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Integrating rules and automated planning in business processes

by

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Juby Joseph Ninan
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Abstract

Healthcare organizations are investigating the use of workflow management systems to support care processes. However the typical workflow management support systems fall short with regard to providing flexibility and they typically do not deal with the planning and scheduling of healthcare resources. Due to the complex and dynamic nature of healthcare processes, flexibility is an important issue to be considered when using systems that automate the flow of activities in the healthcare environment. Additionally, since the performance of processes in terms of cost and time depends largely on the availability and capacity of resources, resource planning is an important issue to be considered when executing processes. This thesis will demonstrate how flexibility by design and flexibility by under-specification can be achieved by combining processes with rules. Furthermore, we will show how resources can be allocated to healthcare processes by integrating them with an automated planning system. To do this, the KIE group of open-source java projects developed by the Red Hat JBoss Community will be used, specifically the jBPM project for business process management, the Drools project for business rule management and OptaPlanner, a framework to solve planning problems. In order to use these projects, various technical issues had to be overcome, mostly regarding jBPM. Many problems were identified and documented during modeling, execution and simulations of processes. Some of these problems were also reported to the developers of the JBoss community and fixes in later versions were also tested.

Contents

List of figures

List of tables

1 Introduction

This chapter introduces the background and the problem context for this research in Section 1.1 and Section 1.2 respectively. Then the main purpose of this study is explained in Section 1.3 and the main research questions are formulated in Section 1.4. The research approach and scope is discussed in Section 1.5 and Section 1.6 respectively. Finally this chapter concludes with the outline on how this report is structured in Section 1.7.

1.1 Background

Despite the unprecedented rate of advancements in medical science and technology, healthcare organizations are constantly facing the challenge of ensuring clinical excellence and providing quality services to their patients, while reducing operational costs [1]. A recent study on the global outlook of healthcare identified some major issues that health care providers will face in 2014. These include a growing aging population and a rising prevalence of chronic diseases which are expected to drive the demand for healthcare services. This growing demand is likely to result in a surge in healthcare costs, an uneven quality of clinical care being delivered and an imbalance in access to care due to workforce shortages [2].

Due to these increasing healthcare demands, hospitals have to streamline their processes to deliver high quality clinical care while simultaneously reducing costs. Here workflow technology can be used to provide support for controlling and monitoring healthcare processes [3]. Workflow Management Systems (WfMS) can be used to support healthcare processes by managing the temporal order and correct coordination of various activities in the process [4]. Studies have shown that implementing clinical care pathways (evidence based protocols) using WfMS have led to significant improvements in clinical care performance and reduced costs of care due to shorter length of stay and decrease in the number of laboratory tests, consultation and imaging procedures [5], [6].

However, attempting to automate the flow of clinical processes can lead to many problems, because such processes are complex, diverse and require considerable flexibility [7], [3]. A different number of examinations and treatments may be required even for a group of patients with the same diagnosis. Additionally, the order in which these examinations and treatments are carried out may also vary. The care process for a patient needs to be adapted based on inferences derived from the patient's medical history, intermediary test results, or in response to the way the patient reacts to the specific prescriptions or treatments [3]. The use of workflow technologies in the healthcare domain has often been critiqued due to the rigidity enforced by first generation WfMS, which restrict hospitals from reacting to process changes and exceptional situations in an agile manner [7]. Since variations in the course of a disease or treatment process are very common in the clinical environment, there is a need for designing flexible workflows [4], [7].

Another limitation inherent in existing WfMS is that they do not deal with the planning and scheduling of resources (resource management/resource allocation) [8]. Even with limited resources, business processes are expected to be executed within short time periods and at lower costs. This is especially true for healthcare institutes that are under increasing pressure to deliver better services to more people using limited financial and human resources [9]. When designing systems to control and monitor processes, it is important to consider how resources should be allocated based on their periodic availability, fair usage and in a manner to balance the distribution of their workload [10].

Currently, there are many vendors that provide such Business Process Management Systems (extensions of WfMS) which are usually expensive commercial products [11]. For instance, the license cost plus one year maintenance cost for the standard edition for IBM and Oracle's Business Process Management (BPM) offering for a small entry level environment is USD $654,100 and USD $347,700 respectively [12]. The costs (license fee and one year support) for the advanced editions for the IBM and Oracle's BPM offering for larger environments is USD $ 5.3 million and USD $ 1.5 million respectively [12]. On the other hand, open source BPM software is gaining traction in the market. This is mainly due to possible cost savings, flexible license agreements and assistance from the open source community to fix bugs and problems [11].

jBPM, a community project developed by JBoss (a company acquired by Red Hat) is a pioneering example of an open source BPM suite that is widely used [11], [13], [14]. It has a light weight, extensible workflow engine at its core that allows for the execution of business processes using the BPMN 2.0 standard specification [15]. In addition, the Drools Business Rule Management System (BRMS) and OptaPlanner, an optimization software are amongst other projects developed by the JBoss Community. The Drools BRMS has a rule engine at its core and has its own native language (Drools Rule Language) for writing rules [16]; while OptaPlanner is a local search and optimization tool that can be used to optimize business resource usage. It is designed to be a light weight, embeddable planning engine which is used to solve constraint satisfaction problems [17].

The JBoss community follows an agile approach to software development and hence there are a number of versions of the Drools, jBPM and OptaPlanner projects that are released every 3-6 months, with performance upgrades, new features, new APIs and fixes for bugs and errors. The evolution or a brief history of these projects can be seen in Appendix A, along with a timeline. At the time this research project started, the last official release was 6th version of the Drools, jBPM and OptaPlanner projects. Collectively, these open source project (Drools 6.0, jBPM 6.0 and OptaPlanner 6.0) have been grouped under an umbrella name called 'KIE', an acronym for 'Knowledge Is Everything' [16]. This research investigates how the projects belonging to the KIE group can be combined to overcome the limitations in WfMS described earlier, and thereby support processes in the healthcare domain.

This research was carried out in close collaboration with Philips Research, for Philips Healthcare. They want to introduce a digital platform for their healthcare services. A core part of this platform includes workflow technologies. However since workflow technologies are rarely used in healthcare domain, Philips Research cannot evaluate whether current commercial workflow products can meet all their requirements for healthcare. Hence open-source projects like those in the KIE group are used because they can be easily extended. Further Philips also believes that jBPM is a mature product that would fully satisfy their needs. In this research, the other projects belonging to the KIE group are also explored and their maturity is evaluated for the purpose of Philips.

1.2 Problem Context

Since deviations from pre-planned processes are quite frequent in hospitals, flexibility is an important issue to be considered when using a WfMS in the healthcare environment. Additionally, such systems should also deal with the planning and allocation of healthcare resources, which are critical for the performance of the processes. In this section, we address how these two issues can be overcome, by combining projects belonging to the KIE group.

1.2.1 Issue of flexibility in WfMS

WfMS used in the clinical environment should be able to cope with change due to the complex and dynamic nature of healthcare processes [7]. However adaptation is not one of the strong suits of the BPM approach. So, in order to accommodate change, new process models have to be created, new services have to be assembled and existing running process instances need to be migrated manually [18]. In contrast, the strength of the Business Rule Management approach lies in its ability to adapt to change. Here desired behavior is described using rules and these rules can be easily changed since they are formulated in a declarative manner independent of specific processes, events and other rules [18]. Therefore it seems favorable to combine business processes with business rules to overcome the problem of rigidity in business process automation systems.

In clinical procedures, these rules can be used to represent medical knowledge and assist in decision making when responding to critical events or exceptional situations. They could be used to evaluate patient's medical history, signs, lab test results, medications and provide diagnostic decisions. They could also be used to provide suggestions for treatments, or to avoid drug prescription errors [4].

The BPM community has recognized the need for flexible workflow systems that are capable of handling real world exceptions, uncertainty and evolving processes for many years [7]. As a response to these needs, process support paradigms such as adaptive processes and case handling have been proposed. Adaptive workflow systems (such as ADEPT2) allows for dynamic changes in the process model of specific running process instances [7]. Workflow systems that are capable of case handling (such as FLOWer) focuses on the data perspective rather than the control flow perspective to aid process flexibility [3]. In case handling, the knowledge worker decides what activities should be performed to achieve a goal for a specific case based on the information available (rather than a predefined process control structure) [19].

In this research, we will study how processes designed in jBPM can be combined with rules written in the Drools Rule Language and executed by the Drools rule engine, to achieve process flexibility. A taxonomy of flexibility was proposed by [3], where four types of flexibility (by design, by deviation, by under-specification and by change) for the control flow perspective was distinguished. However there has been no previously published work, on how rules can be used to achieve these flexibility types. In this research, the rules used while designing the processes are also associated to these flexibility types.

1.2.2 Issue of Resource Planning in WfMS

Due to the increasing demand for healthcare services, rising expenditures and workforce shortages, the planning and scheduling of healthcare resources is vital. These resources, which include personnel (physicians, nurses, etc.), medical equipment, specialized laboratories, beds, ambulances, etc., have to be coordinated in such a way so as to offer successful services on time and within budget for routine and emergency problems [20].

As such, many kinds of planning and scheduling problems can be encountered in the healthcare domain. Some common problems include the allocation of beds to patients, allocation of shifts to personnel (nurses, doctors), drug logistics, ambulance scheduling and operating theatre scheduling [20]. These problems are often NP complete, where it is easy to verify a solution; however it is difficult to find an optimal solution to the problem in reasonable time mainly due the large search space of solutions. Moreover these problems typically have a number of constraints; some of which must not be violated (hard constraints), while others should not be violated if it can be avoided (soft constraints). The various complex constraints under which hospital management operates makes the use of automated planning and scheduling systems essential. As such automated planning and scheduling is an active area of research within Artificial Intelligence and Operational Research [20].

Since the performance of processes in terms of cost and time depends largely on the capacity and availability of resources, it becomes important to develop resource allocation plans. These resource allocation plans should be considered while processes are being executed, and then suitable resources can be allocated to process instances at runtime. Planning the allocation of resources for a large number of process instances also guarantees that the business requirements will be fulfilled [21]. Therefore it seems promising to integrate automated planning and scheduling systems in a WfMS and similar work can be found in literature. For instance, the SWIM system by [22] was designed to integrate process instantiation with task allocation and execution, along with scheduling techniques. The MILOS system developed by [23] was a process modeling and enactment system which also provided support for resource allocation and time scheduling of tasks. More recent efforts included the work of [24], where the authors had presented a generic design and a concrete implementation approach for a calendar based schedule-aware WfMS.

Although several researchers have investigated how to integrate automated planning and scheduling systems in a WfMS, there is no previous work found where a planning system like OptaPlanner is integrated in a process modeled in jBPM. Therefore this research will demonstrate how OptaPlanner can be used to solve a specific planning problem in the healthcare domain and how it can be integrated within processes designed in jBPM.

1.3 Purpose of study

The main purpose of this study is to find out how business rules and an automated planning system can be integrated in a Business Process Management System (BPMS) used in the healthcare context. To achieve this goal, this research will address how rules (defined in the Drools Rule Language) can be used to achieve flexibility while designing healthcare processes in jBPM. It will also address the issue on how to optimally plan the allocation of healthcare resources using an automated planning system such as OptaPlanner, and how such a system can be integrated in jBPM. As such this thesis will demonstrate how Drools, jBPM and OptaPlanner can be made to interact with each other.

1.4 Research questions

Based on the problem context described in Section 1.2, the main research question is formulated as -

How can the KIE group of open-source projects (namely Drools, jBPM and OptaPlanner) be used to support processes in healthcare?

In order to answer this question, the following sub research questions have to be answered -

1. How can Drools business rules be used to design flexible processes in jBPM?

2. How can OptaPlanner be used to support the planning of healthcare resources?

3. Can these three projects (Drools, jBPM and OptaPlanner) be combined to offer a meaningful interaction? If so, how do they interplay and what is the benefit of using all three at once, as opposed to isolation?

Additionally, it is important to note that these questions cannot be simply answered by looking at the manuals of the projects belonging to the KIE group or their running examples.

1.5 Research methodology

In this section, the approach followed to conduct this research is explained in 5 stages:

Stage 1 – Studying the jBPM Business Process Management Suite

Since there were many versions of jBPM with different documentations and API changes, the research initially started with a comparison of the features and process modeling notations supported in jBPM versions 5.4 and 6.0.1 (the last 2 officially released versions). jBPM 6.0.1 was then chosen for this study, mainly because the entire life cycle of a business process from authoring through execution to monitoring and management is supported in a single workbench, which is called the **KIE Workbench**. Next, the various features supported in jBPM 6.0.1 were further explored; these included the graphical process modeler (a web based designer and eclipse based modeler), web based data modeler, web based form builder, business process simulation capabilities and business activity monitoring.

During process modeling and execution, many problems were identified and documented with possible workarounds. Some problems which occurred during simulations were reported to the developers and fixes in versions 6.0.2 and 6.1.0 were also tested. Moreover the steps to be followed for creating users and assigning them roles and groups were not correctly specified in the jBPM 6 documentation. A solution for this was found by combining steps in the documentation of the 5th and 6th versions.

Stage 2- Studying the Drools Business Rule Management System

The second stage of the research involved exploring the Drools Business Rule Management System. To do this, the working execution of the Drools rule engine had to be studied, along with learning how to write business rules using the Drools Rule Language (DRL). Only then could sample projects be tested using the Drools Integrated Development Environment (IDE) as an Eclipse plug-in.

