Abstract
This document describes how to get started with decision services, process services, and planning solutions in Red Hat Process Automation Manager.
# Table of Contents

[Table of Contents](#)  

**PREFACE** ........................................................................................................................................... 6

**MAKING OPEN SOURCE MORE INCLUSIVE** ..................................................................................... 7

**PART I. GETTING STARTED WITH DECISION SERVICES IN RED HAT PROCESS AUTOMATION MANAGER** ............................................................................................................................. 8

**CHAPTER 1. SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL** ................................................. 9

  1.1. ACCESSING SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL 9

**CHAPTER 2. RED HAT PROCESS AUTOMATION MANAGER BPMN AND DMN MODELERS** .............................................. 11

  2.1. INSTALLING THE RED HAT PROCESS AUTOMATION MANAGER VS CODE EXTENSION BUNDLE 11

  2.2. CONFIGURING THE RED HAT PROCESS AUTOMATION MANAGER STANDALONE EDITORS 12

**CHAPTER 3. CREATING AND EXECUTING DMN AND BPMN MODELS USING MAVEN** .................................................. 16

**CHAPTER 4. CREATING THE TRAFFIC VIOLATIONS PROJECT IN BUSINESS CENTRAL** .................................................. 18

**CHAPTER 5. DECISION MODEL AND NOTATION (DMN)** .................................................................................... 19

  5.1. CREATING THE TRAFFIC VIOLATIONS DMN DECISION REQUIREMENTS DIAGRAM (DRD) 19

  5.2. CREATING THE TRAFFIC VIOLATIONS DMN CUSTOM DATA TYPES 21

  5.3. ASSIGNING CUSTOM DATA TYPES TO THE DRD INPUT AND DECISION NODES 25

  5.4. DEFINING THE TRAFFIC VIOLATIONS DMN DECISION LOGIC 26

**CHAPTER 6. TEST SCENARIOS** .................................................................................................................. 29

  6.1. TESTING THE TRAFFIC VIOLATIONS USING TEST SCENARIOS 29

**CHAPTER 7. DMN MODEL EXECUTION** ........................................................................................................ 33

  7.1. EXECUTING A DMN SERVICE USING THE KIE SERVER REST API 33

**CHAPTER 8. ADDITIONAL RESOURCES** ...................................................................................................... 47

**PART II. GETTING STARTED WITH PROCESS SERVICES IN RED HAT PROCESS AUTOMATION MANAGER** ... 48

**CHAPTER 9. OVERVIEW** ......................................................................................................................... 49

**CHAPTER 10. SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL** .................................................. 50

  10.1. ACCESSING SAMPLE PROJECTS AND BUSINESS ASSETS IN BUSINESS CENTRAL 50

**CHAPTER 11. CREATING USERS** ................................................................................................................. 52

**CHAPTER 12. CREATING AND EXECUTING DMN AND BPMN MODELS USING MAVEN** .................................................. 54

**CHAPTER 13. CREATING THE MORTGAGE-PROCESS PROJECT** ............................................................................. 56

**CHAPTER 14. CREATING THE MORTGAGE-PROCESS DATA OBJECTS** ........................................................................ 57

  14.1. CREATING THE APPLICANT DATA OBJECT 57

  14.2. CREATING THE PROPERTY DATA OBJECT 58

  14.3. CREATING THE VALIDATIONERRORDO DATA OBJECT 58

  14.4. CREATING THE APPLICATION DATA OBJECT 59

**CHAPTER 15. BUSINESS PROCESSES IN BUSINESS CENTRAL** ............................................................................. 61

  15.1. CREATING THE BUSINESS PROCESS 61

    15.1.1. Creating outgoing connections and exclusive gateways 62

    15.1.2. Defining the validation data 64

    15.1.3. Calculating the mortgage 68

    15.1.4. Increasing the down payment 73
31.1. DEPLOYING THE EMPLOYEE ROSTERING SAMPLE PROJECT IN BUSINESS CENTRAL

31.2. RE-CREATING THE EMPLOYEE ROSTERING SAMPLE PROJECT

31.2.1. Setting up the employee rostering project

31.2.2. Problem facts and planning entities

31.2.3. Creating the data model for the employee rostering project

31.2.3.1. Creating the employee roster planning entity

31.2.3.2. Creating the employee roster planning solution

31.2.4. Employee rostering constraints

31.2.4.1. DRL (Drools Rule Language) rules

31.2.4.2. Defining constraints for employee rostering using the DRL designer

31.2.5. Creating rules for employee rostering using guided rules

31.2.5.1. Guided rules

31.2.5.2. Creating a guided rule to balance employee shift numbers

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

31.2.5.4. Creating a guided rule to match skills to shift requirements

31.2.5.5. Creating a guided rule to manage day off requests

31.2.6. Creating a solver configuration for employee rostering

31.2.7. Configuring Solver termination for the employee rostering project

31.3. ACCESSING THE SOLVER USING THE REST API

31.3.1. Registering the Solver using the REST API

31.3.2. Calling the Solver using the REST API

CHAPTER 32. GETTING STARTED WITH JAVA SOLVERS: A CLOUD BALANCING EXAMPLE

32.1. DOMAIN MODEL DESIGN

32.1.1. Designing a domain model

32.1.2. The Computer Class

32.1.3. The Process Class

32.1.4. The CloudBalance Class

32.2. RUNNING THE CLOUD BALANCING HELLO WORLD

32.3. SOLVER CONFIGURATION

32.4. SCORE CONFIGURATION

32.4.1. Configuring score calculation using Java

32.4.2. Configuring score calculation using Drools

32.5. FURTHER DEVELOPMENT OF THE SOLVER

CHAPTER 33. EXAMPLES PROVIDED WITH RED HAT BUSINESS OPTIMIZER

33.1. DOWNLOADING AND RUNNING THE EXAMPLES

33.1.1. Downloading Red Hat Business Optimizer examples

33.1.2. Running Business Optimizer examples

33.1.3. Running the Red Hat Business Optimizer examples in an IDE (IntelliJ, Eclipse, or Netbeans)

33.1.4. Running the web examples

33.2. TABLE OF BUSINESS OPTIMIZER EXAMPLES

33.3. N QUEENS

33.4. CLOUD BALANCING

33.5. TRAVELING SALESMAN (TSP - TRAVELING SALESMAN PROBLEM)

33.6. DINNER PARTY

33.7. TENNIS CLUB SCHEDULING

33.8. MEETING SCHEDULING

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

33.10. MACHINE REASSIGNMENT (GOOGLE ROADEF 2012)

33.11. VEHICLE ROUTING

33.11.1. Domain model for Vehicle routing
33.12. PROJECT JOB SCHEDULING .................................................. 187
33.13. TASK ASSIGNING ................................................................. 189
33.14. EXAM TIMETABLING (ITC 2007 TRACK 1 - EXAMINATION) ..... 191
  33.14.1. Domain model for Exam timetabling ................................. 193
33.15. NURSE ROSTERING (INRC 2010) ........................................... 194
33.16. TRAVELING TOURNAMENT PROBLEM (TTP) ....................... 199
33.17. CHEAP TIME SCHEDULING ................................................. 201
33.18. INVESTMENT ASSET CLASS ALLOCATION (PORTFOLIO OPTIMIZATION) .................................................. 204
33.19. CONFERENCE SCHEDULING ................................................. 204
33.20. ROCK TOUR ........................................................................... 207
33.21. FLIGHT CREW SCHEDULING .................................................. 208

APPENDIX A. VERSIONING INFORMATION ............................................ 209

APPENDIX B. CONTACT INFORMATION .................................................. 210
PREFACE

As a developer of business decisions and processes, you can use Red Hat Process Automation Manager to develop decision services and process services using a variety of available assets. You can also use Red Hat Business Optimizer 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 Process Automation Manager or the Red Hat Process Automation Manager DMN modeler in VSCode to design a variety of decision services. Red Hat Process Automation 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 Process Automation Manager, see Designing a decision service using DMN models.

Prerequisites

- Red Hat JBoss Enterprise Application Platform 7.3 is installed. For installation information, see Red Hat JBoss Enterprise Application Platform 7.3 Installation Guide.

- Red Hat Process Automation Manager is installed and configured with KIE Server. For more information see Installing and configuring Red Hat Process Automation Manager on Red Hat JBoss EAP 7.3.

- Red Hat Process Automation Manager is running and you can log in to Business Central with the developer role. For more information, see Planning a Red Hat Process Automation 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, processes, or other assets that you create in your own Red Hat Process Automation Manager projects. Each sample project is designed differently to demonstrate process automation, decision management, or business optimization assets and logic in Red Hat Process Automation Manager.

NOTE

Red Hat does not provide support for the sample code included in the Red Hat Process Automation 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 class room 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 Process Automation Manager projects.

Prerequisites

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

1. In Business Central, go to Menu → Design → Projects. If there are existing projects, you can access the samples by clicking on 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 process automation, decision management, or business optimization assets and logic in Red Hat Process Automation 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.

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 PROCESS AUTOMATION MANAGER BPMN AND DMN MODELERS

Red Hat Process Automation 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 Process Automation Manager VSCode extension**: Enables you to view and design BPMN models, DMN models, and test scenario files in Visual Studio Code (VSCode). The VSCode extension requires VSCode 1.46.0 or later.
  To install the Red Hat Process Automation Manager VSCode extension, select the Extensions menu option in VSCode 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 PROCESS AUTOMATION MANAGER VSCode EXTENSION BUNDLE

Red Hat Process Automation Manager provides a Red Hat Business Automation Bundle VSCode 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 VSCode. VSCode is the preferred integrated development environment (IDE) for developing new business applications. Red Hat Process Automation Manager also provides individual DMN Editor and BPMN Editor VSCode extensions for DMN or BPMN support only, if needed.

**IMPORTANT**

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

**Prerequisites**

- The latest stable version of VSCode is installed.

**Procedure**

1. In your VSCode 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 VSCode, select it and click Install.
3. For optimal VSCode editor behavior, after the extension installation is complete, reload or close and re-launch your instance of VSCode.

After you install the VSCode extension bundle, any .dmn, .bpmn, or .bpmn2 files that you open or create in VSCode 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 Process Automation Manager project in VSCode.

### 2.2. CONFIGURING THE RED HAT PROCESS AUTOMATION MANAGER STANDALONE EDITORS

Red Hat Process Automation 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 in three ways:

- 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**
      ```html
      <script src="https://<YOUR_PAGE>/dmn/index.js"/></script>
      ```

      **Script tag for your HTML page for the BPMN editor**
      ```html
      <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

```bash
npm install @redhat/kogito-tooling-kie-editors-standalone
```

b. Import each editor library to your TypeScript file:

Importing each editor

```typescript
import * as DmnEditor from '@redhat/kogito-tooling-kie-editors-standalone/dist/dmn'
import * as BpmnEditor from '@redhat/kogito-tooling-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

```typescript
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('')</td>
</tr>
<tr>
<td></td>
<td>- Promise.resolve('&lt;DIAGRAM_CONTENT_DIRECTLY_HERE&gt;')</td>
</tr>
<tr>
<td></td>
<td>- fetch('MyDmnModel.dmn').then(content =&gt; content.text())</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><code>getContent(): Promise&lt;string&gt;</code></td>
<td>Returns a promise containing the editor content.</td>
</tr>
<tr>
<td><code>setContent(content: string): void</code></td>
<td>Sets the content of the editor.</td>
</tr>
<tr>
<td><code>getPreview(): Promise&lt;string&gt;</code></td>
<td>Returns a promise containing an SVG string of the current diagram.</td>
</tr>
<tr>
<td><code>subscribeToContentChanges(callback: (isDirty: boolean) =&gt; void): (isDirty: boolean) =&gt; void</code></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><code>unsubscribeToContentChanges(callback: (isDirty: boolean) =&gt; void): void</code></td>
<td>Unsubscribes the passed callback when the content changes in the editor.</td>
</tr>
<tr>
<td><code>markAsSaved(): void</code></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><code>undo(): void</code></td>
<td>Undoes the last 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>redo(): void</td>
<td>Redoes the last undone change in the editor. Also, it activates the subscribed callbacks related to content change.</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;PROVIDER&gt;::&lt;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 VSCode using the Red Hat Process Automation Manager VSCode extension instead of Business Central. You can then integrate your archetypes with your Red Hat Process Automation 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 Process Automation Manager VSCode extension.

Procedure

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

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

   Generating a project using Maven archetype

   ```
   mvn archetype:generate \
   -DarchetypeGroupId=org.kie \
   -DarchetypeArtifactId=kie-kjar-archetype \
   -DarchetypeVersion=7.48.0.Final-redhat-00004 
   ```

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

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

3. In your VSCode 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 VSCode to create assets for your business application. You can create the assets supported by Red Hat Process Automation Manager VSCode extension using the following ways:

   - To create a business process, create a new file with `.bpmn` or `.bpmn2` in `PROJECT_HOME/src/main/java/org/kie/businessapp` directory, such as `Process.bpmn`. 
• To create a DMN model, create a new file with .dmn in PROJECT_HOME/src/main/java/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/main/java/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 Process Automation 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 Process Automation Manager provides a default space called MySpace, as shown in the following image. You can use the default space to create and test example projects.

   Figure 4.1. Default space
   ![Spaces → MySpace]

2. Click Add Project.

3. Enter traffic-violation in the Name field.

4. Click Add.

   Figure 4.2. Add Project window
   ![Add Project window]

The Assets view of the project opens.
CHAPTER 5. DECISION MODEL AND NOTATION (DMN)

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.

**Figure 5.4. The custom data types tab**

> No custom data types have been defined.

Data types are referenced in the input and output values for decision tables. Custom data types allow you to reference more complex data types, beyond the simple “default” types.

Currently, there are no custom data types available for you to view or edit. To get started, add a custom data type.
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>
<tr>
<td>Actual Speed</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.

**Figure 5.5. The tDriver custom data type**

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

- \textbf{Amount} (number)
- \textbf{Points} (number)

11. Click \textbf{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 \textbf{DMN Input Data} and \textbf{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 \textbf{Model} tab on the DMN designer and click the \textbf{Properties} \(\square\) icon in the upper-right corner of the DMN designer to expose the DRD properties.

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

3. Select the \textbf{Violation} input data node and select \texttt{tViolation} from the \textbf{Data type} drop-down menu.

4. Select the \textbf{Fine} decision node and select \texttt{tFine} from the \textbf{Data type} drop-down menu.

5. Select the \textbf{Should the driver be suspended?} decision node and set the following properties:

- \textbf{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

<table>
<thead>
<tr>
<th>Violation Type (string)</th>
<th>Violation Actual Speed - Violation Speed Limit (number)</th>
<th>Fine (Amount) (number)</th>
<th>Points (number)</th>
<th>Driver Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;speed&quot;</td>
<td>[10..30]</td>
<td>500</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>&quot;speed&quot;</td>
<td>&gt;= 30</td>
<td>1000</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>&quot;parking&quot;</td>
<td>-</td>
<td>100</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>&quot;driving under the influence&quot;</td>
<td>-</td>
<td>1000</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.9. Should the driver be suspended expression

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

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 Process Automation 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 Process Automation Manager currently supports both the new Test Scenarios designer and the former Test Scenarios (Legacy) designer. The default designer is the new test scenarios designer, which supports 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.

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

<table>
<thead>
<tr>
<th>#</th>
<th>Scenario description</th>
<th>Offense</th>
<th>Violation</th>
<th>Fine</th>
<th>Should the driver be suspended?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Above speed limit 10km/h - 30km/h</td>
<td>speed</td>
<td>100</td>
<td>120</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Above speed limit more than 30 km/h</td>
<td>speed</td>
<td>100</td>
<td>150</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Parking violation</td>
<td>parking</td>
<td>insert value</td>
<td>insert value</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>DUI violation</td>
<td>drinking under the influence</td>
<td>insert value</td>
<td>insert value</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Driver suspended</td>
<td>speed</td>
<td>100</td>
<td>140</td>
<td>7</td>
</tr>
</tbody>
</table>

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 Process Automation 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 Process Automation 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 a Red Hat Process Automation 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.

