to 30 seconds.
5. Click Validate in the upper-right corner to check the Score Director Factory configuration is correct. If validation fails, address any problems described in the error message, and try again to validate until the configuration passes.
6. Click Save to save the Solver configuration.

11.3. ACCESSING THE SOLVER USING THE REST API

After deploying or re-creating the sample solver, you can access it using the REST API.

You must register a solver instance using the REST API. Then you can supply data sets and retrieve optimized solutions.

**Prerequisites**

- The employee rostering project is set up and deployed according to the previous sections in this document. You can either deploy the sample project, as described in Section 11.1, “Deploying the employee rostering sample project in Business Central”, or re-create the project, as described in Section 11.2, “Re-creating the employee rostering sample project”.

11.3.1. Registering the Solver using the REST API

You must register the solver instance using the REST API before you can use the solver.

Each solver instance is capable of optimizing one planning problem at a time.

**Procedure**

1. Create a HTTP request using the following header:
2. Register the Solver using the following request:

```plaintext
PUT 
http://localhost:8080/kie-server/services/rest/server/containers/employeerostering_1.0.0-SNAPSHOT/solvers/EmployeeRosteringSolver
```

Request body

```xml
<solver-instance>
  <solver-config-file>employeerostering/employeerostering/EmployeeRosteringSolverConfig.solver.xml</solver-config-file>
</solver-instance>
```

11.3.2. Calling the Solver using the REST API

After registering the solver instance, you can use the REST API to submit a data set to the solver and to retrieve an optimized solution.

Procedure

1. Create a HTTP request using the following header:

```plaintext
authorization: admin:admin
X-KIE-ContentType: xstream
content-type: application/xml
```

2. Submit a request to the Solver with a data set, as in the following example:

```plaintext
POST 
http://localhost:8080/kie-server/services/rest/server/containers/employeerostering_1.0.0-SNAPSHOT/solvers/EmployeeRosteringSolver/state/solving
```

Request body

```xml
<employeerostering.employeerostering.EmployeeRoster>
  <employeerostering.employeerostering.EmployeeList>
    <employeerostering.employeerostering.Employee>
      <name>John</name>
      <skills>
        <employeerostering.employeerostering.Skill>
          <name>reading</name>
        </employeerostering.employeerostering.Skill>
      </skills>
    </employeerostering.employeerostering.Employee>
    <employeerostering.employeerostering.Employee>
      <name>Mary</name>
      <skills>
      </skills>
    </employeerostering.employeerostering.Employee>
  </employeerostering.employeerostering.EmployeeList>
</employeerostering.employeerostering.EmployeeRoster>
```
<employeerostering.employeerostering.Employee>
  <name>Petr</name>
  <skills>
    <employeerostering.employeerostering.Skill>
      <name>writing</name>
    </employeerostering.employeerostering.Skill>
    <employeerostering.employeerostering.Skill>
      <name>speaking</name>
    </employeerostering.employeerostering.Skill>
  </skills>
</employeerostering.employeerostering.Employee>
3. Request the best solution to the planning problem:

GET

http://localhost:8080/kie-server/services/rest/server/containers/employeerostering_1.0.0-SNAPSHOT/solvers/EmployeeRosteringSolver/bestsolution