Stage 3- Studying how to use the OptaPlanner framework

During the third stage of the research, a theoretical understanding on how to use the OptaPlanner framework to solve a planning problem was necessary. This mainly involved an understanding of specific annotations used by OptaPlanner when modeling the problem domain as a set of java classes, configuring the solver to use various optimization algorithms and defining the fitness function. The fitness function used for calculating the score of a solution was done by using the Drools Rule Language learnt in the previous stage. Initially a relatively easy planning problem was tried, with simple constraints. Later this planning problem was refined and more complex constraints were added. A benchmarking facility provided by OptaPlanner was also tried to compare the performance of various optimization algorithms w.r.t the specific planning problem.

Stage 4- Integrating Drools rules with business processes in jBPM

The fourth stage of this research involved learning how to use Drools Rules when designing business processes in jBPM. There were two ways to interact with the Drools Rule Engine from jBPM – in a stateless or a stateful manner. Interacting with the Drools Rule Engine in a stateless manner could be done from processes defined from the KIE Workbench. However the stateful interaction with the rule engine is not completely supported from the KIE Workbench at the moment. Currently this can be done from an application specific java project where the jBPM process engine and the Drools Rule engine are embedded.

Stage 5- Integrating a specific OptaPlanner project in jBPM

For the fifth stage of this research, the specific OptaPlanner project created during the third stage had to be integrated in jBPM. However, after studying the documentation for the OptaPlanner [17] and jBPM [25] projects provided by the Red Hat JBoss community, soon led to the realization that there is no out-of-the-box solution for integrating an OptaPlanner project within jBPM. This was later confirmed by discussing the topic (OptaPlanner–jBPM integration) with the JBoss community members [26]. In this thesis, the approach developed to integrate OptaPlanner within jBPM was by using the concept of a domain specific node, also called a custom work item. To do this, certain parts of the OptaPlanner project had to be modified so as to work within the jBPM process.

Stage 6- Testing integrations of the Drools, jBPM and OptaPlanner

For the last stage of this research, a simple case describing a healthcare process is introduced for testing and demonstrating the integration of OptaPlanner and Drools rules in jBPM. Furthermore, multiple consultation and presentation sessions were held with the stakeholders within Philips, and the proposed integration designs were presented. This served as a form of external evaluation for the research conducted.

1.6 Research scope

As a constraint imposed by the collaborating business partner, this thesis only investigates the Drools, jBPM and OptaPlanner projects belonging to the KIE group. At the time this thesis research started, the latest official release of jBPM was version 6.0.1. In Figure 1, a timeline showing when this project started and how it relates in time to the versions of jBPM can be seen.

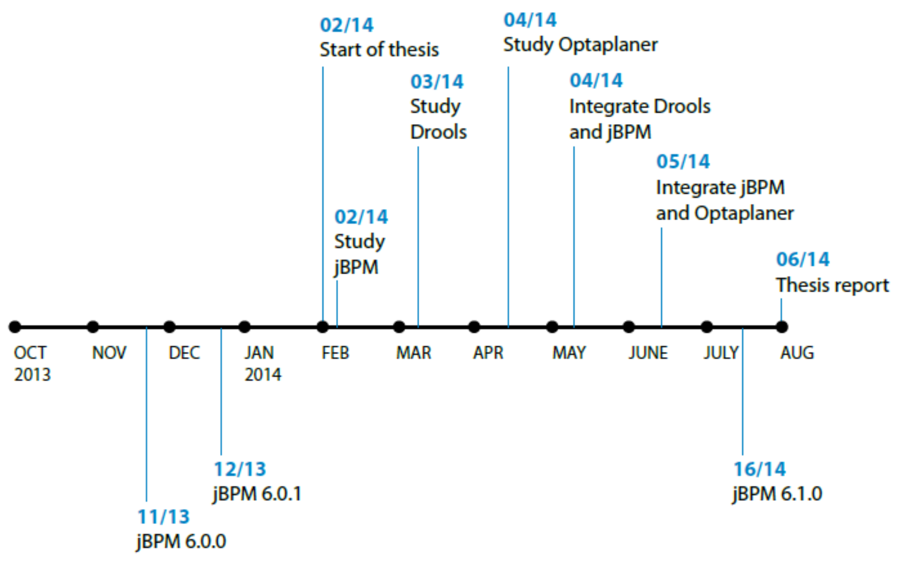


Figure 1: Timeline relating start of thesis research and jBPM versions

The integration of rules in the design of processes is implemented only from the KIE Workbench. The other alternative is to use rules in the design of processes through an application specific java project (where the jBPM workflow engine and the Drools rule engine is embedded) which is outside the scope of this research. Also when using the OptaPlanner framework to solve a planning problem, the details on how to configure the various parameters of the optimization algorithms is not included in the scope of this research. The values for these parameters will be set based on example OptaPlanner projects provided by the JBoss community. Further a simple case describing a healthcare process is used in this thesis to demonstrate the integration of Drools and OptaPlanner in jBPM. The case is a simplified version of the skin cancer treatment process described in [27]. The case was also modified to include a planning problem.

1.7 Thesis structure

This section describes the structure of the thesis text.

Chapter 2 introduces the preliminary concepts related to this thesis; this includes the working execution of the Drools rule engine, the main components and features supported by jBPM and a description of the OptaPlanner framework.

Chapter 3 describes the interplay between jBPM, Drools and OptaPlanner. In this chapter, we will describe how Drools rules can be integrated in jBPM processes, and how Optaplanner can be integrated in jBPM.

Chapter 4 introduces a sample case description of a healthcare process. This process also comprises of a planning problem.

The sample case which was introduced in Chapter 4 is split into two parts in Chapter 5. The first part which comprise of a planning problem is solved using the OptaPlanner framework as a standalone project. Then this OptaPlanner project is integrated in a jBPM process. The second part of the case is used to demonstrate the various ways to integrate Drools rules in jBPM.

Chapter 6 concludes the thesis with a brief discussion of related work from literature and then addresses the research questions. The limitations of this research and some directions for future work are also presented in this chapter. Lastly some commercial software products similar to the projects belonging to the KIE group are also described.

2 Research preliminaries

This chapter introduces preliminary concepts used throughout this master thesis. The modeling and automation of business behavior can be done using two main approaches- Business Rule Management or Business Process Management [18]. The Business Rule Management approach focuses on the use of rules to define business situations, and tries to describe why something has to happen and uses necessary technologies to automate decision logic. The second approach focuses on the flow of activities, and tries to describe what is happening in the business process using visual constructs or notations, and provides necessary technologies to automate the execution of business processes [18].

This chapter is structured as follows. Section 2.1 gives a general introduction to Business Rule Management Systems and then describes the Drools rule engine along with its working execution. This is followed by a general description of Business Process Management Systems in Section 2.2, and then an introduction into the jBPM business process management suite with a brief explanation of the main components it is comprised of, along with the main features it supports. Section 2.3 gives a general introduction to automated planning and scheduling and then describes the OptaPlanner framework and explains how it can be used to solve a planning problem. This chapter concludes with a description on how to setup the environment to successfully use these projects in Section 2.4.

2.1 Business Rule Management System

" *A Business Rule Management System (BRMS) is any software system used to define, deploy, execute, monitor and maintain artifacts called business rules in operational systems within an organization* " [28].

These business rules are statements that define discrete operational policies and practices to influence and guide organizational behavior. They are compact statements describing any facet of a business in an unambiguous language made simple and understandable to all parties involved. They represent the conditions that determine a business event so that it occurs in a way acceptable to the business [29].

A BRMS typically allow users to create, update or delete rules through a rule editing facility. They provide a rule repository where different versions of the business rules can be stored and managed. They also provide a run time environment for a rule engine to process rules through a rule execution facility [28].

Some of the benefits of using a rule engine in software applications include [29], [28] –

1. **Separation of logic and data**
   The separation of business logic represented as rules from data (or domain objects) makes the adaptation of logic to policy changes easier to maintain. Since rules are written in a declarative manner, they are especially useful in situations where the business logic changes frequently. Then existing rules can be easily modified or new rules could be easily added.

2. **Centralization of knowledge**
   Since rules are stored and managed from a centralized location, inconsistencies in business practices can be reduced and duplicate implementation efforts can be avoided.

3. **Understandable rules**
   Rules can be written in a manner to resemble natural language, thus making them easy to understand, define and modify by business analysts or domain experts.

One such business rule management system is Red Hat JBoss BRMS, which is based upon the open-source Drools project, which is a java rule engine. The next section describes the Drools rule engine and its working execution.

2.1.1 Drools rule engine

The Drools rule engine originated as a Production Rule System (also called Rule Based System or Production System), which is a type of inference system commonly used to control reasoning in an expert system and where knowledge is represented as production rules. A production rule system consists of three main components as shown in Figure 2 – production memory where production rules reside, working memory where data or facts reside and an inference engine (or a rule interpreter) [30].

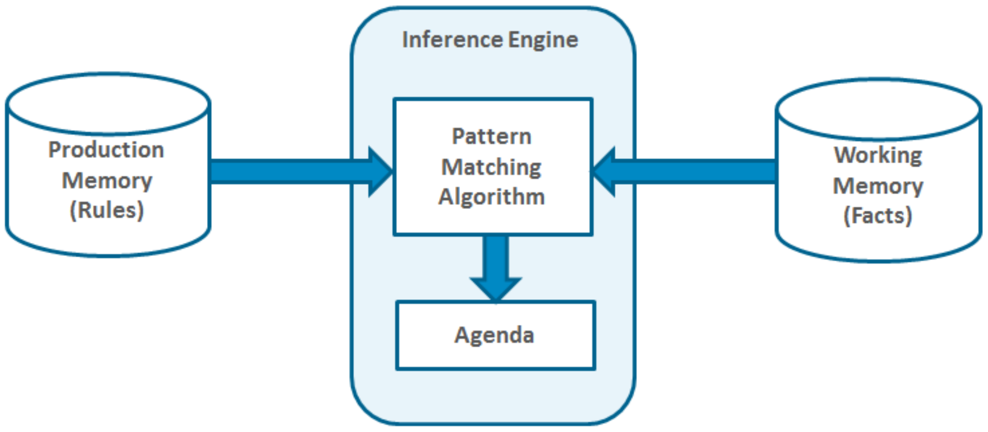


Figure 2: Conceptual diagram of a production rule system (adapted from [16])

Production rules are a knowledge representation technique that has a two-part structure, comprising of a condition and a consequential action [30]. Each production rule in Drools has the following format:

```
rule "rule name"
        when
                //  condition that is matched against facts
        then
                //  action that is to be executed
end
```

In a production system, the rules are stored in the production memory and the facts that are matched against rules (by the Inference Engine) are asserted into the Working Memory, where they can be modified or retracted. The inference engine is responsible for matching facts against production rules, and infers conclusions which result in actions. The process of matching new or existing facts to the rules is called pattern matching and there are many algorithms used by inference engines for pattern matching such as Linear Brute Force Search, Rete, Treat and Leaps. Currently, the sixth version of Drools uses a new lazy algorithm called PHREAK for pattern matching. The engine can also be configured to use the ReteOO algorithm, which is an enhanced and optimized implementation of the Rete algorithm for Object Oriented Systems [16].

Pattern matching can result in conflicting rules, i.e. multiple rules can be concurrently true for the same asserted fact. The agenda is responsible for managing the execution order of rules using a conflict resolution strategy. The execution or firing of a rule can change data, which may result in new facts being inserted in the working memory and in turn be matched against other rules. This mechanism is referred to as forward chaining and can be characterized as reactionary or 'data driven', as assertion of facts into working memory results in executions. Although Drools started as a production rule system, the fifth version of the Drools rule engine introduced backward chaining as well as some functional programming styles. Hence Drools 5 onwards can be described as a hybrid reasoning system [16].

The default working execution of the Drools rule engine will be explained in the next section.

2.1.2 Working execution of Drools rule engine

Information in the object oriented environment is represented as objects. When these objects are inserted into the working memory of the rule engine, they become facts (according to the rule engine's terminology) which are evaluated against the defined conditions of the rules. As a result of the insertion, a wrapper to the object instance (called a FactHandle) is created and returned to the application. Since the FactHandle is a reference to the fact inserted in working memory, it is a means to interact with the working memory from the application, so as to modify or remove facts that have been previously inserted. The act of inserting, modifying or removing facts from working memory is referred to as a Working Memory Action [16].

During the insertion phase, when there is a fact which matches with the condition of a rule, the rule and its matched data is put into the Agenda and is referred to as an Activation (or a Rule Match). The agenda is a table of activations. It is possible that a single Working Memory Action can result in multiple eligible rules. In such situations, the Agenda controls the execution order of these matches using a conflict resolution strategy. Drools provides a number of conflict resolution strategies like salience (rules are given priorities), LIFO (last in first out), FIFO (first in first out), etc. A single activation is then selected to be fired. Firing an activation will result in the execution of the consequence/action part of the rule, which can cause new activations to be created or existing ones to be cancelled. This loop goes on until the agenda is completely cleared [16]. A conceptual diagram explaining this working execution can be seen in Figure 3.