For more information about the KIE Server REST API, see Interacting with Red Hat Process Automation 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 Process Automation Manager installation.

- You have built the DMN project as a KJAR artifact and deployed it to KIE Server. Ideally, you have built the DMN project as an executable model for more efficient execution:

  mvn clean install -DgenerateDMNModel=yes

  For more information about project packaging and deployment and executable models, see Packaging and deploying a Red Hat Process Automation 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:
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:

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

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

```
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**

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

**XML**

```
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:

```
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:

```
<response type="SUCCESS" msg="Ok models successfully retrieved from container 'traffic-violation_1.0.0-SNAPSHOT'">
  <dmn-model-info-list>
    <model>
      <model-namespace>https://github.com/kiegroup/drools/kie-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>
      </decisions>
    </model>
  </dmn-model-info-list>
</response>
```
CHAPTER 7. DMN MODEL EXECUTION

<decision-id>_B5EEE2B1-915C-44DC-BE43-C244DC066FD8</decision-id>
<decision-name>Should the driver be suspended?</decision-name>
</dmn-decision-info>
<inputs>
<dmn-inputdata-info>
<inputdata-id>_CEB959CD-3638-4A87-93BA-03CD0FB63AE3</inputdata-id>
<inputdata-name>Violation</inputdata-name>
<inputdata-typeref>
</inputdata-typeref>
</dmn-inputdata-info>
<dmn-inputdata-info>
<inputdata-id>_B0E810E6-7596-430A-B5CF-67CE16863B6C</inputdata-id>
<inputdata-name>Driver</inputdata-name>
<inputdata-typeref>
</inputdata-typeref>
</dmn-inputdata-info>
</inputs>
</dmn-dmn-decision-info>

<itemdefinitions>
<dmn-itemdefinition-info>
<itemdefinition-id>_9C758F4A-7D72-4D0F-B63F-2F5B8405980E</itemdefinition-id>
<itemdefinition-name>Violation</itemdefinition-name>
<itemdefinition-itemcomponent>
<dmn-itemdefinition-info>
<itemdefinition-id>_0B6FF1E2-ACE9-4FB3-876B-5BB30B88009B</itemdefinition-id>
<itemdefinition-name>Code</itemdefinition-name>
<itemdefinition-typeref>
<namespace-uri>https://github.com/kiegroup/drools/kie-dmn/_60b0114d-e407-43f7-848e-258723b5fac8</namespace-uri>
</itemdefinition-typeref>
</itemdefinition-itemcomponent>
<itemdefinition-itemcomponent/>
<itemdefinition-iscollection>false</itemdefinition-iscollection>
</dmn-itemdefinition-info>
</dmn-itemdefinition-info>
<dmn-itemdefinition-info>
<itemdefinition-id>_27A5DA18-3CA7-4C06-81B7-CF7F050E29</itemdefinition-id>
<itemdefinition-name>date</itemdefinition-name>
<itemdefinition-typeref>
</itemdefinition-typeref>
</dmn-itemdefinition-info>
</itemdefinitions>
CHAPTER 7. DMN MODEL EXECUTION

02493EAAC9D2

E407-43F7-848E-258723B5FAC8

773C240FB9AD

E407-43F7-848E-258723B5FAC8

3B2B873F7800

E407-43F7-848E-258723B5FAC8

D655BB1CA7B1
<itemdefinition-iscollection>false</itemdefinition-iscollection>
</dmn-itemdefinition-info>
</dmn-itemdefinition-info>

7769636316F3</itemdefinition-id>
    <itemdefinition-name>1Fine</itemdefinition-name>
    <itemdefinition-typeref>
        <local-part>number</local-part>
        <prefix></prefix>
    </itemdefinition-typeref>
    <itemdefinition-iscollection>false</itemdefinition-iscollection>
</dmn-itemdefinition-info>

52DFF0D73B2D</itemdefinition-id>
    <itemdefinition-name>Amount</itemdefinition-name>
    <itemdefinition-typeref>
        <local-part>number</local-part>
        <prefix></prefix>
    </itemdefinition-typeref>
    <itemdefinition-iscollection>false</itemdefinition-iscollection>
</dmn-itemdefinition-info>

D47045EC90D0</itemdefinition-id>
    <itemdefinition-name>Points</itemdefinition-name>
    <itemdefinition-typeref>
        <local-part>number</local-part>
        <prefix></prefix>
    </itemdefinition-typeref>
    <itemdefinition-iscollection>false</itemdefinition-iscollection>
</dmn-itemdefinition-info>
</dmn-itemdefinition-info>
</itemdefinitions>
</decisionservices>
</model>

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://github.com/kiegroup/drools/kie-dmn/_60B01F4D-E407-43F7-848E-258723B5FAC8",
```
"model-name" : "Traffic Violation",
"model-id" : "_2CD7D1AA-BD84-4B43-AD21-B0342ADE655A",
"decisions" : [ {
  "decision-id" : "_23428EE8-DC8B-4067-8E67-9D7C53EC975F",
  "decision-name" : "Fine"
}, {
  "decision-id" : "_B5EEE2B1-915C-44DC-BE43-C244DC06FD8",
  "decision-name" : "Should the driver be suspended?"
}],
"inputs" : [ {
  "input-data-id" : "_CEB959CD-3638-4A87-93BA-03CD0FB63AE3",
  "input-data-name" : "Violation",
  "input-data-typeRef" : {
    "local-part" : "tViolation",
    "prefix" : ""
  }
}, {
  "input-data-id" : "_B0E810E6-7596-430A-B5CF-67CE16863B6C",
  "input-data-name" : "Driver",
  "input-data-typeRef" : {
    "local-part" : "tDriver",
    "prefix" : ""
  }
}],
"itemDefinitions" : [ {
  "item-definition-id" : "_13C7EFD8-B85C-43BF-94D3-14FABE39A4A0",
  "item-definition-name" : "tDriver",
  "item-definition-typeRef" : null,
  "item-definition-itemComponent" : [ {
    "item-definition-id" : "_EC11744C-4160-4549-9610-2C757F40DFE8",
    "item-definition-name" : "Name",
    "item-definition-typeRef" : {
      "local-part" : "string",
      "prefix" : ""
    }
  }, {
    "item-definition-itemComponent" : [ ],
    "item-definition-isCollection" : false
  }],
  "item-definition-id" : "_E95BE3DB-4A51-4658-A166-02493EAAC9D2",
  "item-definition-name" : "Age",
  "item-definition-typeRef" : {
    "local-part" : "number",
    "prefix" : ""
  }
}];
"item-definition-id" : "_7B3023E2-BC44-4BF3-BF7E-773C240FB9AD";
Execute the model:

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

5. 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-name" : "Traffic Violation",
  "dmn-context" : {
    "Driver" : {
      "Points" : 15
    },
    "Violation" : {
      "Type" : "speed",
      "Actual Speed" : 135,
      "Speed Limit" : 100
    }
  }
}
```
Example XML request (JAXB format):

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<dmn-evaluation-context>
  <dmn-context xsi:type="jaxbListWrapper" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <type>MAP</type>
    <element xsi:type="jaxbStringObjectPair" key="Violation">
      <value xsi:type="jaxbListWrapper">
        <type>MAP</type>
        <element xsi:type="jaxbStringObjectPair" key="Type">
          <value xsi:type="xs:string" xmlns:xs="http://www.w3.org/2001/XMLSchema">speed</value>
        </element>
        <element xsi:type="jaxbStringObjectPair" key="Speed Limit">
          <value xsi:type="xs:decimal" xmlns:xs="http://www.w3.org/2001/XMLSchema">100</value>
        </element>
        <element xsi:type="jaxbStringObjectPair" key="Actual Speed">
          <value xsi:type="xs:decimal" xmlns:xs="http://www.w3.org/2001/XMLSchema">135</value>
        </element>
      </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" xmlns:xs="http://www.w3.org/2001/XMLSchema">15</value>
        </element>
      </value>
    </element>
  </dmn-context>
</dmn-evaluation-context>
```

**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'",
}
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">
            <type>MAP</type>
            <Violation>
                <Type>speed</Type>
                <Speed Limit>100</Speed Limit>
                <Actual Speed>135</Actual Speed>
                <Should Driver be Suspended?>Yes</Should Driver be Suspended?>
                <Driver>
                    <Points>15</Points>
                </Driver>
                <Fine>
                    <Points>7</Points>
                    <Amount>1000</Amount>
                </Fine>
            </Violation>
            <Should the Driver be Suspended?>Yes</Should the Driver be Suspended?>
            <Fine>
                <Points>7</Points>
                <Amount>1000</Amount>
            </Fine>
        </dmn-context>
    </dmn-evaluation-result>
</response>
```
<element xsi:type="jaxbStringObjectPair" key="Violation">
  <value xsi:type="jaxbListWrapper">
    <element xsi:type="jaxbStringObjectPair" key="Type">
      <value xsi:type="xs:string">
        speed
      </value>
    </element>
    <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">
        <element xsi:type="jaxbStringObjectPair" key="Points">
          <value xsi:type="xs:decimal">
            15
          </value>
        </element>
        <element xsi:type="jaxbStringObjectPair" key="Amount">
          <value xsi:type="xs:decimal">
            1000
          </value>
        </element>
        <element xsi:type="jaxbStringObjectPair" key="Should the driver be suspended?">
          <value xsi:type="xs:string">
            Yes
          </value>
        </element>
      </value>
    </element>
    <element xsi:type="jaxbStringObjectPair" key="Fine">
      <value xsi:type="jaxbListWrapper">
        <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>
        <element xsi:type="jaxbStringObjectPair" key="Should the driver be suspended?">
          <value xsi:type="xs:string">
            No
          </value>
        </element>
      </value>
    </element>
  </value>
</element>

<dmn-context/>
<messages/>
<decisionResults>
<entry>
  <key>_4055D956-1C47-479C-B3F4-BAEB61F1C929</key>
  <value>
    <decision-id>_4055D956-1C47-479C-B3F4-BAEB61F1C929</decision-id>
    <decision-name>Fine</decision-name>
    <result xsi:type="jaxbListWrapper">
      <element xsi:type="jaxbStringObjectPair" key="Points">
        <value xsi:type="xs:decimal">
          15
        </value>
      </element>
    </result>
  </value>
</entry>
</decisionResults>
<message id="_8A408366-D8E9-4626-ABF3-5F69AA01F880">
</message>
</entry>
</entry>
</result>
</messages/>
<status>SUCCEEDED</status>
</value>
</entry>
<entry>
  <key>_8A408366-D8E9-4626-ABF3-5F69AA01F880</key>
</entry>
</result>
</entry>
</result>
</entry>
</result>
</message>
</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 Process Automation Manager using KIE APIs
PART II. GETTING STARTED WITH PROCESS SERVICES IN RED HAT PROCESS AUTOMATION MANAGER

As a business rules and processes developer, you can use Business Central in Red Hat Process Automation Manager or the Red Hat Process Automation Manager BPMN modeler in VSCode to design business processes to meet specific business requirements. Red Hat Process Automation Manager provides sample projects in Business Central that contain business assets for reference purposes. This document describes how to create a new mortgage process project, data objects, and business process to familiarize yourself with Business Central and the process designer.

You will then refer to the Mortgage_Process sample project included in Business Central to review the sample project’s business rules, decision tables, and forms. You will build and deploy the Mortgage_Process sample project and execute the project’s defined functionality.

Prerequisites

- Red Hat JBoss Enterprise Application Platform 7.3 is installed. For details, see the Red Hat JBoss Enterprise Application Platform 7.3 Installation Guide.

- Red Hat Process Automation Manager is installed and configured with KIE Server. For more information, see Installing and configuring Red Hat Process Automation Manager on Red Hat JBoss EAP 7.3.

- Red Hat Process Automation Manager is running and you can log in to Business Central with the developer role. For more information, see Planning a Red Hat Process Automation Manager installation.
CHAPTER 9. OVERVIEW

Business Central enables you to automate your business processes. A business process is a diagram that describes the order in which a series of steps must be executed and consists of predefined nodes and connections. Each node represents one step in the process while the connections specify how to transition from one node to another.

For example, a bank offers a housing mortgage loan service. Using Business Central, the housing mortgage department of the bank creates a complete business process for the mortgage loan.

When a customer wants to buy a new property using credit, the following steps occur:

1. The customer contacts a broker at the bank who assists in filing for a mortgage loan.

2. The broker collects information about the property and the customer, such as the salary of the customer, social security number, the property sale price, and the requested loan amount.

3. The broker then submits a request on behalf of the customer.

Whenever a customer submits a request, a new process instance is created. This ensures consistency in the quality of evaluating each request, provides complete visibility into the status of each request, and makes the process efficient and effective.
CHAPTER 10. 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, processes, or other assets that you create in your own Red Hat Process Automation Manager projects. Each sample project is designed differently to demonstrate process automation, decision management, or business optimization assets and logic in Red Hat Process Automation Manager.

NOTE

Red Hat does not provide support for the sample code included in the Red Hat Process Automation 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 class room 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.

10.1. 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 Process Automation Manager projects.

**Prerequisites**

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

**Procedure**

1. In Business Central, go to **Menu → Design → Projects**. If there are existing projects, you can access the samples by clicking on 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 process automation, decision management, or business optimization assets and logic in Red Hat Process Automation 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 10.1. Asset page selection**

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 11. CREATING USERS

You can create as many Business Central users as you require. User privileges and settings are controlled by the roles assigned to a user and the groups that a user belongs to. For this example, you must create two new users: Katy who will act as the bank’s loan manager and approver, and Bill who will act as the broker requesting the loan. For more information on creating users, see the Creating users chapter of Installing and configuring Red Hat Process Automation Manager on Red Hat JBoss EAP 7.3.

In Business Central, you can use groups and roles to control permissions for a collection of users. You can create as many groups and roles as you want but a group must have at least one user.

- For this example, the user or users working on the tasks must be assigned to one or more of the following groups and roles:
  - approver group: For the Qualify task
  - broker group: For the Correct Data and Increase Down Payment tasks
  - manager role: For the Final Approval task

Procedure

1. Click the gear icon in the upper-right corner, and click Users.
2. Click , enter Katy, click Next, and click Create.
3. Click Yes to set a password and enter Katy in both fields, and click Change.
4. Enter Bill, click Next, and click Create.
5. Click Yes to set a password and enter Bill in both fields, and click Change.
6. Click the Groups tab and click , enter approver, and click Next.
7. Select Katy from the user list, and click Add selected users.
8. Click , enter broker, and click Next.
9. Select Bill from the user list, and click Add selected users.
10. Click Users, select Katy, and click Edit → Roles → Add roles.
11. Select manager, click Add to selected roles, and click Save.
12. Click the Groups tab, and click Edit → Groups → Add to groups.
13. Select approver and kie-server, and click Add to selected groups.
14. Click Save.
15. Select Bill from the user list, click Edit → Roles → Add roles.
16. Select user, and click Add to selected roles.

17. Click the Groups tab, select kie-server, and click Add to selected groups.

18. Click Save.
CHAPTER 12. CREATING AND EXECUTING DMN AND BPMN MODELS USING MAVEN

You can use Maven archetypes to develop DMN and BPMN models in VSCode using the Red Hat Process Automation Manager VSCode extension instead of Business Central. You can then integrate your archetypes with your Red Hat Process Automation 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 Process Automation Manager VSCode extension.

Procedure

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

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

   Generating a project using Maven archetype

   ```
   mvn archetype:generate \
   -DarchetypeGroupId=org.kie \
   -DarchetypeArtifactId=kie-kjar-archetype \
   -DarchetypeVersion=7.48.0.Final-redhat-00004
   ```

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

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

3. In your VSCode 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 VSCode to create assets for your business application. You can create the assets supported by Red Hat Process Automation Manager VSCode extension using the following ways:

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

To create a DMN model, create a new file with .dmn in PROJECT_HOME/src/main/java/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/main/java/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:

```shell
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 Process Automation Manager using KIE APIs.
CHAPTER 13. CREATING THE MORTGAGE-PROCESS PROJECT

A project is a container for assets such as data objects, business processes, guided rules, decision tables, and forms. The project that you are creating is similar to the existing Mortgage_Process sample project in Business Central.