Example response

```xml
< solver-instance >
  < container-id > employee-rostering </ container-id >
  < solver-id > solver1 </ solver-id >
  < solver-config-file > employee-rostering/EmployeeRosteringSolverConfig.solver.xml </ solver-config-file >
  < status > NOT_SOLVING </ status >
  < score scoreClass="org.optaplanner.core.api.score.buildin.hardsoft.HardSoftScore">0hard/0soft
  < best-solution class="employeerostering.employeerostering.EmployeeRoster">
    < employeeList >
      < employee-rostering.employeerostering.Employee >
        < name > John </ name >
        < skills >
          < employee-rostering.employeerostering.Skill >
            < name > reading </ name >
          </ employee-rostering.employeerostering.Skill >
        </ skills >
      </ employee-rostering.employeerostering.Employee >
      < employee-rostering.employeerostering.Employee >
        < name > Mary </ name >
        < skills >
          < employee-rostering.employeerostering.Skill >
            < name > writing </ name >
          </ employee-rostering.employeerostering.Skill >
        </ skills >
      </ employee-rostering.employeerostering.Employee >
      < employee-rostering.employeerostering.Employee >
        < name > Petr </ name >
        < skills >
          < employee-rostering.employeerostering.Skill >
            < name > speaking </ name >
          </ employee-rostering.employeerosting.Skill >
        </ skills >
      </ employee-rostering.employeerostering.Employee >
    </ employeeList >
  </ best-solution >
</ solver-instance >
```
<employeeList>
  <shiftList>
    <employeerostering.employeerostering.Shift>
      <timeslot>
        <startTime>2017-01-01T00:00:00</startTime>
        <endTime>2017-01-01T01:00:00</endTime>
      </timeslot>
      <requiredSkill reference="" />
    </employeerostering.employeerostering.Shift>
    <employeerostering.employeerostering.Shift>
      <timeslot reference="" />
      <requiredSkill reference="" />
    </employeerostering.employeerostering.Shift>
    <employeerostering.employeerostering.Shift>
      <timeslot reference="" />
      <requiredSkill reference="" />
    </employeerostering.employeerostering.Shift>
  </shiftList>
  <skillList>
    <employeerostering.employeerostering.Skill reference="" />
    <employeerostering.employeerostering.Skill reference="" />
    <employeerostering.employeerostering.Skill reference="" />
  </skillList>
  <timeslotList>
    <employeerostering.employeerostering.Timeslot reference="" />
  </timeslotList>
  <dayOffRequestList/>
  <shiftAssignmentList/>
  <score>0hard/0soft</score>
</best-solution>
</solver-instance>
CHAPTER 12. GETTING STARTED WITH OPTAPlANNER AND QUARKUS

You can use the https://code.quarkus.redhat.com website to generate a Red Hat build of OptaPlanner Quarkus Maven project and automatically add and configure the extensions that you want to use in your application. You can then download the Quarkus Maven repository or use the online Maven repository with your project.

12.1. APACHE MAVEN AND RED HAT BUILD OF QUARKUS

Apache Maven is a distributed build automation tool used in Java application development to create, manage, and build software projects. Maven uses standard configuration files called Project Object Model (POM) files to define projects and manage the build process. POM files describe the module and component dependencies, build order, and targets for the resulting project packaging and output using an XML file. This ensures that the project is built in a correct and uniform manner.

Maven repositories

A Maven repository stores Java libraries, plug-ins, and other build artifacts. The default public repository is the Maven 2 Central Repository, but repositories can be private and internal within a company to share common artifacts among development teams. Repositories are also available from third parties.

You can use the online Maven repository with your Quarkus projects or you can download the Red Hat build of Quarkus Maven repository.

Maven plug-ins

Maven plug-ins are defined parts of a POM file that achieve one or more goals. Quarkus applications use the following Maven plug-ins:

- Quarkus Maven plug-in (quarkus-maven-plugin): Enables Maven to create Quarkus projects, supports the generation of uber-JAR files, and provides a development mode.

- Maven Surefire plug-in (maven-surefire-plugin): Used during the test phase of the build lifecycle to execute unit tests on your application. The plug-in generates text and XML files that contain the test reports.

12.1.1. Configuring the Maven settings.xml file for the online repository

You can use the online Maven repository with your Maven project by configuring your user settings.xml file. This is the recommended approach. Maven settings used with a repository manager or repository on a shared server provide better control and manageability of projects.

NOTE

When you configure the repository by modifying the Maven settings.xml file, the changes apply to all of your Maven projects.

Procedure

1. Open the Maven ~/.m2/settings.xml file in a text editor or integrated development environment (IDE).
2. Add the following lines to the `<profiles>` element of the `settings.xml` file:

```xml
<!-- Configure the Maven repository -->
<profile>
  <id>red-hat-enterprise-maven-repository</id>
  <repositories>
    <repository>
      <id>red-hat-enterprise-maven-repository</id>
      <url>https://maven.repository.redhat.com/ga/</url>
      <releases>
        <enabled>true</enabled>
      </releases>
      <snapshots>
        <enabled>false</enabled>
      </snapshots>
    </repository>
  </repositories>
  <pluginRepositories>
    <pluginRepository>
      <id>red-hat-enterprise-maven-repository</id>
      <url>https://maven.repository.redhat.com/ga/</url>
      <releases>
        <enabled>true</enabled>
      </releases>
      <snapshots>
        <enabled>false</enabled>
      </snapshots>
    </pluginRepository>
  </pluginRepositories>
</profile>
```