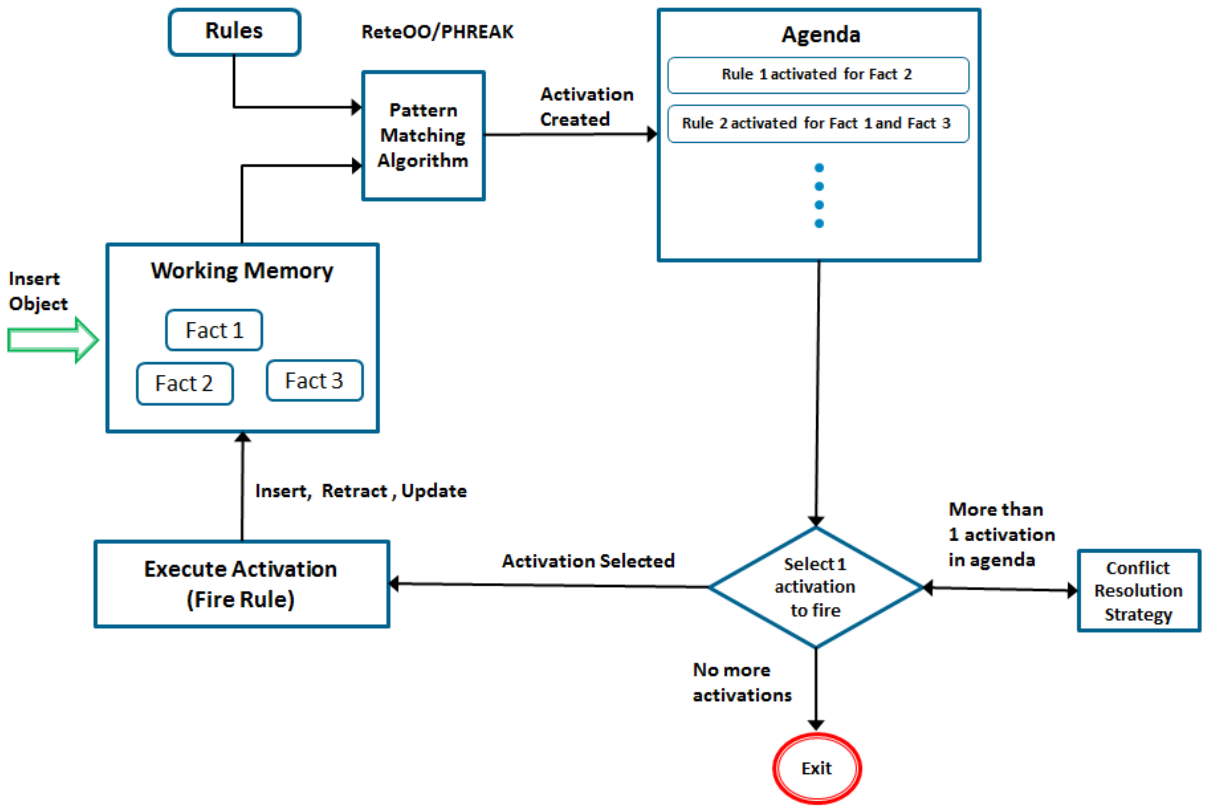

Rules
ReteOO/PHREAK
Pattern Matching Algorithm
Activation Created
Agenda
Rule 1 activated for Fact 2
Rule 2 activated for Fact 1 and Fact 3
Insert Object
Working Memory
Fact 1
Fact 2
Fact 3
Insert, Retract, Update
Execute Activation (Fire Rule)
Activation Selected
Select 1 activation to fire
More than 1 activation in agenda
Conflict Resolution Strategy
No more activations
Exit

Figure 3: Working execution of Drools rule engine (adapted from [15])

Thus the engine operates in a cyclic 2 phase mode [31] :

Working Memory Action Phase - In this phase, a working memory action (insert, update, or retract) takes place from either the main application code or from the execution of the consequence of a rule.

Agenda Evaluation Phase – In this phase, the engine selects an activation to fire from the agenda. If there are no activations in the agenda, the engine exits. If there are activations, the engine will select one and execute it, and then switch back to Working Memory Action Phase. This process repeats until the agenda is empty.

2.2 Business Process Management System

Although there are many definitions for Business Process Management in literature, we use one defined by [32] as "*Supporting business processes using methods, techniques, and software to design, enact, control, and analyze operational processes involving humans, organizations, applications, documents and other sources of information*". It is a discipline that applies knowledge combined from management science and information technology to operational business processes [33]. It can be considered as an extension of the traditional Workflow Management approach that mainly focuses on automating business processes, whereas BPM has a broader scope and also includes the analysis of processes, management of operations and the organization of work [32], [33].

As such, a business process management system can be defined as "a *generic software system that is driven by explicit process designs to enact and manage operational business processes*" [32].

jBPM, an open-source community project by JBoss initially started as simple workflow engine used for the enactment of business processes, which has grown significantly in the last few years, to support the entire business process lifecycle, from process authoring and analysis, to execution, monitoring and management [15]. In the next section, the main components involved in the jBPM architecture are explained followed by a description of the main features supported by jBPM 6.

2.2.1 Components in jBPM

The main components involved in the jBPM architecture are explained in this section. A conceptual diagram representing the various components and their interactions is shown in Figure 4.

The core of jBPM consists of a set of components for parsing and executing various kinds of knowledge assets (processes, rules, etc.) that are stored in a **Knowledge Repositor**y. The **Semantic Knowledge Based Modul**e is responsible for defining the language semantics and how it will be translated to the process engine's internal structure. It contains several parsers to handle different types of resource types (BPMN2, DRL, etc.). The jBPM project is built on top of the Drools project; hence the process engine and the rule engine are merged to work together [15]. The working of the rule engine has been previously explained in Section 2.1.1. In this section we will focus more on the process engine and the other components.

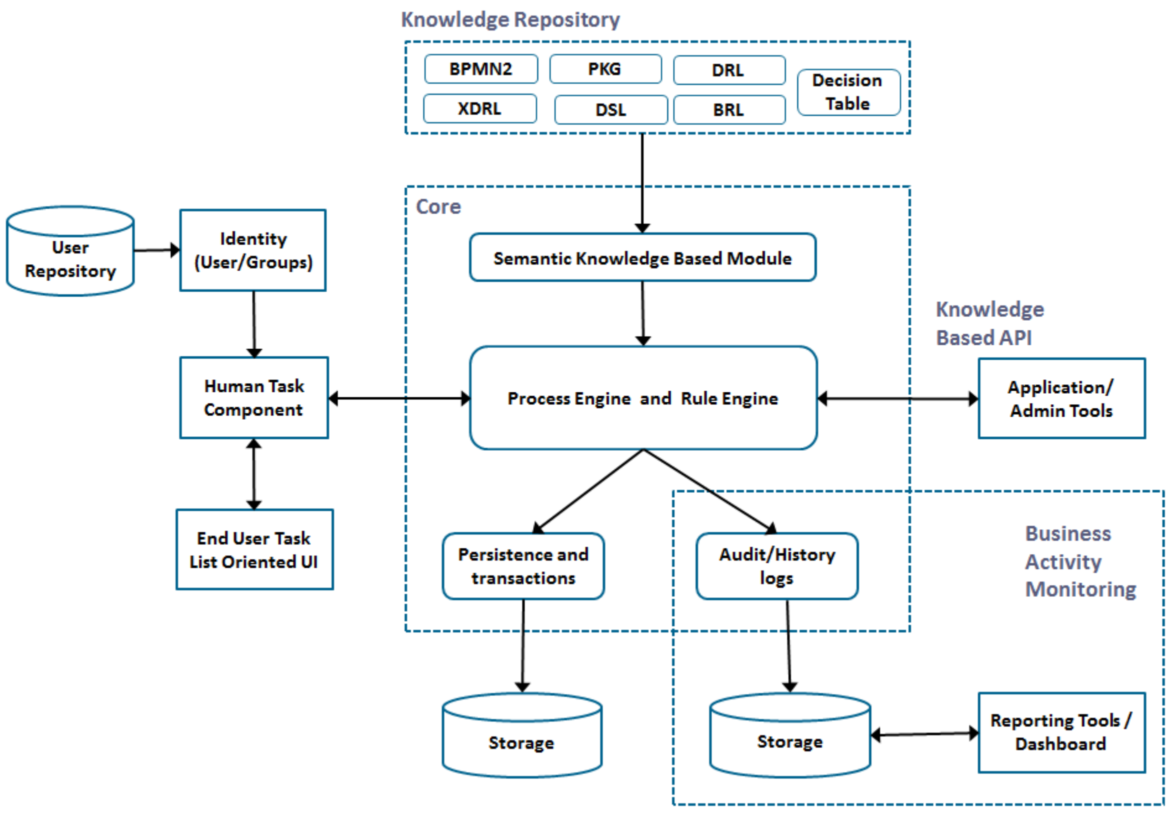


Figure 4: Main components in jBPM (adapted from [15])

The process engine is responsible for creating new process instances and maintaining their state. The internal structure representing different activities from the process definition is defined in the process engine, along with the mechanisms to instantiate the process definitions and then execute them. The process engine is responsible for creating the process definition structure and the process instance structure.

The **process definition structure** is the static representation of the business process. When a business process is modeled using a graphical process modeler, this graphical representation is stored as an XML file which is compliant with the BPMN2.0 specifications, which is then parsed by the BPMN2 parser in the semantic module. The outcome of the parsing process results in the creation of a structure of objects representing a graph. This structure called the process definition contains all the activities in the graphical representation [15]. This parsing process can be seen in Figure 5.

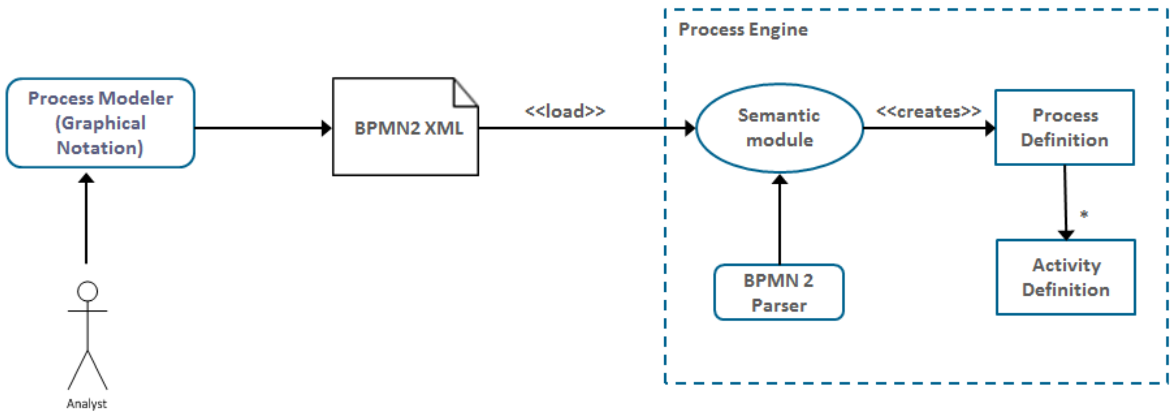


Figure 5: Parsing process in jBPM [15]

The process engine then creates an instance of the '**process instance structure'**, for every process that is to be executed. This structure represents the running process and the information it should handle. This information is required to keep track of the activities being created during process execution.

The mechanism to create the process instances depends on the engine implementation. Prior to the release of the fifth version of jBPM, the process engine used a Token Based Approach for process executions. In this approach, a token was created for every process instance that will traverse the process activities and carry the information required for those activities. The process instance dies when the token reaches the last activity (end node) and the process is then marked as completed [15].

However, since the release of jBPM 5, the mechanism for process execution was implemented using the Node Instance Based Approach. In this approach, a new instance representing the execution status of a particular activity (from the process definition) is dynamically created. Every time the process execution comes across an activity from the process definition, its respective node instance is created and placed inside a node instance collection, which is inside a process instance. When the activity is completed, the node instance is removed from the collection. Thus this collection or list of node instances represents the activities that are currently being executed [15].

Processes which take a long period of time to be completed (especially processes involving human tasks), requires a mechanism to store the state of the running instance, along with the information it is handling into a file system or a database. The **persistence and transaction component** is responsible for defining this mechanism to store the runtime information of process instances and also decides how and when the process engine transactions have to be created, committed or roll backed. There is also an **Audit/History Logs module** which allows users to query historical data about the processes. This information retrieved is useful for Business Activity Monitoring and reporting tools [15].

During process execution, if there is a user task activity in the process definition, then a human task is created and the actor responsible for carrying out that task will see a new activity that needs to be completed in the task list inbox. The **Human Task Component** is responsible for managing the life cycle of a human task (created, in progress, suspended, completed, etc.) through a set of services/APIs that are defined by the Web Services Human Task (WS-HT) standard specification. It also provides the functionality to design custom task lists and task forms for the end user. The WS-HT specification is the default implementation for the human task service provided by jBPM, but it is also possible to replace it with any custom human task service implementation. The Human Task Component is made to interact with the process engine, the end user's interface and **an Identity Component** that is capable of interacting with a repository where the user and group information of the organization is stored. This interaction is required to map the organizational structure of user and groups to the roles defined in the process [15].