Procedure

1. In Business Central, go to Menu → Design → Projects.
   Red Hat Process Automation Manager provides a default space called MySpace, as shown in the following image. You can use the default space to create and test example projects.
   
   **Figure 13.1. Default space**

   ![Spaces](MySpace)

2. Click Add Project.
3. Enter mortgage-process in the Name field.
4. Click Configure Advanced Options and modify the GAV fields with the following values:
   - Group ID: com.myspace
   - Artifact ID: mortgage-process
   - Version: 1.0.0
5. Click Add.

The Assets view of the project opens.
CHAPTER 14. CREATING THE MORTGAGE-PROCESS DATA OBJECTS

Data objects are the building blocks for the rule assets that you create. Data objects are custom data types implemented as Java classes in specified packages of your project. These custom data types determine what data your assets and your decision services are based on.

The mortgage process project uses the following data objects:

- Applicant
- Property
- ValidationErrorDO
- Application

14.1. CREATING THE APPLICANT DATA OBJECT

Follow these steps to create the Applicant data object, which contains information about the applicant. This is the basic information required to apply for the loan in this tutorial.

Procedure

1. In Business Central, click on the MySpace default space.
2. Click Menu → Design → Projects and click mortgage-process.
3. Click Add Asset and select Data Object.
4. Enter Applicant in the Data Object field of the Create new Data Object window.
5. Select com.myspace.mortgage_app from the Package drop-down menu and click Ok.
6. Enter Applicant in the Label field of the 'Applicant'- general properties section.
7. Click +add field and input the following Applicant data object values. Click Create and continue after each addition. For the last addition, click Create.

Figure 14.1. Applicant data object field values

8. Click Save.
14.2. CREATING THE PROPERTY DATA OBJECT

Follow these steps to create the **Property** data object, which contains information about the property details, such as the property age and price.

**Procedure**

1. In Business Central, click on the **MySpace** default space.
2. Click **Menu → Design → Projects** and click **mortgage-process**.
3. Click **Add Asset** and select **Data Object**.
4. Enter **Property** in the **Data Object** field of the **Create new Data Object** window.
5. Select **com.myspace.mortgage_app** from the **Package** drop-down menu and click **Ok**.
6. Enter **Property** in the **Label** field of the ‘Property’ - general properties section.
7. Click **+add field** and input the following **Property** data object values. Click **Create and continue** after each addition. For the last addition, click **Create**.

![Figure 14.2. Property data object field values](image)

8. Click **Save**.

14.3. CREATING THE VALIDATIONERRORDO DATA OBJECT

Follow these steps to create the **Validation>ErrorDO** data object, which specifies the cause of an application error.

**Procedure**

1. In Business Central, click on the **MySpace** default space.
2. Click **Menu → Design → Projects** and click **mortgage-process**.
3. Click **Add Asset** and select **Data Object**.
4. Enter **Validation>ErrorDO** in the **Data Object** field of the **Create new Data Object** window.
5. Select **com.myspace.mortgage_app** from the **Package** drop-down menu and click **Ok**.
6. Enter `ValidationErrorDO` in the **Label** field of the 'ValidationErrorDO'- general properties section.

7. Click **+add field** and input the following `ValidationErrorDO` data object values. Click **Create and continue** after each addition. For the last addition, click **Create**.

**Figure 14.3. ValidationErrorDO data object field values**

<table>
<thead>
<tr>
<th>Model</th>
<th>Overview</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validation Error (ValidationErrorDO)</td>
<td>![add field]</td>
<td></td>
</tr>
<tr>
<td>Identifier</td>
<td>Label</td>
<td>Type</td>
</tr>
<tr>
<td>error</td>
<td>Error and cause</td>
<td>String</td>
</tr>
</tbody>
</table>

8. Click **Save**.

### 14.4. CREATING THE APPLICATION DATA OBJECT

Follow these steps to create the **Application** data object, which contains information about the mortgage details, such as the down payment and the mortgage amount.

**Procedure**

1. In Business Central, click on the **MySpace** default space.

2. Click **Menu → Design → Projects** and click **mortgage-process**.

3. Click **Add Asset** and select **Data Object**.

4. Enter **Application** in the **Data Object** field of the **Create new Data Object** window.

5. Select `com.myspace.mortgage_app` from the **Package** drop-down menu and click **Ok**.

6. Enter **Application** in the **Label** field of the 'Application'- general properties section.

7. Click **+add field** and input the following **Application** data object values. Click **Create and continue** after each addition. For the last addition, click **Create**.

**Figure 14.4. Application data object field values**

<table>
<thead>
<tr>
<th>Model</th>
<th>Overview</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>![add field]</td>
<td></td>
</tr>
<tr>
<td>Identifier</td>
<td>Label</td>
<td>Type</td>
</tr>
<tr>
<td>amortization</td>
<td>Years of amortization</td>
<td>Integer</td>
</tr>
<tr>
<td>applicant</td>
<td>Applicant</td>
<td>Applicant</td>
</tr>
<tr>
<td>downpayment</td>
<td>Down Payment</td>
<td>Integer</td>
</tr>
<tr>
<td>errors</td>
<td>Error details</td>
<td><code>Validation Error</code></td>
</tr>
<tr>
<td>mortgageamount</td>
<td>Mortgage amount</td>
<td>Integer</td>
</tr>
<tr>
<td>property</td>
<td>Property</td>
<td>Property</td>
</tr>
</tbody>
</table>
8. Click **Save**.
CHAPTER 15. BUSINESS PROCESSES IN BUSINESS CENTRAL

A business process is a diagram that describes the order in which a series of steps must be executed using a flow chart. A business process consists of a collection of nodes that are linked to each other using connections. Each of the nodes represents one step in the overall process while the connections specify how to transition from one node to the other.

The sample Mortgage_Process contains the following predefined MortgageApprovalProcess business process.

15.1. CREATING THE BUSINESS PROCESS

The following procedures guide you through the creation of tasks, connections, and gateways that make up the MortgageApprovalProcess business process. The mortgage validation business process determines whether a mortgage application contains all required data. If the specified data requirements are met, the application proceeds on to the mortgage calculation business process.

Procedure

1. In Business Central, go to Menu → Design → Projects → Mortgage-Process.

2. Click Add Asset → Business Process.

3. Enter the following values:
   - Business Process: MortgageApprovalProcess
   - Package: Select com.myspace.mortgage_app
     The Package specifies the location inside the existing project where the asset will be created. In this example, it is created in com/myspace/mortgage_app.
4. Click Ok. The diagram editor opens.

5. In the upper-right corner, click the Properties icon.


7. Enter the following values:
   - Name: application
   - Data Type: Application [com.myspace.mortgage_app]

15.1.1. Creating outgoing connections and exclusive gateways

This section shows you how to create outgoing connections, exclusive gateways, and business rule tasks. Use exclusive gateways to make decisions and react to events based on the available data.

Red Hat Process Automation Manager contains a predefined selection of node types to simplify business process creation. The predefined node panel is located on the left side of the diagram editor.
1. Drag a start event node onto the canvas.

2. Create an outgoing connection from the start event to an exclusive gateway:
   a. On the canvas, click the start event node and click the Create Parallel icon.
   b. Hover over the icon of the parallel and click the Convert into Exclusive icon.

3. Create an outgoing connection from the exclusive gateway to a business rule task:
   a. On the canvas, click the exclusive gateway and click the Create Task icon.
   b. Hover over the icon of the task and click the Convert into Business Rule icon.

4. Configure the business rule task:
   a. Click the business rules task.
   b. If the Properties panel is not open, in the upper-right corner click the Properties icon.
c. In the Properties panel, enter Validation in the Name field.

d. Expand Implementation/Execution, select New from the Rule Flow Group menu, and input validation.

e. In the On Exit Action field, enter the following Java expression:

```
System.out.println(application.getProperty());
```

f. Expand Data Assignments and click next to Assignments.

g. In the Validation Data I/O window, click Add and create the following assignments:

- Data Inputs and Assignments
  - Name: application
  - Data Type: Application [com.myspace.mortgage_app]
  - Source: application

- Data Outputs and Assignments
  - Name: application
  - Data Type: Application [com.myspace.mortgage_app]
  - Target: application

Figure 15.1. Validation Data I/O assignments

5. Click OK in the Validation Data I/O window.

6. Above the canvas, click Save to confirm your changes.

15.1.2. Defining the validation data
This section shows you how to define the validation data that determines whether the application data is correct, contains an error, or has missing information.

**Procedure**

1. Create an outgoing connection from the Validation task to an exclusive gateway:
   a. Click the Validation task and click the Create Parallel icon.
   b. Hover over the icon of the parallel and click the Convert into Exclusive icon.

2. Create an outgoing connection from the exclusive gateway to a new business rule task:
   a. Click the exclusive gateway and click the Create Task icon.
   b. Drag the new task below the exclusive gateway as shown below.
   c. Hover over the icon of the task and click the Convert into Business Rule icon.
   d. If the Properties panel is not open, in the upper-right corner click the Properties icon.
   e. In the Properties panel, enter Retract Validation in the Name field.
   f. Expand Implementation/Execution, select New from the Rule Flow Group menu, and input error.

3. Configure the connection between the exclusive gateway and the business rule task:
a. Click the connection.

b. If the Properties panel is not open, in the upper-right corner click the Properties icon.

c. In the Properties panel, enter Invalid in the Name field.

d. Expand Implementation/Execution and select Expression in the Condition Expression section.

e. From the list, select drools and enter ValidationErrorDO() in the Condition Expression field.

4. Create an outgoing connection from the Retract Validation task to a new user task:

   a. Click the Retract Validation task and click the Create Task icon.
b. Drag the new task below the Validation task as shown below.

c. Hover over the icon of the task and click the Convert into User icon.

![Diagram of task flow]

d. Click on the new user task and in the Properties panel, enter Correct Data in the Name field.

e. Expand Implementation/Execution and enter CorrectData in the Task Name field.

f. Select New from the Groups menu, and input broker.

g. Click next to Assignments.

h. In the Correct Data Data I/O window, click Add and create the following assignments:

- Name: application
- Data Type: Application [com.myspace.mortgage_app]
- Source: application
  - Data Outputs and Assignements
- Name: application
- Data Type: Application [com.myspace.mortgage_app]
- Target: application
i. Click **OK** in the **Correct Data Data I/O** window.

j. Above the canvas, click **Save** to confirm your changes.

5. Click on the **Correct Data** user task, then click the **Create sequence Flow** icon and drag it back to the first exclusive gateway. Your workflow should look similar to the following diagram:

![Diagram of workflow](image)

15.1.3. Calculating the mortgage

The mortgage calculation business process determines the applicant’s mortgage borrowing limit.

**Procedure**

1. Return to the second exclusive gateway and create an outgoing connection to a new business rule task.

2. Click the created connection and in the **Properties** panel, input **Valid** in the **Name** field.
a. Expand Implementation/Execution and select Expression in the Condition Expression section.

b. From the list, select drools and enter not ValidationErrorDO() in the Condition Expression field.

3. Click the new business rule task and in the Properties panel, input Mortgage Calculation in the Name field.

![Diagram of a business rule task with conditions and actions]

a. Expand Implementation/Execution, select New from the Rule Flow Group menu, and input mortgagecalculation.

4. Expand Data Assignments and click next to Assignments.

5. In the Mortgage Calculation Data I/O window, click Add to create the following assignments and click Save.
6. Click OK in the Mortgage Calculation Data I/O window.

7. Click an empty space on the canvas, scroll down, expand Process Data, and click next to Process Variables. Enter the following values:
   - **Name:** inlimit
   - **Data Type:** Boolean

8. Create an outgoing connection from the Mortgage Calculation task to a new user task.

9. Click the user task, enter Qualify in the Name field.

10. Expand Implementation/Execution and enter Qualify in the Task Name field.

11. Select New from the Groups menu, and input approver.

12. Click next to Assignments. In the Qualify Data I/O window, click Add to create the following assignments:
13. Click OK in the Qualify Data I/O window.

14. Above the canvas, click Save to confirm your changes.

15. Click on the Qualify user task, click on the Create parallel menu icon, and convert it to an exclusive gateway.

16. Drag the new exclusive gateway below the Qualify user task.

17. Create an outgoing connection from the exclusive gateway and connect it to a new user task.

18. Click the connection and input In Limit in the Name field of the Properties panel.

19. Expand Implementation/Execution and select Condition in the Condition Expression section.

20. Select inlimit from the Process Variable drop-down menu and select Is true from the Condition drop-down menu.
21. Click the user task, enter **Final Approval** in the **Name** field.

22. Expand **Implementation/Execution** and enter **Final Approval** in the **Task Name** field.

23. Select **New** from the **Groups** menu, and input **manager**.

24. Click next to **Assignments**. In the **Final Approval Data I/O** window, click **Add** to create the following assignments:
25. Click OK in the Final Approval Data I/O window.

26. Above the canvas, click Save to confirm your changes.

15.1.4. Increasing the down payment

The increasing the down payment business process checks to see if the applicant qualifies for the loan by increasing their down payment. The final result is either the final loan approval, or loan denial based on the applicant’s inability to increase the down payment.

Procedure

1. Click on the Final Approval user task and select Create End from the user task quick menu.

2. Move the end event below the Final Approval user task.
3. Return to the exclusive gateway that connects with the Final Approval user task. Create a second outgoing connection and connect it to a new user task.
4. Click the connection and input **Not in Limit** in the **Name** field of the **Properties** panel.

5. Expand **Implementation/Execution** and select **Condition** in the **Condition Expression** section.

6. Select **inlimit** from the **Process Variable** drop-down menu and select **Is false** from the **Condition** drop-down menu.
7. Click an empty space on the canvas, scroll down, expand **Process Data**, and click next to **Process Variables**. Enter the following values:

- **Name**: `incdownpayment`
- **Data Type**: `Boolean`

![Process Data](image)

8. Click the new user task and in the **Properties** panel, input **Increase Down Payment** in the **Name** field.

9. Expand **Implementation/Execution** and enter **IncreaseDownPayment** in the **Task Name** field.

10. Select **New** from the **Groups** menu, and input **broker**.

11. Click next to **Assignments**. In the **Increase Down Payment Data I/O** window, click **Add** to create the following assignments:

   ![Increase Down Payment Data I/O window](image)

   **Figure 15.6. Increase Down Payment Data I/O assignments**
12. Click **OK** in the *Increase Down Payment Data I/O* window.

13. Above the canvas, click **Save** to confirm your changes.

14. Click on the *Increase Down Payment* user task, click on the *Create parallel* menu icon, and convert it to an exclusive gateway.

15. Drag the new exclusive gateway below the *Increase Down Payment* user task.

16. Create an outgoing connection from the exclusive gateway to an end event.

17. Click the connection and input **Down payment not increased** in the **Name** field of the *Properties* panel.

18. Expand *Implementation/Execution* and select *Expression* in the *Condition Expression* section.

19. Input `return !incdownpayment;` and select **java** from the drop-down menu.

20. Create an outgoing connection from the exclusive gateway and connect it to the first exclusive gateway.

21. Click the connection and input **Down payment increased** in the **Name** field of the *Properties* panel.

22. Expand *Implementation/Execution* and select *Expression* in the *Condition Expression* section.

23. Input `return incdownpayment;` and select **java** from the drop-down menu.

24. Above the canvas, click **Save** to confirm your changes and save the entire business process.

**Figure 15.7. Final version of the business process**
CHAPTER 16. 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.

16.1. VIEWING THE MORTGAGE_PROCESS BUSINESS RULES

The goal of this chapter is to introduce you to the predefined business rules for the Mortgage_Process project. For this tutorial, you do not create and define the business rules. Instead, review the WHEN and THEN rules that are already defined in the Mortgage_Process sample project’s preconfigured business rules. For information about creating guided business rules, see Designing a decision service using guided rules.

16.1.1. Viewing the Validate Down Payment guided rule

Review the WHEN and THEN rules so that you understand how the conditions are set and used later when you run the process.