3. Add the following lines to the `<activeProfiles>` element of the `settings.xml` file and save the file.

```xml
<activeProfile>red-hat-enterprise-maven-repository</activeProfile>
```

### 12.1.2. Downloading and configuring the Quarkus Maven repository

If you do not want to use the online Maven repository, you can download and configure the Quarkus Maven repository to create a Quarkus application with Maven. The Quarkus Maven repository contains many of the requirements that Java developers typically use to build their applications. This procedure describes how to edit the `settings.xml` file to configure the Quarkus Maven repository.

**NOTE**

When you configure the repository by modifying the Maven `settings.xml` file, the changes apply to all of your Maven projects.

2. Expand the downloaded archive.

3. Change directory to the ~/.m2/ directory and open the Maven settings.xml file in a text editor or integrated development environment (IDE).

4. Add the following lines to the <profiles> element of the settings.xml file, where QUARKUS_MAVEN_REPOSITORY is the path of the Quarkus Maven repository that you downloaded. The format of QUARKUS_MAVEN_REPOSITORY must be file://$PATH, for example file:///home/userX/rh-quarkus-2.13.GA-maven-repository/maven-repository.

   <profile>
     <id>red-hat-enterprise-maven-repository</id>
     <repositories>
       <repository>
         <id>red-hat-enterprise-maven-repository</id>
         <url>QUARKUS_MAVEN_REPOSITORY</url>
         <releases>
           <enabled>true</enabled>
         </releases>
         <snapshots>
           <enabled>false</enabled>
         </snapshots>
       </repository>
     </repositories>
     <pluginRepositories>
       <pluginRepository>
         <id>red-hat-enterprise-maven-repository</id>
         <url>QUARKUS_MAVEN_REPOSITORY</url>
         <releases>
           <enabled>true</enabled>
         </releases>
         <snapshots>
           <enabled>false</enabled>
         </snapshots>
       </pluginRepository>
     </pluginRepositories>
   </profile>

5. Add the following lines to the <activeProfiles> element of the settings.xml file and save the file.

   <activeProfile>red-hat-enterprise-maven-repository</activeProfile>
IMPORTANT

If your Maven repository contains outdated artifacts, you might encounter one of the following Maven error messages when you build or deploy your project, where \textit{ARTIFACT\_NAME} is the name of a missing artifact and \textit{PROJECT\_NAME} is the name of the project you are trying to build:

- Missing artifact \textit{PROJECT\_NAME}
- [ERROR] Failed to execute goal on project \textit{ARTIFACT\_NAME}; Could not resolve dependencies for \textit{PROJECT\_NAME}

To resolve the issue, delete the cached version of your local repository located in the \texttt{~/.m2/repository} directory to force a download of the latest Maven artifacts.

12.2. CREATING AN OPTAPLANNER RED HAT BUILD OF QUARKUS MAVEN PROJECT USING THE MAVEN PLUG-IN

You can get up and running with a Red Hat build of OptaPlanner and Quarkus application using Apache Maven and the Quarkus Maven plug-in.

Prerequisites

- OpenJDK 11 or later is installed. Red Hat build of Open JDK is available from the Software Downloads page in the Red Hat Customer Portal (login required).
- Apache Maven 3.6 or higher is installed. Maven is available from the Apache Maven Project website.

Procedure

1. In a command terminal, enter the following command to verify that Maven is using JDK 11 and that the Maven version is 3.6 or higher:

   \texttt{mvn --version}

2. If the preceding command does not return JDK 11, add the path to JDK 11 to the PATH environment variable and enter the preceding command again.

3. To generate a Quarkus OptaPlanner quickstart project, enter the following command:


   This command create the following elements in the \texttt{/optaplanner-quickstart} directory:

   - The Maven structure
   - Example \texttt{Dockerfile} file in \texttt{src/main/docker}
The application configuration file

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>projectGroupId</td>
<td>The group ID of the project.</td>
</tr>
<tr>
<td>projectArtifactId</td>
<td>The artifact ID of the project.</td>
</tr>
<tr>
<td>extensions</td>
<td>A comma-separated list of Quarkus extensions to use with this project. For a full list of Quarkus extensions, enter <code>mvn quarkus:list-extensions</code> on the command line.</td>
</tr>
<tr>
<td>noExamples</td>
<td>Creates a project with the project structure but without tests or classes.</td>
</tr>
</tbody>
</table>

The values of the `projectGroupId` and the `projectArtifactId` properties are used to generate the project version. The default project version is `1.0.0-SNAPSHOT`.