2.2.2 Features supported by jBPM

In this section, some of the features supported by jBPM 6 are described [25]:

1. A web-based designer and an Eclipse based modeler for graphical process modeling using the BPMN 2.0 standard specification maintained by the Object Management Group (OMG). A list of BPMN 2.0 notations and workflow patterns supported by jBPM version 6.0.1 and version 5.4 is mentioned in Appendix B.
2. A data modeler to create data objects along with their attributes (the getters and setters for each attribute gets automatically defined). The data modeler is used to create complex data structures like a graph of objects. These data objects can then be used as process variables within the process definition.
3. A web-based form builder to create process and task forms. These task forms can be automatically generated from process variables and task variables, and then customized later using the form editor. These forms are the front end for Human Tasks within the business process, and are used to display or request data from end users/ actors.
4. jBPM also supports Business Process Simulation capabilities from the web-based designer. The simulation is based on Business Process Simulation Interchange Standard (BPSim) which is a WfMC standard. A detailed explanation of the features supported by jBPM simulation is explained in Appendix C, along with some problems encountered during simulations.
5. Tooling for Business Activity Monitoring (BAM) is also supported, which is used for the creation of dashboards. More details of the BAM feature are explained in Appendix D.

The detailed steps on how to install jBPM 6.0.1 and how to get started with the setup are explained in Appendix E, along with some problems encountered while designing processes from the web based designer.

2.3 Automated planning and scheduling

Automated planning and scheduling has been an active area of research within the Operational Research community and Artificial Intelligence community for a long time [20] [34]. Here planning is defined as *"the process of putting in a sequence or partial order a set of activities/actions to fulfil temporal and resource constraints required to achieve a certain goal"* [20], whereas scheduling is defined as *"the allocation of activities/ actions over time to resources according to certain performance criteria"* [20]. Many researchers consider scheduling as a special case of planning [20].

Many real world problems can be grouped as planning and scheduling problems, where resources are to be allocated in a manner so as to optimize performance objectives. One approach to solve such problems is by using constraint satisfaction techniques, where the problem is to be modeled as a set of decision variables. Each decision variable will have a set of possible values and a set of constraints that restrict the allowed combination of values to variables. Then the task is to find a solution where the values are to be assigned to variables in a manner so as to satisfy all constraints [35].

Such problems can be solved by using complete search algorithms (Exact algorithms) to systematically explore the complete solution search space, to find all possible assignments of values to variables. If a solution to the problem exists, then it is guaranteed that the algorithm will find the optimal one. If there is no solution to the problem, it can be proved that the problem is not solvable. However, using such algorithms that perform an exhaustive search may take a very long time. As an alternative approach, it is possible to use incomplete search algorithms that do not explore the whole solution search space; but may still find a reasonable or 'good-enough' solution (close to the optimal solution) within a significantly short period of time. This class of algorithms are called metaheuristics and include evolutionary algorithms (such as genetic algorithm, evolutionary strategies, etc.) and local search techniques (such as hill climbing, simulated annealing, tabu search, late acceptance, etc.) [35].

One software framework used to solve such planning and scheduling problems with constraint satisfaction techniques is OptaPlanner. It is an open source java project released under the Apache Software License. In the next sections, we will describe the OptaPlanner project and the steps to be followed when using it to solve a planning problem.

2.3.1 OptaPlanner

"OptaPlanner is a lightweight, embeddable planning engine that optimizes planning problems" [17].

These planning problems are characterized by the fact that they are NP complete, they have constraints (usually hard and soft constraints) and they have large search space of solutions to choose from. This makes it necessary to use automated planning and scheduling systems to solve such problems. The OptaPlanner project (previously called Drools Planner) is one such software that can be used to solve constraint satisfaction problems by using a combination of optimization algorithms (construction heuristics and meta-heuristics) with efficient score calculations [17].

The logic for calculating the score for every possible solution is defined in the fitness function. This is an objective way to compare different solutions, and to choose the solution which has the highest score. The fitness function or the scoring techniques are based on constraints, which can be a positive constraint (to be maximized), negative constraint (to be minimized), or a combination of both. The fitness function can be implemented using Java or the Drools rule engine. Using the Drools rule engine, to calculate the score of a solution reduces the complexity and effort to write scalable constraints in a declarative manner. Moreover by using the forward chaining mechanism of the Drools rule engine, allows for delta based score calculation instead of a full score calculation on each evaluation of a solution. Then only those constraints that have changes in one or more conditions since the previous evaluation will be recalculated. This type of score implementation has huge performance and scalability gains, without the need of writing a complex incremental score calculation algorithm [17]. In this thesis, the Drools rule engine will be used to perform the score calculations and every constraint will be represented as rules written in the Drools Rule Language. This gives the developer the flexibility to easily add new constraints or modify existing ones [17].

Although the Drools rule engine is efficient at calculating the score of a solution, it is not suitable for finding new solutions. In order to find new improved solutions, a solver is built which uses multiple optimization algorithms (construction heuristics, meta-heuristics) in an ordered sequence. A construction heuristic is first used to get from an empty solution to an initialized solution. This initialized solution can then be given to the local search algorithm to find a good solution. At each solution, the local search algorithm (meta-heuristic) will try all possible moves to change to the next solution. It will then choose the best move with the highest score as the 'next step'. The local search algorithm decides which is the 'next step' with the help of three configurable components– A MoveSelector which selects/generates all possible moves of the current solution, an Acceptor which will filter out those moves which are unacceptable and a Forager which will gather all the accepted moves and choose the best move which is the next step [17].

The next section describes how the OptaPlanner framework can be used to solve a planning problem.

2.3.2 Solving a planning problem using the OptaPlanner framework

In order to solve a planning problem using the OptaPlanner framework, the problem domain has to be modelled as java objects and a fitness function for calculating the score of a solution must be defined. A file containing the various solver configuration parameters must be set. This solver configuration file is used as an input by a solver factory which builds an instance of the solver as an output. Then a problem data set specific to the planning problem has to be generated or retrieved from a specific data source (database, file system). This problem data set is then loaded into the solver as the planning problem. A command to solve the problem is then issued. Then the best solution found by the solver can be retrieved [17]. A conceptual diagram on how to build the solver is shown in Figure 6

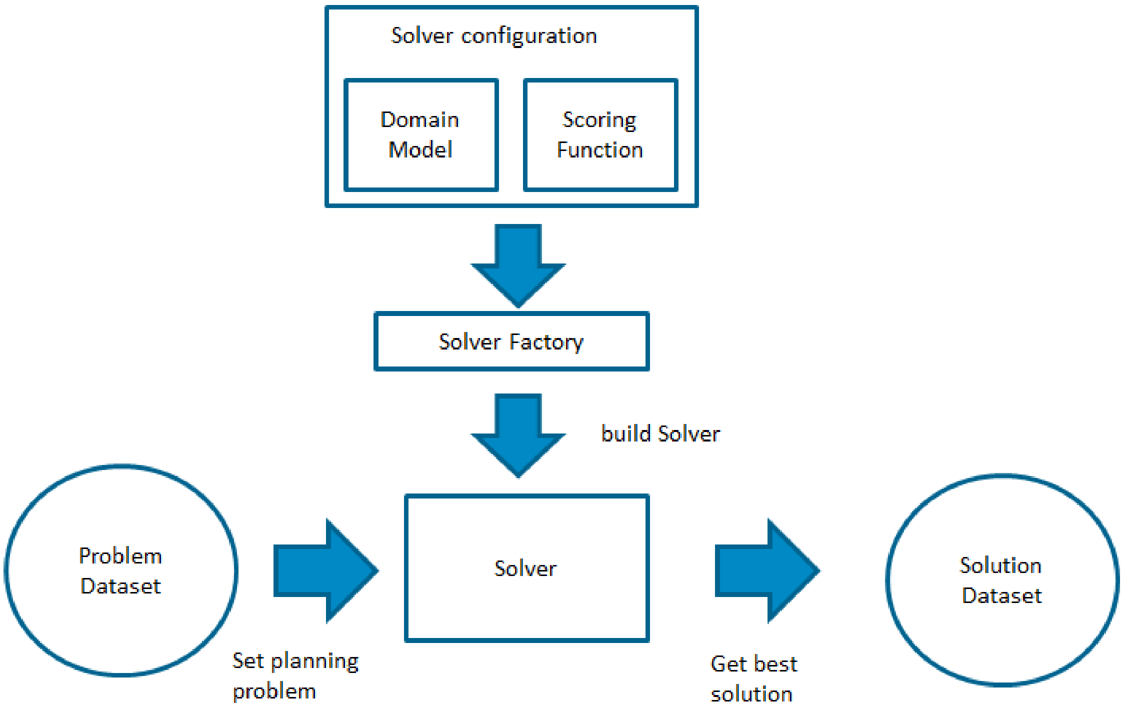


Figure 6: Building the solver (adapted from [17])

The following steps explain how the domain model can be created, how the solver can be configured and how a benchmarking facility provided by OptaPlanner can be used.

1) Modeling the problem domain

The problem domain which is modeled as JavaBeans/POJOs (Plain Old Java Objects) has to have specific annotations [17]. In order to do this, the main classes involved in the planning problem must be first identified and categorized as a *planning entity* or a *problem fact*. Both the *planning entity* and *problem fact* are POJOs, used by the scoring constraint. However, the *planning entity* has an attribute (or attributes) whose value **changes** during solving/planning while this is not the case for the problem fact. The property of the planning entity that change is referred to as a *planning variable* and a *planning entity* must have at least one *planning variable*. The value of this *planning variable* is called the *planning value* and it can be a *problem fact*, another object or even another *planning entity*. Also another class called the *planning solution* must be defined while modeling the problem domain. This class should contain the collection of *problem facts* and *planning entities*. It must also have an attribute representing the score of the solution. The annotations for the *planning entity*, *planning variable* and *planning solution* must be set, so that OptaPlanner can understand the problem domain [17].

2) Configuring the solver

Configuring the solver can be done using java or XML, and mainly involves:-

- Specifying the solution class and the planning entity.
- Specifying the type of score implementation (using Java or Drools) and the location of the resource where the score implementation has been done.
- Specifying the type of score definition. This is required in situations when one score constraint outranks another score constraint, irrespective of the number of times the latter is violated. For such situations, score constraints can be defined at different score levels. The different types of scores that can be used are *Simple* score, *Hard Soft* score, *Hard Medium Soft* score, *Bendable Scores* or a custom score type implementation. A Simple score has only a single score level with a single *Integer* value associated with it. Similarly, a Hard Soft score has two score levels, with two integer values. It is typically used for problems which have hard constraints (which must not be violated) and soft constraints (which should not be violated, if it can be avoided). Likewise a *Hard Medium Soft* score has 3 scoring levels –hard, medium and soft. A Bendable Score is an array of hard Integer values and an array of soft Integer values, i.e. it has a configurable number of levels (for instance, bendable score has 3 hard levels and 4 soft levels) [17].
- Specifying when OptaPlanner should terminate or stop solving. The solver can be configured to terminate in a number of ways, when
    - a particular amount of time has been reached
    - a certain score has been reached
    - a particular number of steps have been completed
    - the best score has not improved in a number of steps

- Specifying the algorithms to be used as construction heuristics and meta-heuristics. A list of optimization algorithms are provided by OptaPlanner to choose from, as shown in Appendix F.

3) Benchmarking facility

Some optimization algorithms perform better than others, for a specific problem domain. The results obtained from the solver largely depend on the configuration of the optimization algorithms [17]. Since changing the parameters of the local search algorithm (meta-heuristics) can affect the results significantly, OptaPlanner provides a benchmark facility, where it is possible to compare the performance results of different configurations and then select the best one. A conceptual diagram on how OptaPlanner's benchmarking facility works is shown in Figure 7.

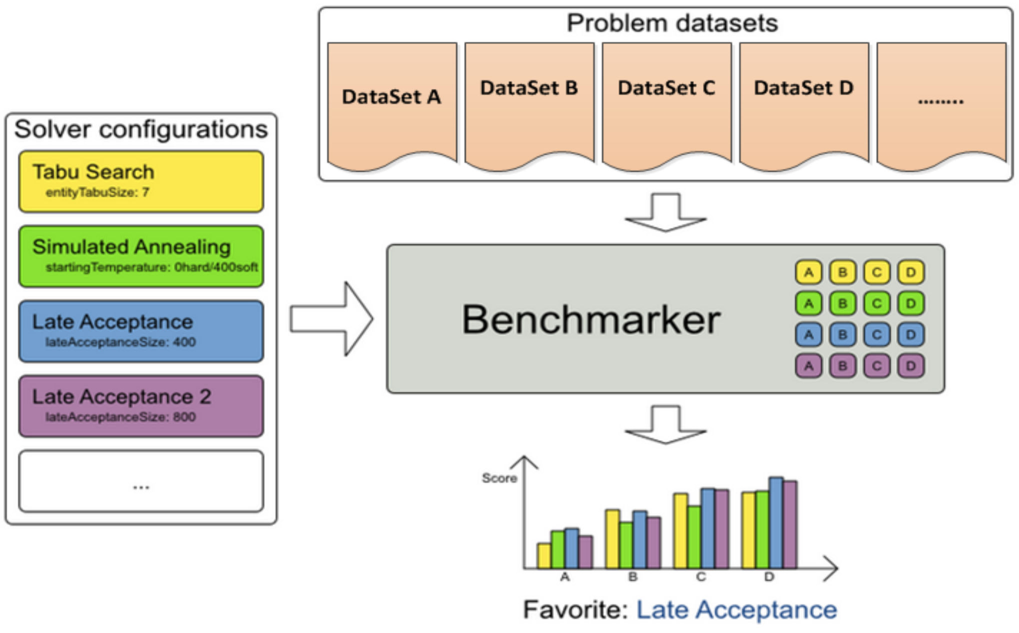


Figure 7: Benchmarking in OptaPlanner [17]

After the problem domain has been modeled and the fitness function has been defined, the OptaPlanner Benchmarking facility has to be configured to use multiple solver phases with different parameter settings, and different problem data sets of varying sizes have to be loaded. A number of solvers will run depending on the number of configurations and the number of loaded problem data sets (For instance 3 configuration settings on 2 problem data sets will run 6 solvers). When all the solvers terminate, a benchmark report is created showing the performance of each solver on each problem data set, and the solver configuration with the best performance for all data sets will be recommended.