Procedure

1. Click Menu → Design → Projects, and click Mortgage_Process.
2. From the asset list, click the right arrow to view the second page of the asset list and click the Validate Down Payment guided rule.
3. Review the Validate Down Payment guided rule’s WHEN and THEN conditions and values.

16.1.2. Viewing the RetractValidationErr guided rule

Review the WHEN and THEN rules so that you understand how the conditions are set and used later when you run the process.

Procedure

1. Click Menu → Design → Projects, and click Mortgage_Process.
2. From the asset list, click the right arrow to view the second page of the asset list and click the **RetractValidationErr** guided rule.

3. Review the **RetractValidationErr** guided rule's **WHEN** and **THEN** conditions and values.

<table>
<thead>
<tr>
<th>WHEN</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. There is a ValidationErrCall [value]</td>
<td>1. Delete ValidationErrCC [value]</td>
</tr>
</tbody>
</table>

**(options)**

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>dialect</td>
<td>error</td>
</tr>
<tr>
<td>runflow-group</td>
<td>error</td>
</tr>
</tbody>
</table>
CHAPTER 17. GUIDED DECISION TABLES

Guided decision tables are a wizard-led alternative to spreadsheet decision tables for defining business rules in a tabular format. With guided decision tables, you are led by a UI-based wizard in Business Central that helps you define rule attributes, metadata, conditions, and actions based on specified data objects in your project. After you create your guided decision tables, the rules you defined are compiled into Drools Rule Language (DRL) rules as with all other rule assets.

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

17.1. VIEWING THE MORTGAGE DECISION TABLE

The goal of this chapter is to introduce you to the MortgageDecisionTable decision table. For this tutorial, you do not create and set the decision table conditions. Instead, review the values and the conditions that are already defined in the Mortgage_Process sample project’s MortgageDecisionTable Guided Decision Tables asset. For information about creating decision tables, see Designing a decision service using guided decision tables.

Prerequisites

- The business rules have been defined. For more information, see Section 16.1, “Viewing the Mortgage_Process business rules”.

Procedure

1. In Business Central, go to Menu → Design → Projects → Mortgage_Process.

2. Scroll down and click the MortgageDecisionTable Guided Decision Tables asset.
CHAPTER 18. FORMS IN BUSINESS CENTRAL

A form is a layout definition for a page, defined as HTML, that is displayed as a dialog window to the user during process and task instantiation. Task forms acquire data from a user for both the process and task instance execution, whereas process forms take input and output from process variables.

The input is then mapped to the task using the data input assignment, which you can use inside of a task. When the task is completed, the data is mapped as a data output assignment to provide the data to the parent process instance.

18.1. VIEWING THE MORTGAGE_PROCESS FORMS

The goal of this chapter is to introduce you to the Mortgage_Process sample project’s predefined forms which are used for collecting user data for the mortgage application business process. For this tutorial, you do not create and modify the Mortgage_Process forms. Instead, review the predefined sample forms. For information about creating forms, see Designing business processes using BPMN models.

Procedure

1. In Business Central, go to Menu → Design → Projects → Mortgage_Process.

2. From the asset list, click the right arrow to view the second page of the asset list and select the Applicant form.


4. From the asset list, select the Property form. The Property form is shown below:
5. Click **Menu → Design → Projects → Mortgage_Process**.

6. From the asset list, select the **Application form**. The **Application form** is shown below:

---

**Figure 18.3. Application sample form**

---

---

---

---

---
7. Click the X icon in the upper-right corner to close the editor.
CHAPTER 19. DEPLOYING THE MORTGAGEAPPROVALPROCESS PROCESS APPLICATION

The following chapter instructs you how to build and deploy a new instance of the Mortgage_Process application in Red Hat Process Automation Manager.

Prerequisites

- KIE Server is deployed and connected to Business Central.

Procedure

1. In Business Central, go to Menu → Design → Projects → Mortgage_Process.

2. Click Deploy.

- If no KIE container (deployment unit) is included with the project name, a container with default values is automatically created.

- If an older version of the project is already deployed, go to the project settings and change the project version. When finished, save the change and click Deploy. This deploys a new version of the same project with the latest changes in place, alongside the older version(s).

   **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 and toggle the Development Mode option. 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.

3. 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 20. EXECUTING THE MORTGAGEAPPROVALPROCESS PROCESS APPLICATION

Now that you have deployed the project, you can execute the project’s defined functionality. For this tutorial you input data into a mortgage application form acting as the mortgage broker. The **MortgageApprovalProcess** business process runs and determines whether or not the applicant has offered an acceptable down payment based on the decision rules that you defined earlier. The business process either ends the rule testing or requests that the applicant increase the down payment to proceed. If the application passes the business rule testing, the bank’s approver reviews the application and either approve or deny the loan.

**Prerequisites**

- KIE Server is deployed and connected to Business Central.
- The **Mortgage_Process** application has been deployed.
- The users working on the tasks are members of the following groups and roles:
  - **approver** group: For the **Qualify** task
  - **broker** group: For the **Correct Data** and **Increase Down Payment** tasks
  - **manager** role: For the **Final Approval** task

**Procedure**

1. Log in to Red Hat Process Automation Manager as Bill (the broker) and click **Menu → Manage → Process Definitions**.

2. Click the three vertical dots in the **Actions** column and select **Start** to start to open the **Application** form and input the following values in to the form fields:

   - Down Payment: **30000**
   - Years of amortization: **10**
   - Name: **Ivo**
   - Annual Income: **60000**
   - SSN: **123456789**
   - Age of property: **8**
   - Address of property: **Brno**
   - Locale: **Rural**
   - Property Sale Price: **50000**

3. Click **Submit** to start a new process instance. After starting the process instance, the **Instance Details** view opens.

4. Click the **Diagram** tab to view the process flow within the process diagram. The state of the process is highlighted as it moves through each task.
5. Log out of Business Central and log back in as **Katy**.

6. Click **Menu → Track → Task Inbox**. This takes you to the **Qualify** form.

7. Click the three vertical dots in the **Actions** column and select and click **Claim**. The Qualify task **Status** is now **Reserved**.

8. Click the **Qualify** task row to open and review the task information. Click **Claim** and then **Start** at the bottom of the form.
   The application form is now active for approval or denial.

9. To approve the application, select **Is mortgage application in limit?** and click **Complete**.

10. In the **Task Inbox**, click anywhere in the **Final Approval** row to open the **Final Approval** task.

11. In the **Final Approval** row, click the three vertical dots in the **Actions** column and click **Claim**.

12. Click anywhere in the **Final Approval** row to open the **Final Approval** task. Click **Start** at the bottom of the form.

13. Note that the **Inlimit** check box is selected to reflect that that application is ready for final approval. Click **Complete**.

**NOTE**

The **Save** and **Release** buttons are only used to either pause the approval process and save the instance if you are waiting on a field value, or to release the task for another user to modify.
CHAPTER 21. MONITORING THE MORTGAGEAPPROVALPROCESS PROCESS APPLICATION

The following chapter shows how different bank employees, such as a system administrator or a knowledge worker, might use some of the monitoring capabilities to track an instance of the mortgage approval process.

Prerequisites

- KIE Server is deployed and connected to Business Central.

Procedure

2. In the Manage Process Instances window, you can set filters, such as State, Errors, Id, and so on.
3. Select Completed in the State filter to view all completed MortgageApprovalProcess instances.
4. Click on the completed process instance.
5. Click each of the following tabs to get a feel for what type of information is available to monitor a specific process instance:
   - Instance Details
   - Process Variables
   - Documents
   - Logs
   - Diagram
6. Click Menu → Track → Process Reports. This view contains a variety of charts that can help a senior process manager to gain an overview of all processes based on Type, Start Date, Running Time, and so on to assist with task reporting.

21.1. FILTERING PROCESS INSTANCES USING DEFAULT OR ADVANCED FILTERS

Business Central now provides you with default and advanced filters to help you filter and search through running process instances. You can also create custom filters using the Advanced Filters option.

21.1.1. Filtering process instances using default filters

Filter process instances by attributes such as State, Errors, Filter By, Name, Start Date, and Last update.

Procedure
1. In Business Central, go to **Menu → Manage → Process Instances**.

2. On the **Manage Process Instances** page, click the filter icon on the left of the page to expand the **Filters** pane. This pane lists the following process attributes which you can use to filter process instances:

   - **State**: Filter process instances based on their state (Active, Aborted, Completed, Pending, and Suspended).
   - **Errors**: Filter process instances by errors.
   - **Filter By**: Filter process instances based on **Id**, **Initiator**, **Correlation Key**, or **Description** attribute.
     
     i. Select the required attribute.
     
     ii. Enter the search query in the text field below.
     
     iii. Click **Apply**.
   - **Name**: Filter process instances by definition names.
   - **Definition Id**: Filter process instances by process definition IDs.
   - **Deployment Id**: Filter process instances by process deployment IDs.
   - **Parent Process Instance Id**: Filter process instances by parent process instance IDs.
   - **SLA Compliance**: Filter process instances by SLA compliance states.
   - **Start Date**: Filter process instances by creation dates.
   - **Last update**: Filter process instances by last modified dates.

### 21.1.2. Filtering process instances using advanced filters

Use the **Advanced Filters** option to create custom process instance filters. The newly created custom filter is added to the **Saved Filters** pane, which is accessible by clicking on the star icon on the left of the **Manage Process Instances** page.

**Procedure**

1. In Business Central, go to **Menu → Manage → Process Instances**.

2. On the **Manage Process Instances** page, on the left of the page click the **Advanced Filters** icon.

3. In the **Advanced Filters** pane, enter the name and description of the filter, and click **Add New**.

4. Select an attribute from the **Select column** drop-down list, for example, **processName**. The content of the drop-down changes to **processName != value**.

5. Click the drop-down again and choose the required logical query. For the **processName** attribute, choose **equals to**.

6. Change the value of the text field to the name of the process you want to filter.
NOTE

The name must match the value defined in the business process of the project.

7. Click Save and the processes are filtered according to the filter definition.

8. Click the star icon to open the Saved Filters pane.
   In the Saved Filters pane, you can view all the saved advanced filters.
CHAPTER 22. ADDITIONAL RESOURCES

- Designing business processes using BPMN models
PART III. GETTING STARTED WITH CASE MANAGEMENT IN RED HAT PROCESS AUTOMATION MANAGER

As a business rules and processes developer, you can use case management assets in Business Central to create unpredictable and ad hoc case processes. Case workers or process administrators can also use Business Central for case management and execution. Red Hat Process Automation Manager provides example projects with example business assets in Business Central as a reference. This document describes how to create and test an example IT orders project based on the IT_Orders sample project included in Business Central.

Prerequisites

- Red Hat JBoss Enterprise Application Platform 7.3 is installed. For installation information, see Red Hat JBoss Enterprise Application Platform 7.3 Installation Guide.

- Red Hat Process Automation Manager is installed and configured with KIE Server. For more information see Installing and configuring Red Hat Process Automation Manager on Red Hat JBoss EAP 7.3.

- Red Hat Process Automation Manager is running and you can log in to Business Central with the kie-server, user, and admin roles.

- You have reviewed the information in Designing and building cases for case management.
CHAPTER 23. REVIEWING THE IT_ORDERS SAMPLE PROJECT

Before you create your own case management project, review the existing IT_Orders sample case management project in Business Central. This sample project contains predefined case management assets as a reference for your own case projects.

**IMPORTANT**

The business process application example includes features that are Technology Preview only. Technology Preview features are not supported with Red Hat production service level agreements (SLAs), might not be functionally complete, and are not recommended for production. These features provide early access to upcoming product features, enabling customers to test functionality and provide feedback during the development process. For more information about Red Hat Technology Preview support, see Technology Preview Features Support Scope.

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. Select IT_Orders and click **Ok**.

The Assets view of the project opens. Select each example asset to explore how the project is designed to achieve the specified goal or workflow.

Review the orderhardware business process to help you understand the business process flow.
CHAPTER 24. CREATING A NEW IT_ORDERS CASE PROJECT

Create a new IT_Orders project in Business Central to gain an understanding of all of the required assets and how they are used in the project.

Procedure

1. Log in to Business Central and go to Menu → Design → Projects.
   Business Central provides a default space called MySpace, as shown in the following image. You can use the default space to create and test example projects.

   Figure 24.1. Default spaces

2. Click the Add Project drop-down arrow and select the Case project option:

   Figure 24.2. Case project

3. In the Add Project window, enter IT_Orders_New in the Name field and enter a project Description.
Figure 24.3. Add Project window

4. Click **Add** to add the project.
   The **Assets** view of the project opens.
CHAPTER 25. DATA OBJECTS

Data objects are the building blocks for the rule assets that you create. Data objects are custom data types implemented as Java objects in specified packages of your project. For example, you might create a `Person` object with data fields `Name`, `Address`, and `DateOfBirth` to specify personal details for loan application rules. These custom data types determine what data your assets and your decision services are based on.

25.1. CREATING THE ITORDERSERVICE DATA OBJECT

The `ITOrderService` data object specifies the data type that will be used to define the IT Orders variables.

Prerequisites

- The `IT_Orders_New` project is created.

Procedure

1. Click `Add Asset` → `Data Object`.
2. In the Create new Data Object wizard, enter the following values:
   - Data Object: `ITOrderService`
   - Package: `com.myspace.it_orders_new`
3. Click `Ok`.
4. Click + next to the `Package` drop-down menu to specify a new package for the data object.
5. Input `org.jbpm.demo.it_orders.services` and click `Add`.
6. Click `Save`, and then click `Yes, Move` to confirm your changes.

25.2. CREATING THE SURVEY DATA OBJECT

The `Survey` data object contains data fields, such as `deliveredOnTime` and `missingEquipment`. You will use the data and values when you design your case.

Prerequisites

- The `IT_Orders_New` project is created.

Procedure

1. In Business Central, go to `Menu` → `Design` → `Projects` and click `IT_Orders_New`.
2. Click `Add Asset` → `Data Object`.
3. In the Create new Data Object wizard, enter the following values:
   - Data Object: `Survey`
• Package: `com.myspace.it_orders_new`

4. Click Ok.

5. Add the Survey data object constraints.
   a. Click add field.
   b. Enter the following values:
      - Id: `comment`
      - Label: Leave empty
      - Type: String
   c. Click Create and continue, and then enter the following values:
      - Id: `deliveredOnTime`
      - Label: Leave empty
      - Type: Boolean
   d. Click Create and continue, and then enter the following values:
      - Id: `missingEquipment`
      - Label: Leave empty
      - Type: String
   e. Click Create and continue, and then enter the following values:
      - Id: `satisfied`
      - Label: Leave empty
      - Type: Boolean
   f. Click Create.

6. Click Save to confirm your changes.

Figure 25.1. Survey data object details
CHAPTER 26. DESIGNING THE CASE DEFINITION

You design cases using the process designer in Business Central. Case design is the basis of case management and sets the specific goals and tasks for each case. The case flow can be modified dynamically during run time by adding dynamic tasks or processes. In this procedure, you will create this same case definition to familiarize yourself with the case definition design process.

The IT_Orders sample project in Business Central includes the following orderhardware business process case definition.

Figure 26.1. orderhardware business process case definition

Prerequisites
- You have created a new case in Business Central. For more information, see Chapter 24, Creating a new IT_Orders case project.
- You have created the data objects. For more information, see Chapter 25, Data objects.

Procedure
1. In Business Central, go to Menu → Design → Projects and click IT_Orders_New.
2. Click Add Asset → Case Definition.
3. In the Create new Case definition window, add the following required information:
   - **Case Definition**: Input orderhardware. This is usually the subject of the case or project that is being case managed.
   - **Package**: Select com.myspace.it_orders_new to specify the location that the case file is created in.
4. Click Ok to open the process designer.
5. Define values for the case file variables that are accessible to the subprocesses, subcases, and business rules used in the case.

   a. In the upper-right corner, click the Properties icon.

   b. Scroll down and expand Case Management, click in the Case File Variables section, and enter the following:

   Figure 26.2. orderhardware case file variables

   ![Case File Variables Table]

   **NOTE**

   The following case file variables are custom data types:

   - **hwSpec**: org.jbpm.document.Document (type in this value)
   - **survey**: Survey [com.myspace.it_orders_new] (select this value)

6. Click Save.

7. Define the roles involved in the case.

   a. In the upper-right corner, click the Properties icon.

   b. Scroll down and expand Case Management, click in the Case Roles section, and enter the following:
Figure 26.3. orderhardware case roles

- **owner**: The employee who is making the hardware order request. The role cardinality is set to 1, which means that only one person or group can be assigned to this role.