4. To view your OptaPlanner project, change directory to the OptaPlanner Quickstarts directory:

   ```bash
   cd optaplanner-quickstart
   ```

5. Review the `pom.xml` file. The content should be similar to the following example:

   ```xml
   <dependencyManagement>
   <dependencies>
     <dependency>
       <groupId>io.quarkus.platform</groupId>
       <artifactId>quarkus-bom</artifactId>
       <version>2.13.Final-redhat-00006</version>
       <type>pom</type>
       <scope>import</scope>
     </dependency>
     <dependency>
       <groupId>io.quarkus.platform</groupId>
       <artifactId>quarkus-optaplanner-bom</artifactId>
       <version>2.13.Final-redhat-00006</version>
       <type>pom</type>
       <scope>import</scope>
     </dependency>
   </dependencies>
   </dependencyManagement>

   <dependencies>
     <dependency>
       <groupId>io.quarkus</groupId>
       <artifactId>quarkus-resteasy</artifactId>
     </dependency>
     <dependency>
       <groupId>io.quarkus</groupId>
       <artifactId>quarkus-resteasy-jackson</artifactId>
     </dependency>
   </dependencies>
   ```
12.3. CREATING A RED HAT BUILD OF QUARKUS MAVEN PROJECT USING CODE.QUARKUS.REDHAT.COM

You can use the code.quarkus.redhat.com website to generate a Red Hat build of OptaPlanner Quarkus Maven project and automatically add and configure the extensions that you want to use in your application. In addition, code.quarkus.redhat.com automatically manages the configuration parameters required to compile your project into a native executable.

This section walks you through the process of generating an OptaPlanner Maven project and includes the following topics:

- Specifying basic details about your application.
- Choosing the extensions that you want to include in your project.
- Generating a downloadable archive with your project files.
- Using the custom commands for compiling and starting your application.

Prerequisites

- You have a web browser.

Procedure

1. Open https://code.quarkus.redhat.com in your web browser:

2. Specify details about your project:

3. Enter a group name for your project. The format of the name follows the Java package naming convention, for example, com.example.

4. Enter a name that you want to use for Maven artifacts generated from your project, for example code-with-quarkus.

5. Select Build Tool > Maven to specify that you want to create a Maven project. The build tool that you choose determines the items:
   - The directory structure of your generated project
The format of configuration files used in your generated project

The custom build script and command for compiling and starting your application that code.quarkus.redhat.com displays for you after you generate your project

NOTE
Red Hat provides support for using code.quarkus.redhat.com to create OptaPlanner Maven projects only. Generating Gradle projects is not supported by Red Hat.

6. Enter a version to be used in artifacts generated from your project. The default value of this field is 1.0.0-SNAPSHOT. Using semantic versioning is recommended, but you can use a different type of versioning if you prefer.

7. Enter the package name of artifacts that the build tool generates when you package your project. According to the Java package naming conventions the package name should match the group name that you use for your project, but you can specify a different name.

NOTE
The code.quarkus.redhat.com website automatically uses the latest release of OptaPlanner. You can manually change the BOM version in the pom.xml file after you generate your project.

8. Select the following extensions to include as dependencies:

- RESTEasy JAX-RS (quarkus-resteasy)
- RESTEasy Jackson (quarkus-resteasy-jackson)
- OptaPlanner AI constraint solver(optaplanner-quarkus)
- OptaPlanner Jackson (optaplanner-quarkus-jackson)

Red Hat provides different levels of support for individual extensions on the list, which are indicated by labels next to the name of each extension:

- SUPPORTED extensions are fully supported by Red Hat for use in enterprise applications in production environments.
- TECH-PREVIEW extensions are subject to limited support by Red Hat in production environments under the Technology Preview Features Support Scope.
- DEV-SUPPORT extensions are not supported by Red Hat for use in production environments, but the core functionalities that they provide are supported by Red Hat developers for use in developing new applications.
- DEPRECATED extension are planned to be replaced with a newer technology or implementation that provides the same functionality. Unlabeled extensions are not supported by Red Hat for use in production environments.