3 Interplay between jBPM, Drools and OptaPlanner

In this chapter, the interactions between the three projects (jBPM, Drools and OptaPlanner) are described. Since the jBPM project is built on top of the Drools project, i.e. the jBPM workflow engine is merged with the Drools rule engine, we need to learn how they interact and how rules can be used when designing business processes. This interaction between jBPM and Drools is explained in Section 3.1.

In Section 3.2, the integration between jBPM and OptaPlanner is described. This integration is useful when assigning specific resources to manage specific process instances.

3.1 Integrating Drools Rules in jBPM processes

The workflow engine in jBPM is useful for automating the flow of activities in a business process. By using a process modeling language such as BPMN2, we can define the sequence of activities that need to be executed so as to achieve a specific business goal. Next we have to decide on how to represent the business logic within those activities. One approach is to define the business logic in a declarative manner by using business rules. Then a rule engine could be used to evaluate different business situations and make automatic decisions based on the information available. [14].

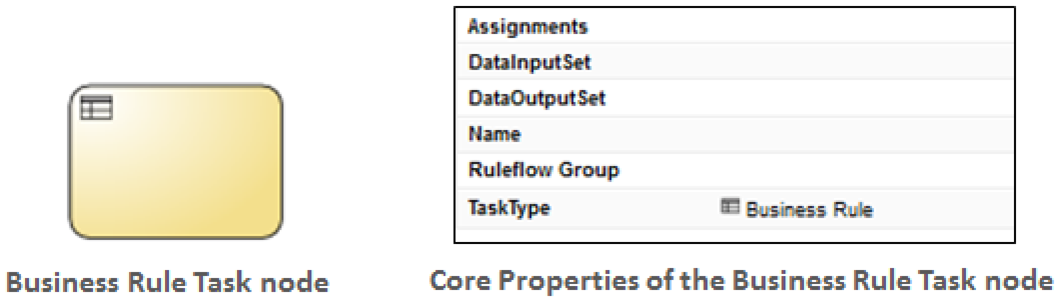
In order to allow the interaction between the jBPM workflow engine and the Drools rule engine, a session has to be created. There are two types of sessions that can be created – a stateless session which does not maintain the state or context between interactions (i.e. it does not keep information from previous calls) and a stateful session which maintains the state and keeps information from various calls and interactions. Additionally a session is created based on a knowledge base, which is a container for the compiled knowledge assets (rules, processes, etc.) [15].

Thus to create a session, a knowledge base has to be created first, then all the required knowledge assets (process definitions, rules, etc.) have to be loaded and only then can a session be instantiated. Typically long running business processes that involve various human actors are defined in a stateful session. Then from these business processes, we can interact with the rule engine in two ways – a stateless manner or a stateful manner. The interaction with the rule engine in a stateless and stateful manner is described in Section 3.1.1 and Section 3.1.2 respectively.

3.1.1 Stateless Interaction with the Drools rule engine

Interacting with the Drools rule engine in a stateless manner can be done when an activity within the business process calls the rule engine to evaluate a set of business rules to perform some complex calculations or data validations or to make some business decisions. In such situations, the information required by the rule engine should be gathered and prepared to be sent, communication problems between the process engine and the rule engine should be dealt with and the data structures involved when the two platforms (Drools and jBPM) interact should be managed [15].

This stateless type of interaction with the Drools rule engine to evaluate some business logic can be done using a Business Rule Task node in the process definition. The information which the rule engine requires has to be sent by specifying the Data Input Set and Data Output Set parameters of the Business Rule Task node. Normally the information interchanged in this type of interaction involves complex data structures like a graph of objects. The classes (with their associated attributes/properties, getters and setters) from which these objects are instantiated, can be created by using the web based data modeler. Now while designing the process, we have to import this class and create an instance of it. This object instance is used in the parameters (Data Input Set and Data Output Set) of the Business Rule Task node. By using such a node in the process definition, we are implicitly creating a stateless session, that exposes an execute() method, that internally inserts all facts provided as parameters [15]. Additionally, another parameter called the RuleFlow Group must be specified, so that the rule engine knows which group of rules must be evaluated, when this node is reached. The rule engine will then evaluate the facts against the rules and calls the fireAllRules() method when a match is found. Firing the rule will result in the execution of the consequence of the rule. Then the result is returned back to the process engine and then the stateless session is disposed. Figure 8 shows a business rule task node, along with its core properties which include the Data Input Set, Data Output Set and the Rule Flow Group.



Assignments	
DataInputSet	
DataOutputSet	
Name	
Ruleflow Group	
TaskType	Business Rule

Figure 8: Business Rule Task node and its core properties

Figure 9 shows a business process defined in a stateful session and two Business Rule task nodes used within the process definition. In this kind of integration, the rule engine is considered just an external component, where a data object is sent and an immediate response is expected. The data objects are inserted as facts that are evaluated against rules by the rule engine. When an activation (rule match) is found, the consequence of the rule is executed which may modify the data object. This execution cycle (rule engine's working execution) is run only once and then the control passes on to the next activity within the process definition [29]. This is a rather encapsulated usage of the business rule service, or a stateless interaction with the rule engine, where the context cannot be reused to add more information later on.

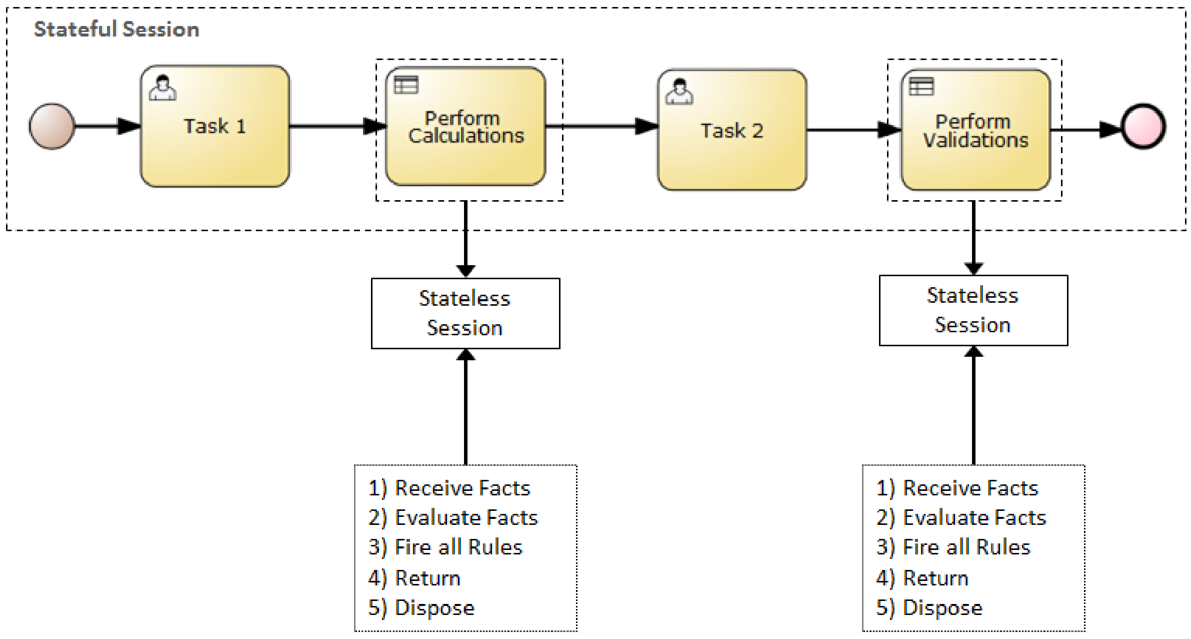


Figure 9: Stateless interaction with the Drools rule engine (adapted from [36])

3.1.2 Stateful interaction with the Drools rule engine

It is also possible to interact with the rule engine in a stateful manner. However this stateful interaction with the rule engine cannot be done directly from the KIE workbench. It can be done from a java project/application where the process engine and rule engine is embedded. Then as soon as a process instance is created, statements can be written to insert the process instance as a fact into the rule engine. By doing this, we can make inferences on all contextual information [14], [29]. In the previous case (i.e. the stateless context), we could only make inferences on those data objects which were inserted as facts provided as parameters to the Business Rule Task node. Additionally if multiple process instances are executed under the same session, rules could be written to analyze those instances and make global decisions about them.

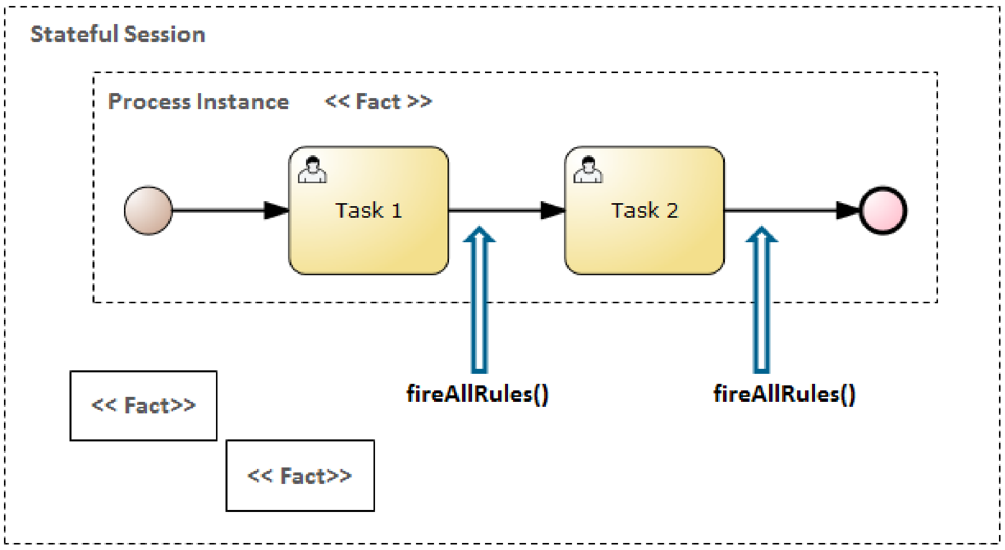


Figure 10: Stateful interaction with the Drools rule engine

Now when interacting with the rule engine in a stateful context (as shown in Figure 10), when we issue the command to insert the process instance as a fact, data contained in the process will be matched against the rules and those rules whose conditional section evaluates to a true will be activated. These activations will be placed in an Agenda and remains there until a method to fire the rules is called. Now if we want the same behavior as in the previous case (Figure 9), the *fireAllRules* method must be called after the activities (*Task 1* and *Task 2*). However it is possible to put the rule engine in a reactive mode, thereby forcing it to fire as soon as activations are created, without the need to explicitly call the method to fire the rules [15].

The rule engine can be put in the reactive mode by adding *Process Event Listeners* and *Agenda Event Listeners* in the application code. These event listeners allow us to get internal engine events and execute actions (such as firing all rules) when these events are triggered. For instance, the *Process Event Listener* has methods like *beforeNodeTriggered, afterNodeTriggered, afterProcessStarted* whose behavior can be overridden and made to fire rules. Similarly the *Agenda Event Listener* has methods which can be overridden to fire rules as soon as activations are created. These methods provided by the event listeners are used as hook points to define custom behavior [15].

3.2 Integrating OptaPlanner in jBPM

In this thesis, the concept of custom work items, also called custom service nodes or domain specific nodes is used for the integration of OptaPlanner in jBPM.

The Service Task activity defined in the BPMN 2.0 specification, allows for the interaction with external services in a generic manner. This service task concept can be used as an extension to plug in domain specific behavior and to handle external interactions. In jBPM, the concept of a work item is used as an extension point to execute these external interactions, by providing the process engine with a custom block/task representing custom behavior. A work item will then represent a unit of work that is executed outside the process engine's scope [15]. In order to create a work item, we must first create a work item definition and then create a work item handler which is explained in the next sections.

3.2.1 Creating a work item definition

When creating such a domain specific node, the data associated with the node must be separated from the procedure on how to handle it. This means that the domain specific node should be declarative and at a higher level of abstraction, i.e. it should not contain any code [25]. This high level definition of the node (called a work item definition) must be created, so that its runtime requirements can be interpreted by the process modeler and thereby allowing users to set parameters as part of the process model. This work item definition is created using the MVEL [37] expression language format. It can include fields such as the name of the domain specific node, its input parameters and output results. There are also fields to customize the graphical representation of these domain specific nodes such as a display name and an icon field where an image can be uploaded [25]. Then this newly created work item has to be registered with the jBPM engine for it to be visible in the palette of the graphical modeler. This can be done by creating a file with a '.wid' extension where the work item definitions will reside and then linking it to the process engine's configuration.