- **manager**: The employee’s manager; the person who will approve or deny the requested hardware. The role cardinality is set to 1, which means that only one person or group can be assigned to this role.

- **supplier**: The available suppliers of IT hardware in the system. The role cardinality is set to 2, which means that more than one supplier can be assigned to this role.

8. Click **Save**.

**26.1. CREATING THE PLACE ORDER SUBPROCESS**

Create the **Place order** subprocess, which is a separate business process that is carried out by the supplier. This is a reusable process that occurs during the course of case execution as described in Chapter 26, *Designing the case definition*.

**Prerequisites**

- You have created a new case in Business Central. For more information, see Chapter 24, *Creating a new IT_Orders case project*.

- You have created the data objects. For more information, see Chapter 25, *Data objects*.

**Procedure**

1. In Business Central, go to **Menu → Design → Projects → IT_Orders_New**.

2. From the project menu, click **Add Asset → Business Process**.

3. In the **Create new Business Process** wizard, enter the following values:
   
   - **Business Process**: place-order
   - **Package**: Select **com.myspace.it_orders_new**

4. Click **Ok**. The diagram editor opens.

5. Click an empty space in the canvas, and in the upper-right corner, click the **Properties** icon.
6. Scroll down and expand **Process Data** and click ![+](image) in the **Process Variables** section and enter the following:

![Process Variables Table](image)

7. Click **Save**.

8. Drag a start event onto the canvas and create an outgoing connection from the start event to a task and convert the new task to a user task.
CHAPTER 26. DESIGNING THE CASE DEFINITION

Model | Overview | Documentation

START EVENTS

- Start
- Start Message
- Start Signal
- Start Timer
- Start Error
- Start Conditional
- Start Escalation
- Start Compensation

Create Task
9. Click the user task and in the Properties panel, input Place order in the Name field.

10. Expand Implementation/Execution, click Add below the Groups menu, click Select → New, and input supplier.

11. Click in the Assignments field and add the following:

   ![Image of Assignments UI]

   For the first input assignment, select Custom for the Data Type and input org.jbpm.document.Document.

12. Click OK.

13. Select the Skippable check box and enter the following text in the Description field: Approved order #{CaseId} to be placed
14. Create an outgoing connection from the **Place order** user task and connect it to an end event.

15. Click **Save** to confirm your changes.

### 26.2. CREATING THE MANAGER APPROVAL BUSINESS PROCESS

The manager approval process determines whether or not the order will be placed or rejected.

**Procedure**

1. In Business Central, go to **Menu → Design → Projects → IT_Orders_New → orderhardware Business Processes.**
2. Create and configure the **Prepare hardware spec** user task:

   a. Expand **Tasks** in the **Object Library** and drag a user task onto the canvas and convert the new task to a user task.

   b. Click the new user task and in the upper-right corner click the **Properties** icon.

   c. Input **Prepare hardware spec** in the **Name** field.

   d. Expand **Implementation/Execution**, click **Add** below the **Groups** menu, click **Select → New**, and input **supplier**.

   e. Input **PrepareHardwareSpec** in the **Task Name** field.

   f. Select the **Skippable** check box and enter the following text in the **Description** field: 
   
   - Prepare hardware specification for #{initiator} (order number #{CaseId})

   g. Click in the **Assignments** field and add the following:

   ![Prepare hardware spec Data I/O](image)

   h. Click **OK**.

3. Create and configure the manager approval user task:

   a. Click the **Prepare hardware spec** user task and create a new user task.

   b. Click the new user task and in the upper-right corner click the **Properties** icon.

   c. Click the user task and in the **Properties** panel input **Manager approval** in the **Name** field.

   d. Expand **Implementation/Execution**, click **Add** below the **Actors** menu, click **Select → New**, and input **manager**.
e. Input **ManagerApproval** in the Task Name field.

f. Click 🔄 in the Assignments field and add the following:

   ![Manager Approval Data I/O](image)

   **Data Inputs and Assignments**

   | Name       | Data Type     | Source
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>_hwspec</td>
<td>org.jboss.documer</td>
<td>caseFile_hwspec</td>
</tr>
<tr>
<td>orderNumber</td>
<td>String</td>
<td>Caseld</td>
</tr>
<tr>
<td>requestor</td>
<td>String</td>
<td>initiator</td>
</tr>
</tbody>
</table>

   **Data Outputs and Assignments**

   | Name       | Data Type | Target
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>approved_</td>
<td>Boolean</td>
<td>approved</td>
</tr>
<tr>
<td>managerComment_</td>
<td>String</td>
<td>caseFile_managerComment</td>
</tr>
</tbody>
</table>

   ![OK button](image)

   g. Click OK.

   h. Select the **Skippable** check box and enter the following text in the Description field:

   Approval request for new hardware for #{initiator} (order number #{Caseld})

   i. Enter the following Java expression in the On Exit Action field:

   ```java
   kcontext.setVariable("caseFile_managerDecision", approved);
   ```

   j. Click Save.

4. Click the **Manager approval** user task and create a Data-based Exclusive (XOR) gateway.
5. Create and configure the **Place order** reusable subprocess:

   a. From the **Object Library**, expand **Subprocesses**, click **Reusable**, and drag the new element to the canvas on the right side of the Data-based Exclusive (XOR) gateway.

   b. Connect the Data-based Exclusive (XOR) gateway to the subprocess.
c. Click the new sub task and in the upper-right corner click the Properties icon.

d. Input **Place order** in the **Name** field.

e. Expand **Data Assignments** and click in the **Assignments** field and add the following:

```
<table>
<thead>
<tr>
<th>Name</th>
<th>Data Type</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaseId</td>
<td>String</td>
<td>CaseId</td>
</tr>
<tr>
<td>Requestor</td>
<td>String</td>
<td>Initiator</td>
</tr>
</tbody>
</table>
```

Data Outputs and Assignments

f. Click **OK**.

g. Click the connection from the Data-based Exclusive (XOR) gateway to the subprocess and click the Properties icon.

h. Expand **Implementation/Execution**, select **Condition**, and set the following condition expressions.
6. Create and configure the order rejected user task:
   a. Click the Data-based Exclusive (XOR) gateway and create a new user task.
   b. Drag the new task to align it below the Place order task.
   c. Click the new user task and in the upper-right corner click the Properties icon.
   d. Input Order rejected in the Name field.
   e. Expand Implementation/Execution and input OrderRejected in the Task Name field.
   f. Click Add below the Actors menu, click Select → New, and input owner.
   g. Click in the Assignments field and add the following:
h. Click OK.

i. Select the Skippable check box and enter the following text in the Description field: 
Order #{{Caseld}} has been rejected by manager

j. Click the Order rejected user task and create an end event.

k. Click Save.

7. Click the connection from the Data-based Exclusive (XOR) gateway to the Order rejected user task and click the Properties icon.

8. Expand Implementation/Execution, select Condition, and set the following condition expressions.

9. Click Save.
Figure 26.4. Manager approval business process
CHAPTER 27. MILESTONES

Milestones are a special service task that can be configured in the case definition designer by adding the milestone node to the process designer palette. When creating a new case definition, a milestone configured as AdHoc Autostart is included on the design palette by default. Newly created milestones are not set to AdHoc Autostart by default.

Case management milestones generally occur at the end of a stage, but they can also be the result of achieving other milestones. A milestone always requires a condition to be defined in order to track progress. Milestones react to case file data when data is added to a case. A milestone represents a single point of achievement within the case instance. It can be used to flag certain events, which can be useful for Key Performance Indicator (KPI) tracking or identifying the tasks that are still to be completed.

Milestones can be in any of the following states during case execution:

- **Active**: The condition has been defined on the milestone but it has not been met.
- **Completed**: The milestone condition has been met, the milestone has been achieved, and the case can proceed to the next task.
- **Terminated**: The milestone is no longer a part of the case process and is no longer required.

While a milestone is available or completed it can be triggered manually by a signal or automatically if AdHoc Autostart is configured when a case instance starts. Milestones can be triggered as many times as required, however, it is directly achieved when the condition is met.

### 27.1. CREATING THE HARDWARE SPEC READY MILESTONE

Create a HardwareSpecReady milestone that is reached when the required hardware specification document is completed.

**Procedure**

1. In the process designer, expand Milestone in the Object Library and drag a new milestone on the canvas and place it on the right side of the Place order end event.

2. Click the new milestone and in the upper-right corner click the Properties icon.

3. Input Hardware spec ready in the Name field.

4. Expand Implementation/Execution and select AdHoc Autostart.

5. Expand Data Assignments, click in the Assignments field, and add the following:
6. Click OK.

27.2. CREATING THE MANAGER DECISION MILESTONE

This milestone is reached when the `managerDecision` variable has been given a response.

**Procedure**

1. In the process designer, expand `Milestone` in the Object Library and drag a new milestone onto the canvas below the `HardwareSpecReady` milestone.

2. Click the new milestone and in the upper-right corner click the Properties icon.

3. Input `Manager decision` in the Name field.

4. Expand Implementation/Execution and select AdHoc Autostart.

5. Expand Data Assignments and click in the Assignments field and add the following:
Click the Source column drop-down, select Constant, and input 
org.kie.api.runtime.process.CaseData(data.get("managerDecision") != null).

6. Click OK.

27.3. CREATING THE ORDER PLACED MILESTONE

This milestone is reached when the ordered variable, which is part of the Place order sub-process, has been given a response.

Procedure

1. In the process designer, expand Milestone in the Object Library and drag a new milestone on the canvas below the Prepare hardware spec user task.

2. Click the new milestone and in the upper-right corner click the Properties icon.

3. Input Milestone 1: Order placed in the Name field.

4. Expand Implementation/Execution and select AdHoc Autostart.

5. Expand Data Assignments, click in the Assignments field, and add the following:

Click the Source column drop-down, select Constant, and input 
org.kie.api.runtime.process.CaseData(data.get("ordered") == true). This means that a case variable named ordered exists with the value true.

6. Click OK.

7. Click Milestone 1: Order placed and create a new script task.

8. Click the new script task and in the upper-right corner click the Properties icon.

9. Input Notify requestor in the Name field.

10. Expand Implementation/Execution and input System.out.println("Notification::Order placed");
11. Click the Notify requestor script task and create a signal end event.

12. Click the signal event and in the upper-right corner click the Properties icon.

13. Expand Implementation/Execution, click the down arrow in the Signal field, and select New.


15. Click the down arrow in the Signal Scope field, select Process Instance.

16. Click Save.

Figure 27.1. Order placed milestone

27.4. CREATING THE ORDER SHIPPED MILESTONE

The condition for this milestone is that a case file variable named shipped is true. AdHoc Autostart is not enabled for this milestone. Instead, it is triggered by a signal event when the order is ready to be sent.

Procedure

1. In the process designer, expand Milestone in the Object Library and drag a new milestone on the canvas below the Notify requestor script task.

2. Click the new milestone and in the upper-right corner click the Properties icon.

3. Input Milestone 2: Order shipped in the Name field.

4. Expand Implementation/Execution and ensure that AdHoc Autostart is not selected.

5. Expand Data Assignments, click in the Assignments field, and add the following:
Click the **Source** column drop-down, select **Constant**, and input

\[
\text{org.kie.api.runtime.process.CaseData(data.get("shipped") == true)}
\]

This means that a case variable named **shipped** exists with the value **true**.

6. Click **OK**.

7. Click **Milestone 2: Order shipped** and create a new script task.

8. Click the new script task and in the upper-right corner click the **Properties** icon.

9. Input **Send to tracking system** in the **Name** field.

10. Expand **Implementation/Execution** and input

    \[
    \text{System.out.println("Order added to tracking system");}
    \]

11. Click the **Send to tracking system** script task and create a signal end event.

12. Click the signal event and in the upper-right corner click the **Properties** icon.

13. Expand **Implementation/Execution**, click the down arrow in the **Signal** field, and select **New**.

14. Input **Milestone 3: Delivered to customer**.

15. Click the down arrow in the **Signal Scope** field, select **Process Instance**.

16. Click **Save**.

**Figure 27.2. Order shipped milestone**

---

27.5. CREATING THE DELIVERED TO CUSTOMER MILESTONE
The condition for this milestone is that a case file variable named `delivered` is `true`. `AdHoc Autostart` is not enabled for this milestone. Instead, it is triggered by a signal event after the order has successfully shipped to the customer.

**Procedure**

1. In the process designer, expand **Milestone** in the **Object Library** and drag a new milestone on the canvas below the **Send to tracking system** script task.