9. Select Generate your application to confirm your choices and display the overlay screen with the download link for the archive that contains your generated project. The overlay screen also shows the custom command that you can use to compile and start your application.
10. Select **Download the ZIP** to save the archive with the generated project files to your system.

11. Extract the contents of the archive.

12. Navigate to the directory that contains your extracted project files:

   ```bash
   cd <directory_name>
   ```

13. Compile and start your application in development mode:

   ```bash
   ./mvnw compile quarkus:dev
   ```

### 12.4. CREATING A RED HAT BUILD OF QUARKUS MAVEN PROJECT USING THE QUARKUS CLI

You can use the Quarkus command line interface (CLI) to create a Quarkus OptaPlanner project.

**Prerequisites**

- You have installed the Quarkus CLI. For information, see Building Quarkus Apps with Quarkus Command Line Interface.

**Procedure**

1. Create a Quarkus application:

   ```bash
   quarkus create app -P io.quarkus:quarkus-bom:2.13.Final-redhat-00006
   ```

2. To view the available extensions, enter the following command:

   ```bash
   quarkus ext -i
   ```

   This command returns the following extensions:

   - optaplanner-quarkus
   - optaplanner-quarkus-benchmark
   - optaplanner-quarkus-jackson
   - optaplanner-quarkus-jsonb

3. Enter the following command to add extensions to the project’s **pom.xml** file:

   ```bash
   quarkus ext add resteasy-jackson
   quarkus ext add optaplanner-quarkus
   quarkus ext add optaplanner-quarkus-jackson
   ```

4. Open the **pom.xml** file in a text editor. The contents of the file should look similar to the following example:

   ```xml
```
CHAPTER 12. GETTING STARTED WITH OPTAPLANNER AND QUARKUS
<groupId>io.quarkus</groupId>
<artifactId>quarkus-junit5</artifactId>
<scope>test</scope>
</dependency>
<dependency>
<groupId>io.rest-assured</groupId>
<artifactId>rest-assured</artifactId>
<scope>test</scope>
</dependency>
</dependencies>

<build>
<plugins>
<plugin>
<groupId>${quarkus.platform.group-id}</groupId>
<artifactId>quarkus-maven-plugin</artifactId>
<br>version>${quarkus.platform.version}</version>
<extensions>true</extensions>
<executions>
<execution>
<goals>
<goal>build</goal>
<goal>generate-code</goal>
<goal>generate-code-tests</goal>
</goals>
</execution>
</executions>
</plugin>
<plugin>
<artifactId>maven-compiler-plugin</artifactId>
<br>version>${compiler-plugin.version}</version>
<configuration>
<parameters>${maven.compiler.parameters}</parameters>
</configuration>
</plugin>
<plugin>
<artifactId>maven-surefire-plugin</artifactId>
<br>version>${surefire-plugin.version}</version>
<configuration>
<systemPropertyVariables>
<java.util.logging.manager>org.jboss.logmanager.LogManager</java.util.logging.manager>
<maven.home>${maven.home}</maven.home>
</systemPropertyVariables>
</configuration>
</plugin>
</plugins>
</build>
<profiles>
<profile>
<id>native</id>
<activation>
<property>
<name>native</name>
</property>
</activation>
</profile>
</profiles>
<plugins>
  <plugin>
    <artifactId>maven-failsafe-plugin</artifactId>
    <version>${surefire-plugin.version}</version>
    <executions>
      <execution>
        <goals>
          <goal>integration-test</goal>
          <goal>verify</goal>
        </goals>
        <configuration>
          <systemPropertyVariables>
            <native.image.path>${project.build.directory}/${project.build.finalName}-runner</native.image.path>
            <java.util.logging.manager>org.jboss.logmanager.LogManager</java.util.logging.manager>
            <maven.home>${maven.home}</maven.home>
          </systemPropertyVariables>
        </configuration>
      </execution>
    </executions>
  </plugin>
</plugins>

<build>
  <properties>
    <quarkus.package.type>native</quarkus.package.type>
  </properties>
</build>

</project>
APPENDIX A. VERSIONING INFORMATION

Documentation last updated on Thursday, March 14th, 2024.
APPENDIX B. CONTACT INFORMATION

Red Hat Decision Manager documentation team: brms-docs@redhat.com