3.2.2 Creating a work item handler

The execution of the work item is the responsibility of the work item manager in the process engine, which in turn delegates this responsibility to a custom work item handler [25]. The work item handler will execute the work item and then sends a completion notice to the Work Item Manager. This Work Item Handler is a java class that implements the *WorkItemHandler* interface, and defines two methods, one to execute the work item and the other to abort the work item. The method responsible for the execution of the work item will contain the necessary logic to call the external service. While the method to abort the work item is responsible for cancelling the external interaction when there is a runtime failure or an explicit cancellation is required [25]. It is in the execution method of the Work Item Handler, where the OptaPlanner project will be called. This working execution of the work item handler is conceptually represented in Figure 11. Finally a work item handler must be mapped to their respective work item definition.

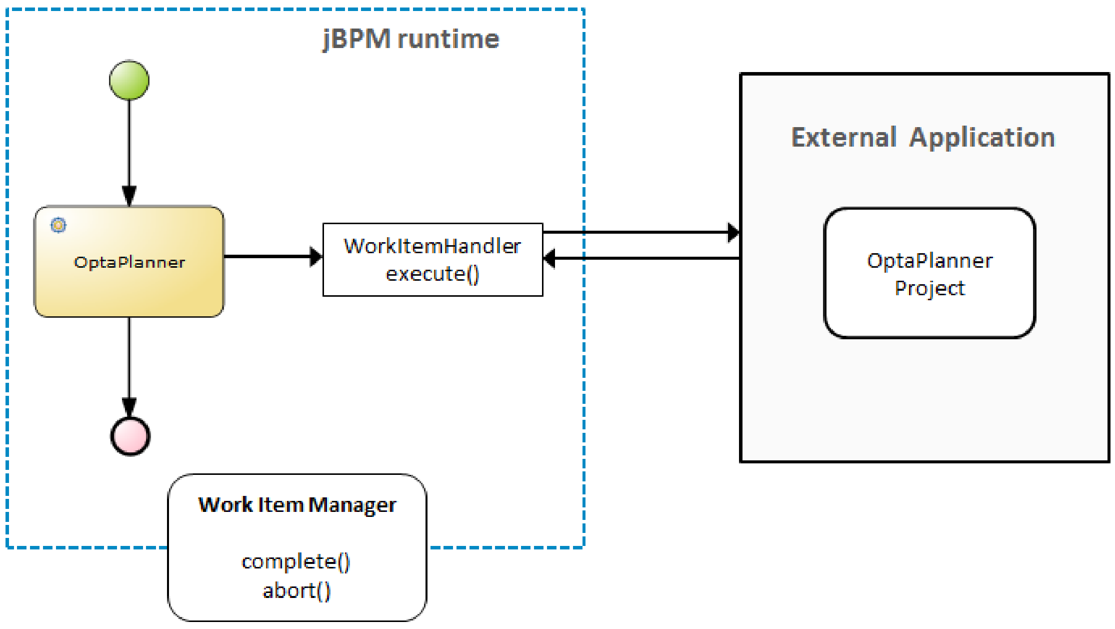


Figure 11: Execution of a work item (adapted from [15])

3.2.3 OptaPlanner work item

The OptaPlanner work item created for this project is used to invoke a specific OptaPlanner project. We do not create fields for the input parameters and output results for the OptaPlanner node when defining the OptaPlanner WorkItem. This is because the problem data set required for the OptaPlanner project is retrieved from a database and similarly the output solution is put into a database. The database from where OptaPlanner retrieves the problem data set is the same as the one where jBPM has been configured to persist run time data. Additionally the database in which OptaPlanner stores the output solution can be accessed from script tasks within jBPM processes.

The same concept can be used if we wanted to create any other OptaPlanner project and integrate it with jBPM.

4 Case Description

In order to demonstrate how a process in jBPM can be integrated with an OptaPlanner project and to show the various ways in which Drools rules can be used within the jBPM process, a simple case describing a healthcare process is introduced in this chapter. This case description is a simplified version of the skin cancer treatment process, based on the research conducted by [27] in the dermatology oncology outpatient clinic at the Catharina hospital, located in Eindhoven. The case is further modified to comprise of a planning problem.

The process starts when patients arrive at a clinic and registers with a secretary at the front desk. Here necessary details of the patient (name, age, medical history, problems, etc.) are recorded. Then the patient has a consultation meeting with a doctor who reviews the patient details and checks up on the patient to make an initial evaluation. The next step involves a biopsy, where a tissue sample of the patient is taken by a nurse and has to be transported to the pathology lab. Tissue samples are sent as a batch to the pathology department where they are assigned to pathologists.

The assigned pathologist then performs a macroscopic study of the sample tissue, followed by freezing, cutting and staining the sample. Then a diagnosis is done and a pathology diagnosis report is sent to a doctor. The results from pathology are used by the doctor, to verify symptoms/conditions of the patient and to give a final diagnosis, and thereby identifying the type of skin cancer – Basal Cell Carcinoma (BCC), Melanoma or Squamous Cell Carcinoma (SCC). Once the type of skin cancer has been identified, the appropriate treatment procedure must be carried out by a specialist. Then post treatment and control checks are performed by a nurse.

A flow chart depicting the control flow for the described process is shown in Figure 12.

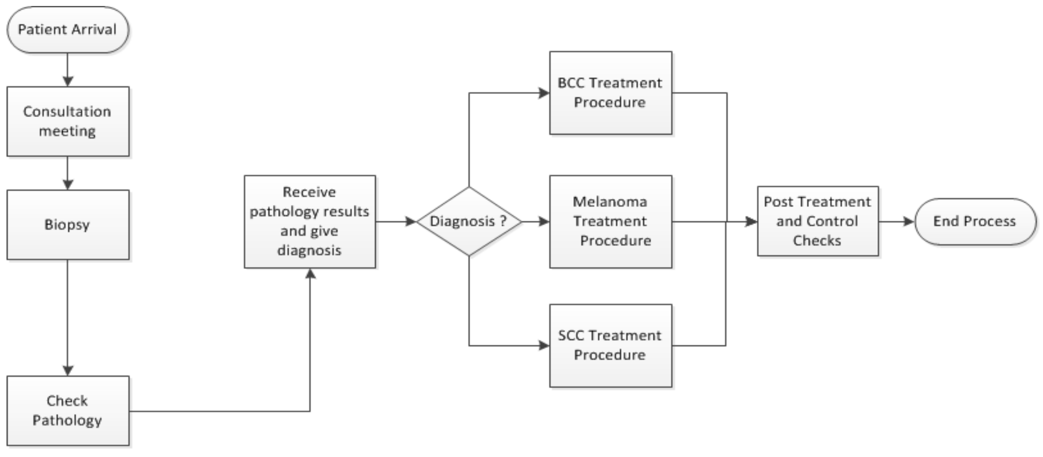


Figure 12: Flow chart of the skin cancer treatment process

The different roles involved for this skin cancer treatment process is shown in Table 1 along with the number of resources available and the tasks that they are responsible for.

Table 1: Roles involved in skin cancer treatment process

Role	Resources available	Activities performed
Secretary	5	• Register patient details
Doctor	8	• Consultation Meeting : - Perform initial check up • Receive pathology results and give diagnosis
Nurse	6	• Biopsy : - Collect tissue sample and fill pathology study request
Pathologist	5	• Check pathology : - Study sample specimen - Cut and stain sample - Create diagnosis report
Specialist	7	• BCC treatment procedure • Melanoma treatment procedure • SCC treatment procedure

Let us further assume during the biopsy step, the tissue sample is assigned a specific identification number, problem type and also a required amount of time needed by a pathologist to study the sample. Additionally each problem type is associated with a specific complexity value. When multiple tissue samples are collected, it is sent as a batch to the pathology lab where they are distributed to pathologists. Every pathologist can solve only specific problems types according to their skill or capability level, and they also have a specific period of time when they are available. These tissue samples should be assigned to the pathologists in a fair manner, while considering the complexity involved in studying the sample and the fact that all samples assigned should fit within the pathologist's available time duration and capability /skill set.

This part of the case can be identified as a planning problem, and will be difficult for an individual to manually come up with a resource allocation plan. This specific part of the planning problem can be solved using the OptaPlanner framework, so as to correctly assign pathologist to analyze specific tissue samples of patients. In the next chapter, we will first solve this planning problem as a standalone project and then later integrate it within the process modeled in jBPM. To demonstrate the interactions between jBPM, Drools and OptaPlanner, the skin cancer treatment process will be divided into two parts as shown in Figure 13. One part to show how jBPM can interact with OptaPlanner, and the second part to show the various ways in which Drools rules can be used within the jBPM process.

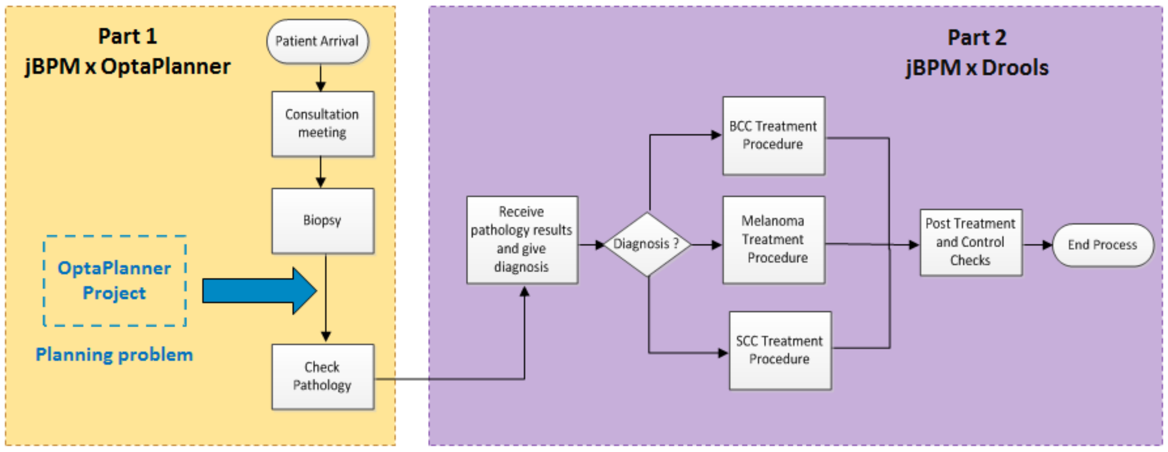


Figure 13: Splitting the skin cancer treatment process into two parts

5 Applying the integration of KIE projects on the case

In the previous chapter, we introduced a simple case which was divided into two parts. The first part of the case comprised of a planning problem where tissue samples of patients should be assigned to pathologists based on specific constraints. In this chapter, we will first give an overview of the planning problem in Section 5.1.1 and then solve the problem using the OptaPlanner framework as a standalone project in Section 5.1.2. We will then explain how this specific OptaPlanner project can be integrated with jBPM in Section 5.1.3. The second part of the case will be used to show the various ways in which Drools rules could be used within the process modelled in jBPM as explained in Section 5.2.

5.1 Part 1 of case

5.1.1 Overview of the planning problem

5.1.2 Applying the OptaPlanner Framework

Figure 14: Identifying the planning entity

Figure 15: Main classes for the problem domain

Figure 16: Implementing hard and soft constraints as rules in the Drools Rule Language

Figure 17: XML file showing the problem data set for 5 cases and 2 pathologists

Figure 18: XML solver configuration

5.1.3 Integrating OptaPlanner with jBPM

Figure 19: Assigning case specific details during the consultation and biopsy phase

Figure 20: Invoking OptaPlanner as a custom work item

Figure 21: Assigning pathologist to perform pathology process

5.2 Part 2 of case

In this section the second part of the case will be modelled in jBPM with the help of Drools rules.

5.2.1 Integrating Drools rules in jBPM

Although there can be a number of ways to integrate rules with processes, three approaches used in this thesis are described in the following sections.

Approach 1- Rules to set decision variables

The control flow of a business process defines the execution order of different activities. A process instance takes different paths defined in the business process through decision nodes, also called gateways in BPMN. These decision nodes/ gateways use the values of certain decision variables, in order to choose a certain path during the execution of the business process.

One approach to combine rules with processes is to allow the rule engine to set the value of these decision variables in response to specific conditions. In order to do this, a business rule task node can be added in the process model before the gateway node. This business rule node should be linked to a set of rules to be evaluated at runtime. Moreover the data which is required for the evaluation of the conditional part of the rule and the data required for the execution of consequence /action part of the rule must be explicitly provided to the rule engine as input and output parameters in the business rule task node.