2. Click the new milestone and in the upper-right corner click the **Properties** icon.

3. Input **Milestone 3: Delivered to customer** in the **Name** field.

4. Expand **Implementation/Execution** and ensure that **AdHoc Autostart** is not selected.

5. Expand **Data Assignments**, click in the **Assignments** field, and add the following:

   ```
   Click the **Source** column drop-down, select **Constant**, and input `org.kie.api.runtime.process.CaseData(data.get("delivered") == true)`. This means that a case variable named `delivered` exists with the value `true`.
   
   Click **OK**.
   
   Click **Milestone 3: Delivered to customer** and create a new user task.
   
   a. Click the new user task and in the upper-right corner click the **Properties** icon.
   
   b. Input **Customer satisfaction survey** in the **Name** field.
   
   c. Expand **Implementation/Execution**, click **Add** below the **Actors** menu, click **Select → New**, and input `owner`.
   
   d. Input **CustomerSurvey** in the **Task Name** field.
   
   e. Select the **Skippable** check box and enter the following text in the **Description** field: **Satisfaction survey for order #{CaseId}**
   
   f. Click in the **Assignments** field and add the following:
g. Click OK.

8. Click the **Customer satisfaction survey** user task and create an end event.

9. Click **Save** to confirm your changes.

**Figure 27.3. Delivered to customer milestone**

The IT Orders case can be closed after all milestone sequences are completed. However, due to the ad hoc nature of cases, the case could be reopened if, for example, the order was never received by the customer or the item is faulty. Tasks can be re-triggered or added to the case definition as required, even during run time.
CHAPTER 28. DEPLOYING AND TESTING THE IT ORDER CASE PROJECT

After you create and define all components of the new IT_Orders_New case project, deploy and test the new project.

Prerequisites

- You have a running KIE Server instance connected to Business Central. For more information see Installing and configuring Red Hat Process Automation Manager on Red Hat JBoss EAP 7.3.
- You have created a new case in Business Central. For more information, see Chapter 24, Creating a new IT_Orders case project.
- You have created the data objects. For more information, see Chapter 25, Data objects.
- You have created the Place order subprocess. For more information, see Section 26.1, “Creating the Place order subprocess”.
- You have designed the orderhardware case definition. For more information, see Chapter 26, Designing the case definition.

Procedure

1. In Business Central, go to Menu ➔ Design ➔ Projects and click IT_Orders_New.
2. Click Deploy.
4. Go to Menu ➔ Deploy and click Execution Servers and verify that a new container is deployed and started.
5. Use the Case Management Showcase application to start a new case instance. For instructions about using the Showcase application, see Using the Showcase application for case management.
CHAPTER 29. ADDITIONAL RESOURCES

- Designing and building cases for case management
- Using the Showcase application for case management
- Getting started with business processes
PART IV. GETTING STARTED WITH RED HAT BUSINESS OPTIMIZER

As a business rules developer, you can use the Red Hat Business Optimizer 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 Red Hat Business Optimizer.
CHAPTER 30. INTRODUCTION TO RED HAT BUSINESS OPTIMIZER

Red Hat Business Optimizer 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, Red Hat Business Optimizer 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).

Red Hat Business Optimizer is open source software under the Apache Software License 2.0. It is 100% pure Java and runs on most Java virtual machines.

30.1. 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:

- The number of people
- Amount of time
- Budget
- Physical assets, for example, machinery, vehicles, computers, buildings, and so on

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 Business Optimizer helps Java programmers solve constraint satisfaction problems efficiently. It combines optimization heuristics and metaheuristics with efficient score calculation.
30.2. 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 given 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, Business Optimizer finds a good solution in reasonable time for such planning problems.

30.3. 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**

An optimal solution is a solution with the highest score. 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 given 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.

Business Optimizer 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 Business Optimizer, you can switch the optimization algorithm by changing the solver configuration in a few lines of XML or code.

### 30.4. 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 Business Optimizer, score constraints are written in an object oriented language such as Java, or in Drools rules.

This type of code is flexible and scalable.
CHAPTER 31. GETTING STARTED WITH SOLVERS 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 Business Optimizer 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.

31.1. 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 Business Optimizer. Use the following procedure to deploy and run the employee rostering sample in Business Central.

Prerequisites

- Red Hat Process Automation Manager has been downloaded and installed. For installation options, see Planning a Red Hat Process Automation Manager installation.

- You have started the KIE Server and logged in to Business Central with a user that has admin permissions. For more information about getting started, see Getting started with decision services.

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.

31.2. 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 31.1, “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.

31.2.1. Setting up the employee rostering project

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

Prerequisites

- Red Hat Process Automation 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 Business Optimizer. Assigns employees to shifts based on their skill.

   Optionally, click Configure Advanced Options to populate the Group ID, Artifact ID, and Version information.

   - Group ID: employeerostering
   - Artifact ID: employeerostering
   - Version: 1.0.0-SNAPSHOT

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

31.2.2. 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 Business Optimizer 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.

### 31.2.3. 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 31.2.1, "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 31.1. Skill**

    | id   | Type   |
    |------|--------|
    | name | String |
Table 31.2. Employee

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>String</td>
</tr>
<tr>
<td>skills</td>
<td>employeerostering.employeerostering.Skill[List]</td>
</tr>
</tbody>
</table>

Table 31.3. Shift

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>requiredSkill</td>
<td>employeerostering.employeerostering.Skill</td>
</tr>
<tr>
<td>timeslot</td>
<td>employeerostering.employeerostering.Timeslot</td>
</tr>
</tbody>
</table>

Table 31.4. DayOffRequest

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>date</td>
<td>LocalDate</td>
</tr>
<tr>
<td>employee</td>
<td>employeerostering.employeerostering.Employee</td>
</tr>
</tbody>
</table>

Table 31.5. ShiftAssignment

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>employee</td>
<td>employeerostering.employeerostering.Employee</td>
</tr>
<tr>
<td>shift</td>
<td>employeerostering.employeerostering.Shift</td>
</tr>
</tbody>
</table>

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

### 31.2.3.1. 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 Business Optimizer 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 31.2.3, “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 Red Hat Business Optimizer dock by clicking the on the right.


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

5. In the Red Hat Business Optimizer 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.

31.2.3.2. 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 Business Optimizer 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 31.2.3, “Creating the data model for the employee rostering project” and Section 31.2.3.1, “Creating the employee roster planning entity”.

Procedure

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

2. Create the following fields:

   Table 31.6. EmployeeRoster

<table>
<thead>
<tr>
<th>id</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>dayOffRequestList</td>
<td>employeerostering.employeerostering.DayOffRequest[List]</td>
</tr>
</tbody>
</table>
3. In the Data Objects perspective, open the Red Hat Business Optimizer dock by clicking the

[Image] 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>employeeList</td>
<td>employeerostering.employeerostering.Employee[List]</td>
</tr>
</tbody>
</table>

7. With the employeeList field selected, open the Red Hat Business Optimizer 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.

### 31.2.4. 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.

31.2.4.1. 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 (when) and actions (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

```drl
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

```drl
rule "Underage"
  salience 15
  agenda-group "applicationGroup"
```

when
  $application : LoanApplication()
  Applicant(age < 21)
then
  $application.setApproved( false );
  $application.setExplanation( "Underage" );
end

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.

### 31.2.4.2. 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:

```
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*.

### 31.2.5. 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.

#### 31.2.5.1. 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**.

#### 31.2.5.2. 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: $-$
      ($shiftCount.intValue()*$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*.

31.2.5.3. 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*.

---

31.2.5.4. 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 excluded.
    d. Click the icon next to excluded, 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 + 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.

31.2.5.5. 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.

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.employeeroster  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:

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

   ```java
   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.

31.2.6. 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 Process Automation 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.

31.2.7. Configuring Solver termination for the employee rostering project
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 31.2.6, "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.

31.3. 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 31.1, "Deploying the employee rostering sample project in Business Central", or re-create the project, as described in Section 31.2, "Re-creating the employee rostering sample project".

31.3.1. 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:

**PUT**

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

Request body

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

### 31.3.2. 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:

```
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:

**POST**

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

Request body

```
<employeerostering.employeerostering.EmployeeRoster>
  <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>
  </employeeList>
</employeerostering.employeerostering.EmployeeRoster>
```
<employeerostering.employeerostering.Skill>
  <name>writing</name>
</employeerostering.employeerostering.Skill>
</employeerostering.employeerostering.Employee>
<employeerostering.employeerostering.Employee>
  <name>Petr</name>
  <skills>
    <employeerostering.employeerostering.Skill>
      <name>speaking</name>
    </employeerostering.employeerostering.Skill>
  </skills>
</employeerostering.employeerostering.Employee>
</employeeList>
<shiftList>
<employeerostering.employeerostering.Shift>
  <timeslot>
    <startTime>2017-01-01T00:00:00</startTime>
    <endTime>2017-01-01T01:00:00</endTime>
  </timeslot>
  <requiredSkill reference="../employeeList/employeeList/employeerostering.employeerostering.Employee/skills/employeerostering.employeerostering.Skill"/>
</employeerostering.employeerostering.Shift>
<employeerostering.employeerostering.Shift>
  <timeslot reference="../../employeerostering.employeerostering.Shift/timeslot"/>
</employeerostering.employeerostering.Shift>
<employeerostering.employeerostering.Shift>
  <timeslot reference="../../employeerostering.employeerostering.Shift/timeslot"/>
</employeerostering.employeerostering.Shift>
</shiftList>
<skillList>
</skillList>
<timeslotList>
<employeerostering.employeerostering.Timeslot reference="../shiftList/employeerostering.employeerostering.Shift/timeslot"/>
</timeslotList>
<dayOffRequestList/>
<shiftAssignmentList>
<employeerostering.employeerostering.ShiftAssignment>
  <shift reference="../shiftList/employeerostering.employeerostering.Shift"/>
</employeerostering.employeerostering.ShiftAssignment>
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>employeerostering</container-id>
  <solver-id>solver1</solver-id>
  <solver-config-file>employeerostering/employeerostering/EmployeeRosteringSolverConfig.solver.xml</solver-config-file>
  <status>NOT_SOLVING</status>
  <score scoreClass="org.optaplanner.core.api.score.buildin.hardsoft.HardSoftScore">0hard/0soft</score>
  <best-solution class="employeerostering.employeerostering.EmployeeRoster">
    <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>
          <employeerostering.employeerostering.Skill>
            <name>writing</name>
          </employeerostering.employeerostering.Skill>
        </skills>
      </employeerostering.employeerostering.Employee>
      <employeerostering.employeerostering.Employee>
        <name>Petr</name>
        <skills>
          <employeerostering.employeerostering.Skill>
            <name>speaking</name>
          </employeerostering.employeerosting.Skill>
        </skills>
      </employeerostering.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="../../../employeeList/employeerostering.employeerostering.Employee/skills/employeerostering.employeerostering.Skill"/>
</employeerostering.employeerostering.Shift>
<employeerostering.employeerostering.Shift>
	<timeslot reference="../../employeerostering.employeerostering.Shift/timeslot"/>
	<requiredSkill reference="../../../employeeList/employeerostering.employeerostering.Employee[3]/skills/employeerostering.employeerostering.Skill"/>
</employeerostering.employeerostering.Shift>
<employeerostering.employeerostering.Shift>
	<timeslot reference="../../employeerostering.employeerostering.Shift/timeslot"/>
</employeerostering.employeerostering.Shift>
</shiftList>
<skillList>
</skillList>
<timeslotList>
<employeerostering.employeerostering.Timeslot reference="../shiftList/employeerostering.employeerostering.Shift/timeslot"/>
</timeslotList>
<dayOffRequestList/>
<shiftAssignmentList/>
<score>0hard/0soft</score>
</best-solution>
</solver-instance>
CHAPTER 32. GETTING STARTED WITH JAVA SOLVERS: A CLOUD BALANCING EXAMPLE

An example demonstrates development of a basic Red Hat Business Optimizer solver using Java code.

Suppose your company owns a number of cloud computers and needs to run a number of processes on those computers. You must assign each process to a computer.

The following hard constraints must be fulfilled:

- Every computer must be able to handle the minimum hardware requirements of the sum of its processes:
  - **CPU capacity**: The CPU power of a computer must be at least the sum of the CPU power required by the processes assigned to that computer.
  - **Memory capacity**: The RAM memory of a computer must be at least the sum of the RAM memory required by the processes assigned to that computer.
  - **Network capacity**: The network bandwidth of a computer must be at least the sum of the network bandwidth required by the processes assigned to that computer.

The following soft constraints should be optimized:

- Each computer that has one or more processes assigned incurs a maintenance cost (which is fixed per computer).
  - **Cost**: Minimize the total maintenance cost.

This problem is a form of *bin packing*. In the following simplified example, we assign four processes to two computers with two constraints (CPU and RAM) with a simple algorithm:
The simple algorithm used here is the First Fit Decreasing algorithm, which assigns the bigger processes first and assigns the smaller processes to the remaining space. As you can see, it is not optimal, as it does not leave enough room to assign the yellow process D.

Business Optimizer finds a more optimal solution by using additional, smarter algorithms. It also scales: both in data (more processes, more computers) and constraints (more hardware requirements, other constraints).

The following summary applies to this example, as well as to an advanced implementation with more constraints that is described in Section 33.10, “Machine reassignment (Google ROADEF 2012)”: 
Cloud optimization

Assign processes to machines more efficiently.

CloudBalancing benchmark

Cloud hosting cost
OptaPlanner versus traditional algorithm with domain knowledge

Average: -18%

Min/Max: -16% to -21%
# datasets: 5
Biggest dataset: 1600 computers
4800 processes

5 mins Simulated Annealing vs First Fit Decreasing

MachineReassignment benchmark

Hardware congestion
OptaPlanner versus arbitrary feasible assignments

Average: -63%

Min/Max: -25% to -97%
# datasets: 20
Biggest dataset: 50k machines
5k processes

5 mins Tabu Search vs First Feasible Fit

Don't believe us? Run our open benchmarks yourself: http://www.optaplanner.org/code/benchmarks.html

Table 32.1. Cloud balancing problem size

<table>
<thead>
<tr>
<th>Problem size</th>
<th>Computers</th>
<th>Processes</th>
<th>Search space</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 computers-6 processes</td>
<td>2</td>
<td>6</td>
<td>64</td>
</tr>
<tr>
<td>3 computers-9 processes</td>
<td>3</td>
<td>9</td>
<td>10^4</td>
</tr>
<tr>
<td>4 computers-12 processes</td>
<td>4</td>
<td>12</td>
<td>10^7</td>
</tr>
<tr>
<td>100 computers-300 processes</td>
<td>100</td>
<td>300</td>
<td>10^600</td>
</tr>
<tr>
<td>200 computers-600 processes</td>
<td>200</td>
<td>600</td>
<td>10^1380</td>
</tr>
<tr>
<td>400 computers-1200 processes</td>
<td>400</td>
<td>1200</td>
<td>10^3122</td>
</tr>
<tr>
<td>800 computers-2400 processes</td>
<td>800</td>
<td>2400</td>
<td>10^6967</td>
</tr>
</tbody>
</table>

32.1. DOMAIN MODEL DESIGN
Using a domain model helps determine which classes are planning entities and which of their properties are planning variables. It also helps to simplify constraints, improve performance, and increase flexibility for future needs.

### 32.1.1. Designing a domain model

To create a domain model, define all the objects that represent the input data for the problem. In this example, the objects are processes and computers.

A separate object in the domain model must represent a full data set of the problem, which contains the input data as well as a solution. In this example, this object holds a list of computers and a list of processes. Each process is assigned to a computer; the distribution of processes between computers is the solution.

**Procedure**

1. Draw a class diagram of your domain model.
2. Normalize it to remove duplicate data.
3. Write down some sample instances for each class. Sample instances are entity properties that are relevant for planning purposes.
   - **Computer**: Represents a computer with certain hardware and maintenance costs.
     In this example, the sample instances for the *Computer* class are *cpuPower*, *memory*, *networkBandwidth*, and *cost*.
   - **Process**: Represents a process with a demand. Needs to be assigned to a *Computer* by Planner.
     Sample instances for *Process* are *requiredCpuPower*, *requiredMemory*, and *requiredNetworkBandwidth*.
   - **CloudBalance**: Represents the distribution of processes between computers. Contains every *Computer* and *Process* for a certain data set.
     For an object representing the full data set and solution, a sample instance holding the score must be present. Business Optimizer can calculate and compare the scores for different solutions; the solution with the highest score is the optimal solution. Therefore, the sample instance for *CloudBalance* is *score*.
4. Determine which relationships (or fields) change during planning:
   - **Planning entity**: The class (or classes) that Business Optimizer can change during solving. In this example, it is the class *Process*, because we can move processes to different computers.
     - A class representing input data that Business Optimizer can not change is known as a *problem fact*.
   - **Planning variable**: The property (or properties) of a planning entity class that changes during solving. In this example, it is the property *computer* on the class *Process*.
   - **Planning solution**: The class that represents a solution to the problem. This class must represent the full data set and contain all planning entities. In this example that is the class *CloudBalance*.

In the UML class diagram below, the Business Optimizer concepts are already annotated:
32.1.2. The Computer Class

The **Computer** class is a Java object that stores data, sometimes known as a POJO (Plain Old Java Object). Usually, you will have more of this kind of classes with input data.

**Example 32.1. CloudComputer.java**

```java
public class CloudComputer ... {
    private int cpuPower;
    private int memory;
    private int networkBandwidth;
    private int cost;
    ...
    // getters
}
```

32.1.3. The Process Class

The **Process** class is the class that is modified during solving.
We need to tell Business Optimizer that it can change the property `computer`. To do this, annotate the class with `@PlanningEntity` and annotate the `getComputer()` getter with `@PlanningVariable`.

Of course, the property `computer` needs a setter too, so Business Optimizer can change it during solving.

```java
@PlanningEntity(...) public class CloudProcess ...
{
   private int requiredCpuPower;
   private int requiredMemory;
   private int requiredNetworkBandwidth;

   private CloudComputer computer;

   ... // getters

   @PlanningVariable(valueRangeProviderRefs = {"computerRange"})
   public CloudComputer getComputer() {
      return computer;
   }

   public void setComputer(CloudComputer computer) {
      computer = computer;
   }

   // Complex methods
   // ...
}
```

Business Optimizer needs to know which values it can choose from to assign to the property `computer`. Those values are retrieved from the method `CloudBalance.getComputerList()` on the planning solution, which returns a list of all computers in the current data set.

The `@PlanningVariable`'s `valueRangeProviderRefs` parameter on `CloudProcess.getComputer()` needs to match with the `@ValueRangeProvider`'s `id` on `CloudBalance.getComputerList()`.

**NOTE**

You can also use annotations on fields instead of getters.

### 32.1.4. The CloudBalance Class

The `CloudBalance` class has a `@PlanningSolution` annotation.

This class holds a list of all computers and processes. It represents both the planning problem and (if it is initialized) the planning solution.
The **CloudBalance** class has the following key attributes:

- It holds a collection of processes that Business Optimizer can change. We annotate the getter `getProcessList()` with `@PlanningEntityCollectionProperty`, so that Business Optimizer can retrieve the processes that it can change. To save a solution, Business Optimizer initializes a new instance of the class with the list of changed processes.

  1. It also has a `@PlanningScore` annotated property `score`, which is the **Score** of that solution in its current state. Business Optimizer automatically updates it when it calculates a **Score** for a solution instance; therefore, this property needs a setter.

  2. Especially for score calculation with Drools, the property `computerList` needs to be annotated with a `@ProblemFactCollectionProperty` so that Business Optimizer can retrieve a list of computers (problem facts) and make it available to the decision engine.

**Example 32.3. CloudBalance.java**

```java
@PlanningSolution
class CloudBalance {

    private List<CloudComputer> computerList;
    private List<CloudProcess> processList;
    private HardSoftScore score;

    @ValueRangeProvider(id = "computerRange")
    @ProblemFactCollectionProperty
    public List<CloudComputer> getComputerList() {
        return computerList;
    }

    @PlanningEntityCollectionProperty
    public List<CloudProcess> getProcessList() {
        return processList;
    }

    @PlanningScore
    public HardSoftScore getScore() {
        return score;
    }

    public void setScore(HardSoftScore score) {
        this.score = score;
    }

    ...
}
```

### 32.2. RUNNING THE CLOUD BALANCING HELLO WORLD

You can run a sample "hello world" application to demonstrate the solver.
Procedure

1. Download and configure the examples in your preferred IDE. For instructions on downloading and configuring examples in an IDE, see Section 33.1.3, “Running the Red Hat Business Optimizer examples in an IDE (IntelliJ, Eclipse, or Netbeans)”.

2. Create a run configuration with the following main class:

```
org.optaplanner.examples.cloudbalancing.app.CloudBalancingHelloWorld
```

By default, the Cloud Balancing Hello World is configured to run for 120 seconds.

Result

The application executes the following code:

```
Example 32.4. CloudBalancingHelloWorld.java

public class CloudBalancingHelloWorld {

    public static void main(String[] args) {
        // Build the Solver
        SolverFactory<CloudBalance> solverFactory = SolverFactory.createFromXmlResource("org/optaplanner/examples/cloudbalancing/solver/cloudBalancingSolverConfig.xml");
        Solver<CloudBalance> solver = solverFactory.buildSolver();

        // Load a problem with 400 computers and 1200 processes
        CloudBalance unsolvedCloudBalance = new CloudBalancingGenerator().createCloudBalance(400, 1200);

        // Solve the problem
        CloudBalance solvedCloudBalance = solver.solve(unsolvedCloudBalance);

        // Display the result
        System.out.println("Solved cloudBalance with 400 computers and 1200 processes:
                        "+ toDisplayString(solvedCloudBalance));
    }

    ...
}
```

The code example does the following:

1. Build the **Solver** based on a solver configuration (in this case an XML file, `cloudBalancingSolverConfig.xml`, from the classpath). Building the **Solver** is the most complicated part of this procedure. For more details, see Section 32.3, “Solver Configuration”.

```
SolverFactory<CloudBalance> solverFactory = SolverFactory.createFromXmlResource("org/optaplanner/examples/cloudbalancing/solver/cloudBalancingSolverConfig.xml");
Solver solver<CloudBalance> = solverFactory.buildSolver();
```

2. Load the problem.
CloudBalancingGenerator generates a random problem: you will replace this with a class that loads a real problem, for example from a database.

```java
CloudBalance unsolvedCloudBalance = new CloudBalancingGenerator().createCloudBalance(400, 1200);
```

3. Solve the problem.

```java
CloudBalance solvedCloudBalance = solver.solve(unsolvedCloudBalance);
```

4. Display the result.

```java
System.out.println("Solved cloudBalance with 400 computers and 1200 processes:
    + toDisplayString(solvedCloudBalance));
```

### 32.3. SOLVER CONFIGURATION

The solver configuration file determines how the solving process works; it is considered a part of the code. The file is named `examples/sources/src/main/resources/org/optaplanner/examples/cloudbalancing/solver/cloudBalancingSolverConfig.xml`.

#### Example 32.5. cloudBalancingSolverConfig.xml

```xml
<?xml version="1.0" encoding="UTF-8"?>
<solver>
  <!-- Domain model configuration -->
  <scanAnnotatedClasses/>

  <!-- Score configuration -->
  <scoreDirectorFactory>
    <easyScoreCalculatorClass>org.optaplanner.examples.cloudbalancing.optional.score.CloudBalancingEasyScoreCalculator</easyScoreCalculatorClass>
  </scoreDirectorFactory>

  <!-- Optimization algorithms configuration -->
  <termination>
    <secondsSpentLimit>30</secondsSpentLimit>
  </termination>
</solver>
```

This solver configuration consists of three parts:

1. **Domain model configuration**: *What can Business Optimizer change?*
   
   We need to make Business Optimizer aware of our domain classes. In this configuration, it will automatically scan all classes in your classpath (for a `@PlanningEntity` or `@PlanningSolution` annotation):
<scanAnnotatedClasses/>

2. **Score configuration**: *How should Business Optimizer optimize the planning variables? What is our goal?*
   Since we have hard and soft constraints, we use a **HardSoftScore**. But we need to tell Business Optimizer how to calculate the score, depending on our business requirements. Further down, we will look into two alternatives to calculate the score: using a basic Java implementation and using Drools DRL.

   ```xml
   <scoreDirectorFactory>
       <easyScoreCalculatorClass>org.optaplanner.examples.cloudbalancing.optional.score.CloudBalancingEasyScoreCalculator</easyScoreCalculatorClass>
       <!--
       <scoreDrl>org/optaplanner/examples/cloudbalancing/solver/cloudBalancingScoreRules.drl</scoreDrl>
     -->
   </scoreDirectorFactory>
   ```

3. **Optimization algorithms configuration**: *How should Business Optimizer optimize it?* In this case, we use the default optimization algorithms (because no explicit optimization algorithms are configured) for 30 seconds:

   ```xml
   <termination>
       <secondsSpentLimit>30</secondsSpentLimit>
   </termination>
   ```
   Business Optimizer should get a good result in seconds (and even in less than 15 milliseconds if the real-time planning feature is used), but the more time it has, the better the result will be. Advanced use cases might use different termination criteria than a hard time limit.

   The default algorithms will already easily surpass human planners and most in-house implementations. You can use the advanced Benchmarker feature to power tweak to get even better results.

---

### 32.4. SCORE CONFIGURATION

Business Optimizer will search for the **Solution** with the highest **Score**. This example uses a **HardSoftScore**, which means Business Optimizer will look for the solution with no hard constraints broken (fulfill hardware requirements) and as little as possible soft constraints broken (minimize maintenance cost).
Of course, Business Optimizer needs to be told about these domain-specific score constraints. You can define constraints using the Java or Drools languages.

32.4.1. Configuring score calculation using Java

One way to define a score function is to implement the interface `EasyScoreCalculator` in plain Java.

Procedure

1. In the `cloudBalancingSolverConfig.xml` file, add or uncomment the setting:

```xml
<scoreDirectorFactory>
  <easyScoreCalculatorClass>org.optaplanner.examples.cloudbalancing.optional.score.CloudBalancingEasyScoreCalculator</easyScoreCalculatorClass>
</scoreDirectorFactory>
```

2. Implement the `calculateScore(Solution)` method to return a `HardSoftScore` instance.

Example 32.6. CloudBalancingEasyScoreCalculator.java

```java
public class CloudBalancingEasyScoreCalculator implements EasyScoreCalculator<CloudBalance> {

    /**
     * A very simple implementation. The double loop can easily be removed by using Maps as shown in
     */
```
Even if we optimize the code above to use Maps to iterate through the `processList` only once, it is still slow because it does not do incremental score calculation.

To fix that, either use incremental Java score calculation or Drools score calculation. Incremental Java score calculation is not covered in this guide.

### 32.4.2. Configuring score calculation using Drools

```java
public HardSoftScore calculateScore(CloudBalance cloudBalance) {
    int hardScore = 0;
    int softScore = 0;
    for (CloudComputer computer : cloudBalance.getComputerList()) {
        int cpuPowerUsage = 0;
        int memoryUsage = 0;
        int networkBandwidthUsage = 0;
        boolean used = false;

        // Calculate usage
        for (CloudProcess process : cloudBalance.getProcessList()) {
            if (computer.equals(process.getComputer())) {
                cpuPowerUsage += process.getRequiredCpuPower();
                memoryUsage += process.getRequiredMemory();
                networkBandwidthUsage += process.getRequiredNetworkBandwidth();
                used = true;
            }
        }

        // Hard constraints
        int cpuPowerAvailable = computer.getCpuPower() - cpuPowerUsage;
        if (cpuPowerAvailable < 0) {
            hardScore += cpuPowerAvailable;
        }
        int memoryAvailable = computer.getMemory() - memoryUsage;
        if (memoryAvailable < 0) {
            hardScore += memoryAvailable;
        }
        int networkBandwidthAvailable = computer.getNetworkBandwidth() -
                                       networkBandwidthUsage;
        if (networkBandwidthAvailable < 0) {
            hardScore += networkBandwidthAvailable;
        }

        // Soft constraints
        if (used) {
            softScore -= computer.getCost();
        }
    }
    return HardSoftScore.valueOf(hardScore, softScore);
}
```
You can use Drools rule language (DRL) to define constraints. Drools score calculation uses incremental calculation, where every score constraint is written as one or more score rules.

Using the decision engine for score calculation enables you to integrate with other Drools technologies, such as decision tables (XLS or web based), Business Central, and other supported features.

Procedure

1. Add a `scoreDrl` resource in the classpath to use the decision engine as a score function. In the `cloudBalancingSolverConfig.xml` file, add or uncomment the setting:

   ```xml
   <scoreDirectorFactory>
     <scoreDrl>org/optaplanner/examples/cloudbalancing/solver/cloudBalancingScoreRules.drl</scoreDrl>
     </scoreDirectorFactory>
   ```

2. Create the hard constraints. These constraints ensure that all computers have enough CPU, RAM and network bandwidth to support all their processes:

   **Example 32.7. cloudBalancingScoreRules.drl - Hard Constraints**

   ```drl
   import org.optaplanner.examples.cloudbalancing.domain.CloudBalance;
   import org.optaplanner.examples.cloudbalancing.domain.CloudComputer;
   import org.optaplanner.examples.cloudbalancing.domain.CloudProcess;

   global HardSoftScoreHolder scoreHolder;

   // ###################################################################
   // Hard constraints
   // ###################################################################

   rule "requiredCpuPowerTotal"
     when
       $computer : CloudComputer($cpuPower : cpuPower)
     accumulate(
         CloudProcess(
             computer == $computer,
             $requiredCpuPower : requiredCpuPower);
         $requiredCpuPowerTotal : sum($requiredCpuPower);
         $requiredCpuPowerTotal > $cpuPower
     )
     then
       scoreHolder.addHardConstraintMatch(kcontext, $cpuPower - $requiredCpuPowerTotal);
     end

   rule "requiredMemoryTotal"
     ... end
3. Create a soft constraint. This constraint minimizes the maintenance cost. It is applied only if hard constraints are met:

**Example 32.8. cloudBalancingScoreRules.drl - Soft Constraints**

```drl
//
########################################################################
####
// Soft constraints
#
########################################################################
####

rule "computerCost"
    when
      $computer : CloudComputer($cost : cost)
      exists CloudProcess(computer == $computer)
    then
      scoreHolder.addSoftConstraintMatch(kcontext, - $cost);
end
```

### 32.5. FURTHER DEVELOPMENT OF THE SOLVER

Now that this example works, you can try developing it further. For example, you can enrich the domain model and add extra constraints such as these:

- Each **Process** belongs to a **Service**. A computer might crash, so processes running the same service should (or must) be assigned to different computers.

- Each **Computer** is located in a **Building**. A building might burn down, so processes of the same services should (or must) be assigned to computers in different buildings.
CHAPTER 33. EXAMPLES PROVIDED WITH RED HAT BUSINESS OPTIMIZER

Several Red Hat Business Optimizer examples are shipped with Red Hat Process Automation 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 Process Automation Manager distribution.

33.1. DOWNLOADING AND RUNNING THE EXAMPLES

You can download the Red Hat Business Optimizer examples from the Red Hat Software Downloads website and run them.

33.1.1. Downloading Red Hat Business Optimizer examples

You can download the examples as a part of the Red Hat Process Automation Manager add-ons package.

Procedure

1. Download the `rhpam-7.10.0-add-ons.zip` file from the Software Downloads page.
2. Decompress the file.
3. Decompress the `rhpam-7.10-planner-engine.zip` file from the decompressed directory.

Result

In the decompressed `rhpam-7.10-planner-engine` directory, you can find example source code under the following subdirectories:

- `examples/sources/src/main/java/org/optaplanner/examples`
- `examples/sources/src/main/resources/org/optaplanner/examples`
- `webexamples/sources/src/main/java/org/optaplanner/examples`
- `webexamples/sources/src/main/resources/org/optaplanner/examples`

The table of examples in Section 33.2, “Table of Business Optimizer examples” lists directory names that are used for individual examples.

33.1.2. Running Business Optimizer examples

Red Hat Business Optimizer includes a number of examples to demonstrate a variety of use cases.

Prerequisites

- You have downloaded and decompressed the examples. For instructions about these actions, see Section 33.1.1, “Downloading Red Hat Business Optimizer examples”.

Procedure

1. In the `rhpam-7.10.0-planner-engine` folder, open the `examples` directory and use the appropriate script to run the examples:
Linux or Mac:

$ cd examples
$ ./runExamples.sh

Windows:

$ cd examples
$ runExamples.bat

Select and run an example from the GUI application window:

NOTE

Red Hat Business Optimizer itself has no GUI dependencies. It runs just as well on a server or a mobile JVM as it does on the desktop.

33.1.3. Running the Red Hat Business Optimizer 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 Red Hat Business Optimizer examples within your development environment.

Prerequisites

- You have downloaded and extracted the examples. For instructions about these actions, see Section 33.1.1, "Downloading Red Hat Business Optimizer examples".
Procedure

1. Open the Red Hat Business Optimizer 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 directory `examples/sources`.

2. Add all the JARs to the classpath from the directory `binaries` and the directory `examples/binaries`, except for the `examples/binaries/optaplanner-examples-*.jar` file.

3. Add the Java source directory `src/main/java` and the Java resources directory `src/main/resources`.

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.

33.1.4. Running the web examples

Besides the GUI examples, Red Hat Process Automation Manager also includes a set of web examples for Red Hat Business Optimizer. The web examples include:

- Vehicle routing: Calculating the shortest possible route to pick up all items required for a number of different customers using either Leaflet or Google Maps visualizations.
- Cloud balancing: Assigning processes across computers with different specifications and costs.

Prerequisites

- You have downloaded and extracted the Red Hat Business Optimizer examples from the Red Hat Process Automation Manager add-ons package. For instructions, see Section 33.1.1, "Downloading Red Hat Business Optimizer examples".

The web examples require several JEE APIs to run, such as the following APIs:

- Servlet
- JAX-RS
- CDI

These APIs are not required for Business Optimizer itself.

Procedure

1. Download a JEE application server, such as JBoss EAP or WildFly and unzip it.
2. In the decompressed **rhpam-7.10.0-planner-engine** directory, open the subdirectory **webexamples/binaries** and deploy the **optaplanner-webexamples-*.war** file on the JEE application server. If using JBoss EAP in standalone mode, this can be done by adding the **optaplanner-webexamples-*.war** file to the **JBOSS_HOME/standalone/deployments** folder.

3. Open the following address in a web browser: http://localhost:8080/optaplanner-webexamples/.

### 33.2. TABLE OF BUSINESS OPTIMIZER EXAMPLES

Some of the Business Optimizer 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**:  

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 Business Optimizer with competitive software and academic research.