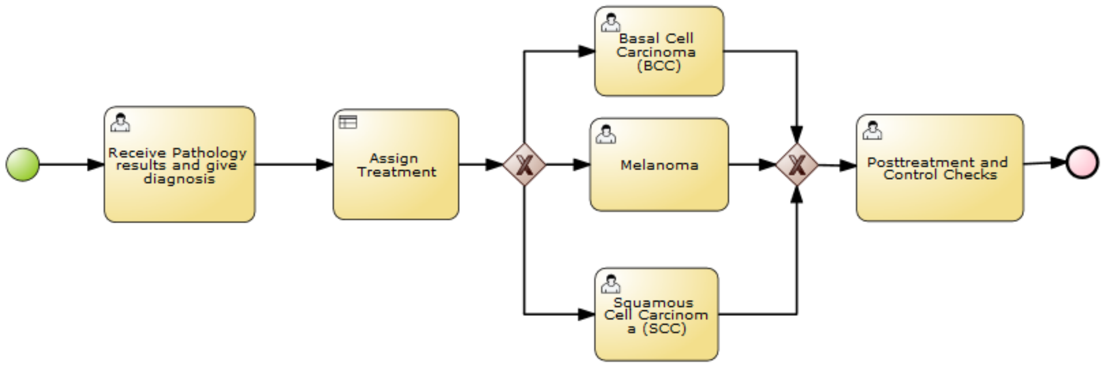

Receive Pathology results and give diagnosis
Assign Treatment
Basal Cell Carcinoma (BCC)
Melanoma
Squamous Cell Carcinom a (SCC)
Posttreatment and Control Checks

Figure 22: Rules setting decision variables

For instance, let us look at the second part of the case described earlier and depicted in Figure 22 as a BPMN model. In the *Receive Pathology results and give diagnosis* human task node, a doctor will verify the conditions (diagnosis) seen in the patient based on the pathology results. Based on the diagnosis, a particular treatment procedure must be selected.

In this case, first a class *Patient* and its associated attributes/properties are first created using the data modeler. Then, while designing the process, this *Patient* class is imported and an instance of the class is created. Then the *Patient* object is put as an input and output parameter of the *Assign Treatment* business rule task node. By doing this the *Patient* object is inserted as a fact into the working memory of the rule engine, where it is evaluated against rules. The specific set of rules to be fired will be specified in the rule-flow group property.

Then three rules will be defined where the conditional part of the rule checks different conditions/symptoms of a patient and the consequence part of the rule sets a decision variable with the appropriate treatment type. This decision variable is then used in a java expression in the outgoing arcs of the decision/gateway node. So at runtime, a specific treatment task is selected based on the decision variable, which is in turn set using rules.

Approach 2 – Rule conditions at Gateway arcs

Another approach, where the same behavior is captured can be seen in Figure 23, where the process model is made simpler by using rule conditions directly at the outgoing arcs of the decision node/gateway node.

Now the business rule task node can be removed, and a statement to insert the patient object into the working memory of the rule engine can be put in the *on exit action* property of the human task node *Receive Pathology results and give diagnosis*. This statement is as follows –

kcontext.getKnowledgeRuntime().insert(patient);

A predefined variable called *kcontext* can be used to access the current process instance or node instance. It can also be used to get and set process variables and also access the created session [25].

Now a rule condition can be used directly at each outgoing arc of the decision node. For instance, Patient (conditionBCC == true) is a Drools rule condition used at the incoming arc of the *Basal Cell Carcinoma (BCC)* node. This rule will propagate the execution for that sequence flow when there is a patient that matches the conditions of the diagnosed disease.

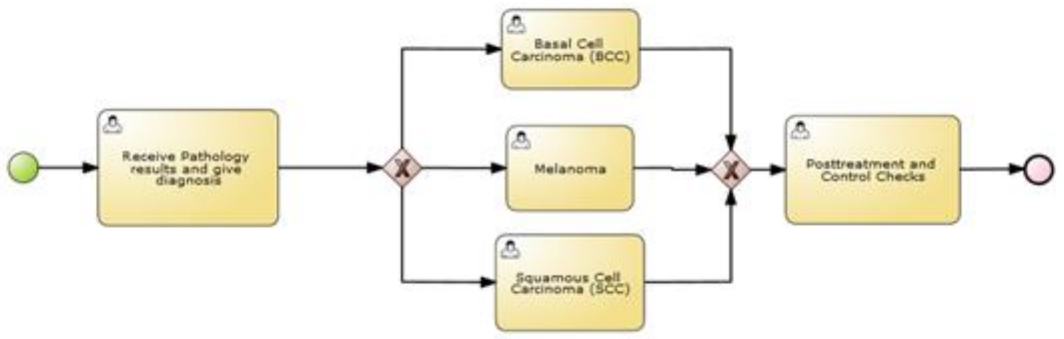

Receive Pathology results and give diagnosis
Basal Cell Carcinoma (BCC)
Melanoma
Squamous Cell Carcinoma (SCC)
Posttreatment and Control Checks

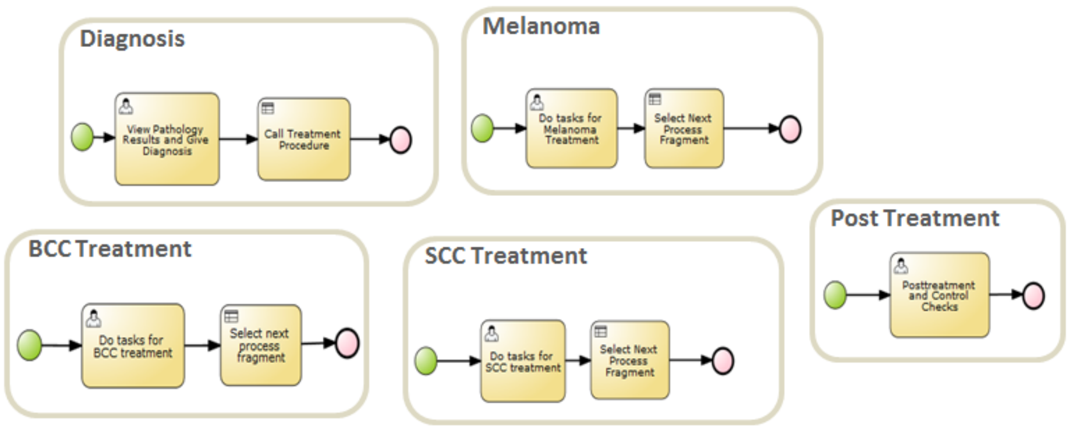
Figure 23: Rule at gateway condition

Approach 3 – Dynamic composition of process fragments

In this approach, the actual process is split into process fragments during design time and rules are used to compose/assemble them during execution or runtime [18].

The same example described previously is now split into five process fragments as shown in Figure 24. During runtime, based on the conditions/symptoms seen in the patient, a specific treatment process will be chosen. On completion of the treatment process, the next process fragment will be chosen, which contains the *Post treatment and Control Checks* task.

For example, the *Call Treatment Procedure* business rule task node is linked to three rules. In each rule, the conditional section evaluates the symptoms seen in the patient and the consequence/action section starts a treatment process for that symptom. To do this, we need to know the process ID (name of its process definition) and input data (*Patient* object) that the process will require. Then this information can be used in a function to create a process instance and then start the instance.


Diagnosis
View Pathology Results and Give Diagnosis
Call Treatment Procedure
Melanoma
Do tasks for Melanoma Treatment
Select Next Process Fragment
BCC Treatment
Do tasks for BCC treatment
Select next process fragment
SCC Treatment
Do tasks for SCC treatment
Select Next Process Fragment
Post Treatment
Posttreatment and Control Checks
Figure 24: Dynamic composition of process fragments

5.2.2 Designing flexible processes using rules

In previous section, some approaches on how rules could be used while designing processes was described. In this section, we will describe its relation to process flexibility.

Flexibility of a process has been defined as "*the ability to deal with both foreseen and unforeseen changes by varying those parts of the model which are affected by them, whilst retaining the essential format of those parts that are not impacted by variations*" [3]. In [3], the authors had presented the taxonomy of flexibility, and distinguished between four types of flexibility for the control flow perspective - (1) flexibility by design, (2) flexibility by deviation, (3) flexibility by under-specification and (4) flexibility by change. In this thesis, rules have been used in the design of business processes to achieve flexibility by design and flexibility by under-specification.

Flexibility by design is "*the ability to incorporate alternative execution paths within a process definition at design time, such that the selection of the most appropriate path can be made at run time* *for each process instance"* [3]. This type of flexibility can be achieved, by using rule conditions at the outgoing arcs of a decision node (or an XOR gateway) within the business process. Then during runtime, the most appropriate execution path will be selected based on the evaluation of the rule condition.

Flexibility by under-specification is "*the ability to execute an incomplete process model at run-time*" [3]. This type of flexibility can be achieved, by using rules within a process to invoke other processes. As explained earlier, this can be done by breaking apart the standard/original model into independent process fragments and then dynamically assembling them at runtime using rules. Here appropriate rules must be developed to select a particular process fragment. This is useful in scenarios where the execution order of different parts of the business process is not known in advance. It may also be useful in special scenarios where certain process instances may require parts of the business process to be omitted or additional parts to be inserted. This is a type of under-specification called late binding, where a missing part of the model is linked to some pre specified functionality at runtime [38].

6 Conclusions

This thesis started with addressing some issues inherent in WfMS that limits its application in the healthcare domain, i.e. these systems fall short with regard to providing flexibility and they do not deal with the planning and scheduling of healthcare resources. One approach to designing flexible processes was to combine them with rules. Furthermore, an approach to address the problem of resource allocation for healthcare processes was to integrate them with an automated planning system. It was decided to use the KIE group of open–source java projects developed by Red Hat JBoss community to overcome these limitations. These projects include the jBPM business process management suite, the Drools project for business rule management and OptaPlanner, a framework to solve planning problems. Through previous chapters we have demonstrated how these projects can be used together to support processes in healthcare.

In this chapter, the final conclusions of this thesis are presented. In Section 6.1, we first discuss some works found from literature related to the main subject of this research, which is followed by addressing the main research questions in Section 6.2. Then some of the limitations of this research and some recommendations for future research are listed in Section 6.3 and Section 6.4 respectively. Lastly, some commercial software products that are similar to the projects belonging to the KIE group are described in Section 6.5.

6.1 Related Work

In this section, we first discuss some works from literature where rules have been used in the design of flexible processes. Then we briefly describe an approach found from literature on how to integrate a WfMS with a planning and scheduling system.

6.1.1 Integrating rules with processes

In [18], the authors had identified multiple patterns for integrating business rules with business processes. They also explained how these patterns could be integrated in a service composition language, like Business Process Execution Language (BPEL). Some of these patterns are summarized in Table 2. The key common point for these patterns was that the rules could be modified during the runtime of a process instance. This is similar to achieving flexibility by change which is *"the ability to modify a process model at runtime such that one or all of the currently executing process instances are migrated to a new process model"* [3]. However achieving this kind of flexibility is currently not possible in jBPM. If any rule has been modified or changed in jBPM, the process model has to be redeployed so that future process instances can take note of the changes.

Table 2: Patterns for integrating rules with processes (adapted from [18] [39])

Pattern Group	Pattern	Brief description
Control flow decisions	Decision Logic Abstraction	The decision logic is defined as business rules
	Decision node to business rule binding	The dynamic mapping of a decision node to a business rule
	Decision with flexible input data	The rule can access any data within the process, instead of explicitly providing the data to the rule engine
	Decision with flexible output	Rules can be used to dynamically assign an activity at the outgoing branch of a decision node
Data constraints	Constraints at predefined checkpoints	Rules can be used to validate constraints on input and output data of an activity
	Constraints at multiple checkpoints	Rules can be used to validate constraints on data at multiple positions in a process
Dynamic process composition	Rule based sub process selection	Rules can be used to select a sub process dynamically
	Rule based process composition	Rules can be used to dynamically assemble process fragments

Additionally in [18], the authors had focused only on the implementation details when integrating rules with processes and did not consider the modeling aspects. The modeling aspects for these set of rule patterns were later investigated in [39], where the authors had combined the R2ML (REWERSE Rule Markup Language) [40] and BPMN languages to introduce a new rule-enhanced business process modeling language called rBPMN. The metamodel for the rBPMN language involved elements from the BPMN metamodel and the R2ML metamodel and some extensions such as rule gateway notation (a gateway with the R symbol).

6.1.2 Integrating automated planning and scheduling in processes

When considering WfMS that deal with the planning and scheduling of resources, one interesting contribution found from literature was the work of [24]. Here the authors had presented a generic design and implementation approach for integrating a WfMS with a calendar-based scheduling facility. They first developed a conceptual model (Colored Petri Net) using CPN tools which served as specification and simulation model for the schedule-aware WfMS. The architecture of this schedule-aware WfMS mainly involved four loosely coupled components – (1) a workflow engine which is responsible for routing cases within the organization, (2) a workflow client application that provides a work-list management component to allow users to select and perform tasks within a case, (3) a calendar where appointments (of tasks to resources) are recorded, and (4) a scheduling service that provides scheduling facilities to the system. The concrete realization of the system was done using the YAWL workflow engine, Microsoft Exchange Server 2007 / Outlook which was the platform for providing a calendar and allowing user interactions, and a scheduling service which was implemented in Java.

A scheduling problem along with the scheduling constraints (for a case) was formulated as a graph. The process definition of a case at a given state was mapped to this graph. The nodes of the graph had properties such as the task name, duration of the task, roles involved for executing the task, split/join semantics of the node, the state of the node (enabled/disabled), etc. This scheduling problem could be sent to the scheduling service by the workflow engine when any of the following situations occurred: when a case was started, when a task in the case was finished, when a user would require an appointment to be rescheduled or even at regular time intervals.