**Table 33.1. Examples overview**

<table>
<thead>
<tr>
<th>Example</th>
<th>Domain</th>
<th>Size</th>
<th>Contest</th>
<th>Directory name</th>
</tr>
</thead>
<tbody>
<tr>
<td>N queens</td>
<td>1 entity class</td>
<td>Entity = 256</td>
<td>Pointless (cheatable)</td>
<td>nqueens</td>
</tr>
<tr>
<td></td>
<td>(1 variable)</td>
<td>Value = 256</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space  = 10^616</td>
<td></td>
<td></td>
</tr>
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<td>1 entity class</td>
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<td>No (Defined by us)</td>
<td>cloudbalancing</td>
</tr>
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<td></td>
</tr>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Traveling</td>
<td>1 entity class</td>
<td>Entity = 980</td>
<td>Unrealistic TSP web</td>
<td>tsp</td>
</tr>
<tr>
<td>salesman</td>
<td>(1 chained variable)</td>
<td>Value = 980</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space  = 10^2504</td>
<td></td>
<td></td>
</tr>
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<td>Example</td>
<td>Domain</td>
<td>Size</td>
<td>Contest</td>
<td>Directory name</td>
</tr>
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<td>---------------------------</td>
<td>--------------------</td>
<td>-------------------------</td>
</tr>
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<td>Dinner party</td>
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<td>Tennis club scheduling</td>
<td>1 entity class</td>
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<td>No (Defined by us)</td>
<td>tennis</td>
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<td></td>
</tr>
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<td>Value $\leftarrow 25$ and $\leftarrow 20$</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Search space $\leftarrow 10^{1171}$</td>
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</tr>
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<td></td>
</tr>
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<td>Unrealistic VRP web</td>
<td>vehiclerouting</td>
</tr>
<tr>
<td></td>
<td>(1 chained variable)</td>
<td>Value $\leftarrow 2795$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 shadow entity class</td>
<td>Search space $\leftarrow 10^{8380}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 automatic shadow variable)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle routing with time windows</td>
<td>All of Vehicle routing</td>
<td>Entity $\leftarrow 2740$</td>
<td>Unrealistic VRP web</td>
<td>vehiclerouting</td>
</tr>
<tr>
<td></td>
<td>(1 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>Example</td>
<td>Domain</td>
<td>Size</td>
<td>Contest</td>
<td>Directory name</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------</td>
<td>-----------------------</td>
<td>-----------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Project job scheduling</td>
<td>1 entity class</td>
<td>Entity ⇐ 640</td>
<td>Nearly realistic MISTA 2013</td>
<td>projectjobscheduling</td>
</tr>
<tr>
<td></td>
<td>(2 variables)</td>
<td>Value ⇐ ? and ⇐ ?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 shadow variable)</td>
<td>Search space ⇐ ?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task assigning</td>
<td>1 entity class</td>
<td>Entity ⇐ 500</td>
<td>No Defined by us</td>
<td>taskassigning</td>
</tr>
<tr>
<td></td>
<td>(1 chained variable)</td>
<td>Value ⇐ 520</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 shadow variable)</td>
<td>Search space ⇐ 10^1168</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 shadow entity class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 automatic shadow variable)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exam timetabling</td>
<td>2 entity classes (same hierarchy)</td>
<td>Entity ⇐ 1096</td>
<td>Realistic ITC 2007 track 1</td>
<td>examination</td>
</tr>
<tr>
<td></td>
<td>(2 variables)</td>
<td>Value ⇐ 80 and ⇐ 49</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space ⇐ 10^3374</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nurse rostering</td>
<td>1 entity class</td>
<td>Entity ⇐ 752</td>
<td>Realistic INRC 2010</td>
<td>nurserostering</td>
</tr>
<tr>
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<td>Value ⇐ 50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space ⇐ 10^1277</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traveling tournament</td>
<td>1 entity class</td>
<td>Entity ⇐ 1560</td>
<td>Unrealistic TTP</td>
<td>travelingtournament</td>
</tr>
<tr>
<td></td>
<td>(1 variable)</td>
<td>Value ⇐ 78</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space ⇐ 10^2301</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheap time scheduling</td>
<td>1 entity class</td>
<td>Entity ⇐ 500</td>
<td>Nearly realistic ICON Energy</td>
<td>cheaptimescheduling</td>
</tr>
<tr>
<td></td>
<td>(2 variables)</td>
<td>Value ⇐ 100 and ⇐ 288</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space ⇐ 10^20078</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>1 entity class</td>
<td>Entity ⇐ 11</td>
<td>No Defined by us</td>
<td>investment</td>
</tr>
<tr>
<td></td>
<td>(1 variable)</td>
<td>Value ⇐ 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space ⇐ 10^4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example</td>
<td>Domain</td>
<td>Size</td>
<td>Contest</td>
<td>Directory name</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------</td>
<td>--------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Conferencescheduling</td>
<td>1 entity class (2 variables)</td>
<td>Entity $\equiv 216$</td>
<td>No Defined by us</td>
<td>conferencescheduling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value $\equiv 18$ and $\equiv 20$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\equiv 10^{552}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock tour</td>
<td>1 entity class (1 chained variable) (4 shadow variables) 1 shadow entity class (1 automatic shadow variable)</td>
<td>Entity $\equiv 47$</td>
<td>No Defined by us</td>
<td>rocktour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value $\equiv 48$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\equiv 10^{59}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight crew scheduling</td>
<td>1 entity class (1 variable) 1 shadow entity class (1 automatic shadow variable)</td>
<td>Entity $\equiv 4375$</td>
<td>No Defined by us</td>
<td>flightcrewscheduling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value $\equiv 750$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search space $\equiv 10^{12578}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

33.3. N QUEENS

Place $n$ queens on a $n$ 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 33.1. 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 33.2. A correct solution for the Four queens puzzle**

![Diagram showing a correct solution for the Four queens puzzle]

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 given n, not on finding the number of possible correct solutions for a given n.

**Problem size**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Search Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>4queens</td>
<td>has 4</td>
<td>256</td>
</tr>
<tr>
<td>8queens</td>
<td>has 8</td>
<td>$10^7$</td>
</tr>
<tr>
<td>16queens</td>
<td>has 16</td>
<td>$10^{19}$</td>
</tr>
<tr>
<td>32queens</td>
<td>has 32</td>
<td>$10^{48}$</td>
</tr>
<tr>
<td>64queens</td>
<td>has 64</td>
<td>$10^{115}$</td>
</tr>
<tr>
<td>256queens</td>
<td>has 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.

**33.3.1. 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 {
```

---

CHAPTER 33. EXAMPLES PROVIDED WITH RED HAT BUSINESS OPTIMIZER

---

165
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, NQueens’s getN() method will always return four.
Figure 33.3. A solution for Four Queens

Table 33.2. 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.

33.4. CLOUD BALANCING

For information about this example, see Chapter 32, Getting started with Java solvers: A cloud balancing example.

33.5. 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:

**TSP optimal solution volatility**

*How much does the optimal solution change if we add 1 new location?*

---

33.6. DINNER PARTY

Miss Manners is throwing another dinner party.

- This time she invited 144 guests and prepared 12 round tables with 12 seats each.
- Every guest should sit next to someone (left and right) of the opposite gender.
- And that neighbour should have at least one hobby in common with the guest.
- At every table, there should be two politicians, two doctors, two socialites, two coaches, two teachers and two programmers.
- And the two politicians, two doctors, two coaches and two programmers should not be the same kind at a table.

Drools Expert also has the normal Miss Manners example (which is much smaller) and employs an exhaustive heuristic to solve it. Planner’s implementation is far more scalable because it uses heuristics to find the best solution and Drools Expert to calculate the score of each solution.

Problem size
wedding01 has 18 jobs, 144 guests, 288 hobby practicians, 12 tables and 144 seats with a search space of $10^{310}$.

### 33.7. 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 unavailabilityPenalties and 72 teamAssignments with a search space of $10^{60}$. 
33.8. 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 $10^{3285}$.

33.9. COURSE TIMETABLEING (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 $10^{722}$.
33.10. MACHINE REASSIGNMENT (GOOGLE ROADEF 2012)

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

![Cloud optimization diagram]

The diagram compares the Traditional algorithm (Construction Heuristic) with the OptaPlanner (Construction Heuristic + Local Search) for cloud optimization.
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 $10^{10000}$. 
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 6 resources, 5 neighborhoods, 50 locations, 4000 machines, 15050 services, 40000 processes and 1 balancePenalties with a search space of $10^{150000}$.
model_b_9 has 3 resources, 5 neighborhoods, 10 locations, 100 machines, 45030 services, 50000 processes and 1 balancePenalties with a search space of $10^{184948}$.
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 33.7. Domain model

33.11. 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 timewindowed variant (CVRPTW) are defined by the VRP web.

**Figure 33.8. 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

**Driving time**

OptaPlanner versus traditional algorithm with domain knowledge

```
<table>
<thead>
<tr>
<th>VehicleRouting benchmark (Belgium datasets)</th>
<th>Average</th>
<th>Mini/Max</th>
<th># datasets</th>
<th>Biggest dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving time</td>
<td>-15%</td>
<td>-9% to -18%</td>
<td>5</td>
<td>2750 deliveries</td>
</tr>
</tbody>
</table>
```

Don't believe us? Run our open benchmarks yourself: http://www.optaplanner.org/code/benchmarks.html

**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 $10^{8380}$. 

178
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-n100-k10 has 3 depots, 10 vehicles and 97 customers with a search space of 10^170.
belgium-tw-d5-n500-k20 has 5 depots, 20 vehicles and 495 customers with a search space of 10^1168.
belgium-tw-d8-n1000-k20 has 8 depots, 20 vehicles and 992 customers with a search space of 10^2607.
belgium-tw-d10-n2750-k55 has 10 depots, 55 vehicles and 2740 customers with a search space of 10^8380.
belgium-tw-n50-k10 has 1 depots, 10 vehicles and 49 customers with a search space of 10^74.
belgium-tw-n100-k10 has 1 depots, 10 vehicles and 99 customers with a search space of 10^170.
belgium-tw-n500-k20 has 1 depots, 20 vehicles and 499 customers with a search space of 10^1168.
belgium-tw-n1000-k20 has 1 depots, 20 vehicles and 999 customers with a search space of 10^2607.
belgium-tw-n2750-k55 has 1 depots, 55 vehicles and 2749 customers with a search space of 10^8380.

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

Homberger_0200_C1_2_1 has 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0200_C2_2_1 has 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0200_R1_2_1 has 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0200_R2_2_1 has 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0200_RC1_2_1 has 1 depots, 50 vehicles and 200 customers with a search space of 10^429.
Homberger_0200_RC2_2_1 has 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 $10^{2840}$.

33.11.1. Domain model for Vehicle routing
The vehicle routing with timewindows 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).
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: the optaplanner-webexamples-*.war has an example which demonstrates such rendering:
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 Planner. For example, GraphHopper etc 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 Planner: 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.

33.12. 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.
Project job scheduling

For each job, choose an execution mode and a start time.

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.

### 33.13. 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 33.9. Value proposition**

**Task assigning**

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

**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 $10^{1168}$. 
33.14. 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 Planner. 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>
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<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>
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<td>934</td>
<td>36</td>
<td>48</td>
<td>168</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>
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<td>22</td>
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<tr>
<td>exam_comp_set7</td>
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<td>598</td>
<td>80</td>
<td>8</td>
<td>20</td>
<td>1</td>
<td>$10^{1678}$</td>
</tr>
</tbody>
</table>

**33.14.1. Domain model for Exam timetabling**

The following diagram shows the main examination domain classes:
Figure 33.11. Examination domain class diagram

Notice that we’ve split 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).

33.15. NURSE ROSTERING (INRC 2010)

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

Populate each work shift with a nurse.

Maternity nurses
- A: Ann
- B: Beth
- C: Cory

Emergency nurses
- D: Dan
- E: Elin
- G: Greg

Basic nurses
- H: Hue
- I: Ilse

Largest staff first

<table>
<thead>
<tr>
<th></th>
<th>Sat 6</th>
<th>Mon 14</th>
<th>Sun 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternity nurses</td>
<td>1 2</td>
<td>1 1</td>
<td>2 1</td>
</tr>
<tr>
<td></td>
<td>C A</td>
<td>C A</td>
<td>A C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency nurses</td>
<td>2 1</td>
<td>1 1</td>
<td>2 1</td>
</tr>
<tr>
<td></td>
<td>D G</td>
<td>D E</td>
<td>D G</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any nurses</td>
<td>1 1</td>
<td>1 1</td>
<td>1 1</td>
</tr>
<tr>
<td></td>
<td>H I</td>
<td>H I</td>
<td>H I</td>
</tr>
</tbody>
</table>

OptaPlanner

<table>
<thead>
<tr>
<th></th>
<th>Sat 6</th>
<th>Mon 14</th>
<th>Sun 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternity nurses</td>
<td>1 2</td>
<td>1 1</td>
<td>2 1</td>
</tr>
<tr>
<td></td>
<td>C A</td>
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<td></td>
</tr>
<tr>
<td>Any nurses</td>
<td>1 1</td>
<td>1 1</td>
<td>1 1</td>
</tr>
<tr>
<td></td>
<td>H I</td>
<td>H I</td>
<td>H I</td>
</tr>
</tbody>
</table>

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.
- **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 33.12. Value proposition**

Employee rostering
Assign shifts to employees more efficiently.

<table>
<thead>
<tr>
<th>Employees</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon 6 14 22</td>
<td>Hospitals</td>
</tr>
<tr>
<td>Tue 6 14 22</td>
<td>Security</td>
</tr>
<tr>
<td>Wed 6 14 22</td>
<td>guard firms</td>
</tr>
<tr>
<td>Thu 6 14 22</td>
<td>Call centers</td>
</tr>
<tr>
<td>Fri 6 14 22</td>
<td>Police and</td>
</tr>
<tr>
<td>Sat 6 14 22</td>
<td>fire department</td>
</tr>
</tbody>
</table>

NurseRostering benchmark  
Employee well-being +53%  
OptaPlanner versus traditional algorithm with domain knowledge

Average Min/Max # datasets Biggest dataset
+19% 752 assignments 50 employees
+85% 26 drivers

Don't believe us? Run our open benchmarks yourself: 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, 3 shiftTypes, 4 patterns, 3 contracts, 10 employees, 28 shiftDates, 144 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, 152 shiftAssignments and 150 requests with a search space of $10^{152}$.

sprint_late04 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_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 $10^{1257}$. 

Figure 33.13. Domain model
33.16. TRAVELING TOURNAMENT PROBLEM (TTP)

Schedule matches between $n$ 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).

**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 $10^{2301}$. |

### 33.17. 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 inflicted.

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 $10^{7807}$.
instance36 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7814}$.
instance37 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7764}$.
instance38 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7736}$.
instance39 has 4 resources, 80 machines, 288 periods and 2000 tasks with a search space of $10^{7783}$. 
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 $10^{20078}$.

### 33.18. 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](#).

### 33.19. CONFERENCE SCHEDULING

Assign each conference talk to a timeslot and a room. Timeslots can overlap. Read/write to/from an *xlsx* file that can be edited with LibreOffice or Excel too.
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 his/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 his/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 his/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 his/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 same 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 his/her talks should be assigned to a timeslot with that tag.
  - Speaker undesired timeslot tag: If a speaker has an undesired timeslot tag, then all his/her talks should not 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 his/her talks should be assigned to a room with that tag.
  - Speaker undesired room tag: If a speaker has an undesired room tag, then all his/her talks should not 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 same theme tag or content tag should be scheduled in the minimum number of days (ideally in the same day).
Conference scheduling

Optimize attendee experience when assigning each talk to a room and a timeslot.

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 $10^{552}$.

33.20. ROCK TOUR

Drive the rock 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 $10^{59}$.

33.21. 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-7days-Europe has 2 skills, 50 airports, 150 employees, 175 flights and 875 flight assignments with a search space of $10^{1904}$.
700 flights-28days-Europe has 2 skills, 50 airports, 150 employees, 700 flights and 3500 flight assignments with a search space of $10^{7616}$.
875 flights-7days-Europe has 2 skills, 50 airports, 750 employees, 875 flights and 4375 flight assignments with a search space of $10^{12578}$.
175 flights-7days-US has 2 skills, 48 airports, 150 employees, 175 flights and 875 flight assignments with a search space of $10^{1904}$. 
APPENDIX A. VERSIONING INFORMATION

Documentation last updated on Wednesday, May 5, 2021.
APPENDIX B. CONTACT INFORMATION

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