The scheduling service would then schedule tasks while considering the ordering sequence of tasks in the process definition. Additionally if multiple roles were involved in the execution of a task, the service would select a resource for each specified role. The scheduling service will then book an appointment in the calendar of those resources involved.

However, our work focused only on finding the best resource capable of handling a particular case. To do this, we have integrated a specific OptaPlanner project within a specific process in jBPM. The OptaPlanner project would solve a specific planning problem and develop a resource allocation plan. Then the actor responsible for handling each case is assigned based on the resource allocation plan.

6.2 Research Questions

In this section, we will address the research question that was formulated in Section 1.4 -

How can the KIE group of open-source projects (namely Drools, jBPM and OptaPlanner) be used to support processes in healthcare?

In order to use these projects, first various technical issues have to be overcome, mostly regarding jBPM. Many problems have been identified during process modeling and execution which have been documented in Appendix F3. For some of these problems, work arounds have been suggested. Moreover some problems and limitations of the Business Process Simulation capabilities provided by jBPM was also identified and documented in Appendix B2. Critical errors such as incorrect semantics for BPMN notations during simulations were reported to developers in the JBoss community [41]. Additionally, the steps to be followed in order to assign roles and groups to users were not completely specified in the jBPM 6 documentation. These steps are listed in Appendix F2.

Now to answer the main research question, the following three sub research questions had to be answered -

1. How can Drools business rules be used to design flexible processes in jBPM?

   Rules implemented in the Drools Rule Language can be used in the design of processes in jBPM to achieve flexibility by design and flexibility by under-specification as demonstrated in Section 5.2.1. Flexibility by design was achieved when rule conditions were used at the outgoing arcs of XOR gateways. Additionally, since complex constraints can be captured using rule conditions, the process model can be made simpler. Flexibility by under-specification was achieved by using rules to invoke other processes. This was done by breaking apart the original model into process fragments and then assembling them at runtime using rules.

2. How can OptaPlanner be used to support the planning of healthcare resources?

   Some of the common planning problems healthcare organization face involves allocation of patients to doctors, allocation of beds to patients, allocation of shifts to nurses, logistics of drugs, scheduling of ambulances and scheduling of operational theatres [20]. As such these planning problems can be solved using the OptaPlanner framework. To do so, the problem domain has to be modeled as a set of java classes with specific annotations (such as the planning entity, planning variable, etc.). The constraints of the planning problem can be represented as rules implemented in the Drools Rule Language. These rules will be used by the Drools rule engine to calculate the score of every solution under evaluation. A solver has to be configured to use an optimization algorithm (construction

heuristics and meta-heuristics) for finding possible solutions. Then the solver is built based on the configurations set. A data set representing the planning problem has to be generated or retrieved from a data source (database, file system, etc.) and then it should be loaded into the solver. Then the appropriate command to solve the problem has to be issued, followed by retrieving the best solution found. This solution found will be the resource allocation plan to be used.
In Chapter 4, a specific planning problem involving cases (patient tissue samples) which are to be distributed to pathologists was introduced. This problem was then solved in Section 5.1.2 using the OptaPlanner framework. Since the solver could be configured in a number of ways, a benchmarking facility provided by OptaPlanner was also tried to find a solver configuration which gives good performance results w.r.t the specific planning problem.

3. Can these 3 projects (Drools, jBPM and OptaPlanner) be combined to offer a meaningful interaction? If so, how do they interplay and what is the benefit of using all 3 at once, as opposed to isolation?

   Yes, it is possible to combine these 3 projects to offer a meaningful interaction. This was demonstrated in Chapter 5, where OptaPlanner and Drools rules were used in jBPM processes based on the case description introduced in Chapter 4. Further, the use of Drools rules in OptaPlanner to represent constraints for a specific planning problem, was shown in Figure 16 and explained in Appendix G.

   Since the jBPM workflow engine is already merged to work with the Drools rule engine, we only had to learn how they interact (i.e. in a stateless and a stateful manner) which was explained in Section 3.1. Additionally, since the OptaPlanner project is also already embedded with the Drools rule engine; we only had to learn how to define a fitness function to calculate the score of a solution using the Drools Rule Language. There was no previous work found where an OptaPlanner project was integrated with jBPM. For this thesis, we used the concept of a domain specific node (or a custom work item) to make this integration possible as explained in Section 3.2

   Using all 3 projects at once provides the benefit of designing flexible processes and also allows the integration of automated planning within the process. We have shown how process flexibility for the control flow perspective can be achieved using Drools rules, specifically how flexibility by design and flexibility by under-specification can be achieved.
   If Drools rules were not used within a process in jBPM, it would not be possible to achieve flexibility by under-specification, i.e. during runtime, the dynamic assembling of process fragments would not be possible.

Additionally by allowing the Drools rule engine to perform score calculations within OptaPlanner, we will be representing all the constraints of the planning problem as separate rules in a single file with a '.drl' extension. This gives us the flexibility to easily add new constraints or update existing ones.
If the Drools rule engine was not used to perform the score calculations, then complex scoring functions would have to be implemented using Java. Then a high maintenance cost would be required if the scoring constraints change regularly. Additionally implementing the score calculations using simple java would make the performance of OptaPlanner slow and less scalable when there are a large number of solutions in the search space [17].

The integration of OptaPlanner with jBPM allows us to use a resource allocation plan during process execution. Then specific resources can be made responsible for managing specific process instances based on the resource allocation plan.
If an automated planning system such as OptaPlanner was not used with jBPM, then a manual resource allocation plan would have to be created and used.

6.3 Limitations

Some of the limitations of this thesis are described in this section.

1. For the first part of the case, which was used to demonstrate the integration of OptaPlanner with jBPM, three disconnected process models were designed-
    - A process model representing the consultation phase and the biopsy phase.
    - A model representing the optimal allocation of cases to pathologists. It was in this process model where the OptaPlanner project was invoked.
    - A model representing the pathology process, where pathologists were assigned to study a specific case/tissue sample (based on a resource allocation plan generated by OptaPlanner).

   This division was done mainly because the appropriate modeling logic to group tissue samples based on a batch size was not successful.

2. Currently whenever the OptaPlanner project is invoked from jBPM, it will retrieve appropriate case (tissue sample) data of all the patients from the database and create a resource allocation plan. This includes previously allocated cases as well. However, it should be designed in such a way that it retrieves the batch of case data for new arrivals only.

3. This thesis had only investigated using Drools rules to achieve flexibility at the control flow perspective.

4. This thesis did not investigate how OptaPlanner could be combined with the simulation engine of jBPM. If such an integration was possible, then in scenarios where the number of patients who arrive in the hospital increases. Then OptaPlanner could be used to find an optimal resource allocation plan, which could be used as an input to run simulations. Then it would be possible to find out if the hospital can manage increasing demands of patients with the best allocation of resources.

6.4 Future Research

In this section, some possible directions for future research are presented:

1. Currently when invoking the OptaPlanner project from a process in jBPM, the problem data set used by OptaPlanner is retrieved from databases. Future research should focus on sending the problem data set as input parameters of the OptaPlanner domain specific node, maybe as an array of objects.

2. For future research, additional constraints should be developed for the OptaPlanner project, such as deadlines for work items/cases and the domain model should be made richer by adding more classes (planning entities and problem facts).

3. The OptaPlanner project should be developed to be a continuous planner in such a way that when a new batch of cases are to be assigned to resources, the new solution should take into account the previous solution as well to ensure fair distribution. In continuous planning, one or more upcoming planning windows will be solved at the same time and then the process is repeated within a time interval (weekly, monthly). Then the past planning windows should be fixed; however they may be used for calculating the score of solutions involved in the upcoming planning window [17].

4. The KIE workbench should be extended to support the stateful interaction with the Drools rule engine. Currently the stateful interaction with the rule engine can only be done from a java project where the process engine and the rule engine is embedded.

5. Future research should focus on the use of Drools rules to achieve flexibility at the data, resource and application perspectives as well.

6.5 Related Commercial Software

In this section, some commercial alternatives to the KIE projects (Drools, jBPM and OptaPlanner) are described. For instance, one leading commercial BPM suite is IBM Business Process Manager, which is available in three configurations (Express, Standard and

Advanced) tailored to suit the needs of small, mid-sized and large organizations. Some of its notable feature includes support for BPMN and BPEL standards, a unified asset repository and a control center for governing the entire BPM lifecycle [42]. This is similar to jBPM, which supports the BPMN and BPEL standards, has a single repository where various types of knowledge assets can be stored and a single workbench from where processes can be authored, executed, managed and monitored.

However some features which jBPM does not support when compared to the IBM Business Process Manager include a Process Optimizer to detect performance bottlenecks based on historical data, and then visualizing it through 'hot-spots' on the process diagram, easy access to any Enterprise Content Management System, integration with SAP systems, process design and application use through mobile platforms. Additionally, IBM's Business Process Manager also has an in-built Performance Data Warehouse that provides business activity monitoring (BAM) capabilities through process status maps, dashboards and service level agreement alerts [42]. In contrast, the jBPM's BAM module only supports creating dashboards for viewing key performance indicators of the business process. Moreover, IBM's BPM offering can be offered as a subscription based cloud service as well [42].

Other products of IBM include Operational Decision Manager (ODM) which is a comprehensive platform for business rule management [43]. A project similar to OptaPlanner is IBM ILOG CPLEX Optimization Studio which is an analytical decision support toolkit for developing optimization models. It is embedded with two optimization engines (one for mathematical programming and the other for constraint programming) used for solving planning and scheduling problems. These problems are modeled using the Optimization Programming Language (OPL) provided by IBM [44]. This software product is not integrated with the IBM's BPM offering.

Another well recognized commercial BPM suite is provided by Appian. Besides the core BPM functionality provided, it also focuses on the use of cloud and mobile computing platforms to create a configurable and interconnected process management environment [45]. Additionally Appian BPM suite is integrated with live data streams from various social networks and also supports dynamic adaptation to process changes (i.e. modifying running process instances on the fly) [46]. None of these features are supported by jBPM at the moment.

Another well-established vendor in the BPM market is Pegasystems, that provides software for creating sophisticated, dynamic process applications with advanced case handling and analytics features. It has also extended its core capabilities with mobile and social technologies [45]. Such features are currently not supported by jBPM.

However most of these features provided by commercial BPMS are in the development roadmap for future versions of jBPM such as [47]:

- Simulation replay – which will support scenarios for simulation based on information from history logs
- BPM projects in the cloud
- BPM connectors and adapters to extend how the engine can integrate with external services
- Dynamic processes - to change running process instances on the fly. This is similar to achieving flexibility by change.
- User interfaces to support mobile users to participate in processes or monitor them
- Case handling
- Tools to support the migration of running process instances to new process definitions
- Process mining

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Appendix A. History of Drools, jBPM, OptaPlanner

The first works on the Drools rule engine was initiated by Bob McWhirter in 2001, and was based on a brute force linear search approach. However due to the limitations of this approach, Drools 1.0 was not released. The next version Drools 2.0 was released in June 2005, where the rule engine used a partial implementation of the Rete algorithm for pattern matching, and rules were written in XML scripting language. By October 2005, the Drools project was incorporated into the JBoss Enterprise Middleware Suite (JEMS) and the project was led by Mark Proctor. A year later, in 2006 JBoss was acquired by Red Hat, Inc. and many of the features from the JBoss community projects were integrated into enterprise-class middleware software products. In June 2006, Drools 3.0 was released and included a full implementation of the Rete algorithm. Moreover this version introduced the '.drl' format, specifically for writing rules in the Drools Rule Language. By July 2007, Drools 4.0 was released, with major performance improvements for the rule engine, and more significantly, a business rule management system functionality was added [48], [49].

The next big release, Drools 5.0 was in 2009, which introduced the Business Logic integration Platform which provided a unified and integrated platform for Rules, Workflow and Event Processing. This platform included 5 main modules- Drools Expert (the rule engine itself), Drools Guvnor (the business rule management system), Drools Fusion (the module for complex event processing) and Drools Flow (providing workflow capabilities). It also included a module called Drools Solver which used search and optimization algorithms combined with Drools Expert (the rule engine) for solving planning problems [48].

The first official release of the jBPM project was in early 2004, followed by the 2.0 release later in the year. During the same period, the jBPM project was introduced into the JBoss family of products. The next version jBPM 3.0 was released in 2005, where the workflow engine supported the jBPM Process Definition Language (jPDL) and also introduced a web based console, which provided an easy to use graphical interface for managing processes and instances. In jBPM 4, the workflow engine was made to support jPDL as well as the BPMN 2.0 standard specification for creating process models [49], [50].

In February 2011, the 5th version of jBPM was released, where the workflow engine was integrated with the Drools rule engine. The jBPM 5 project inherited the code from Drools Flow project and Drools Expert. It also included the monitoring and management of processes through a web based console. BPMN 2 was used as the process definition language, which standardizes the visual representation of modeling notations for creating business processes, as well as their underlying XML representation [47], [50].

By late 2013, the sixth version of the Drools project, jBPM project and OptaPlanner (previously called Drools Planner) project was released and was grouped under an umbrella name called 'KIE', which was an acronym for 'Knowledge Is Everything'. This KIE group of projects also included the UberFire project for building workbenches and a DashBoard Builder which provided reporting capabilities [16], [47].

A time line showing the evolution of these projects can be seen in Figure 25.

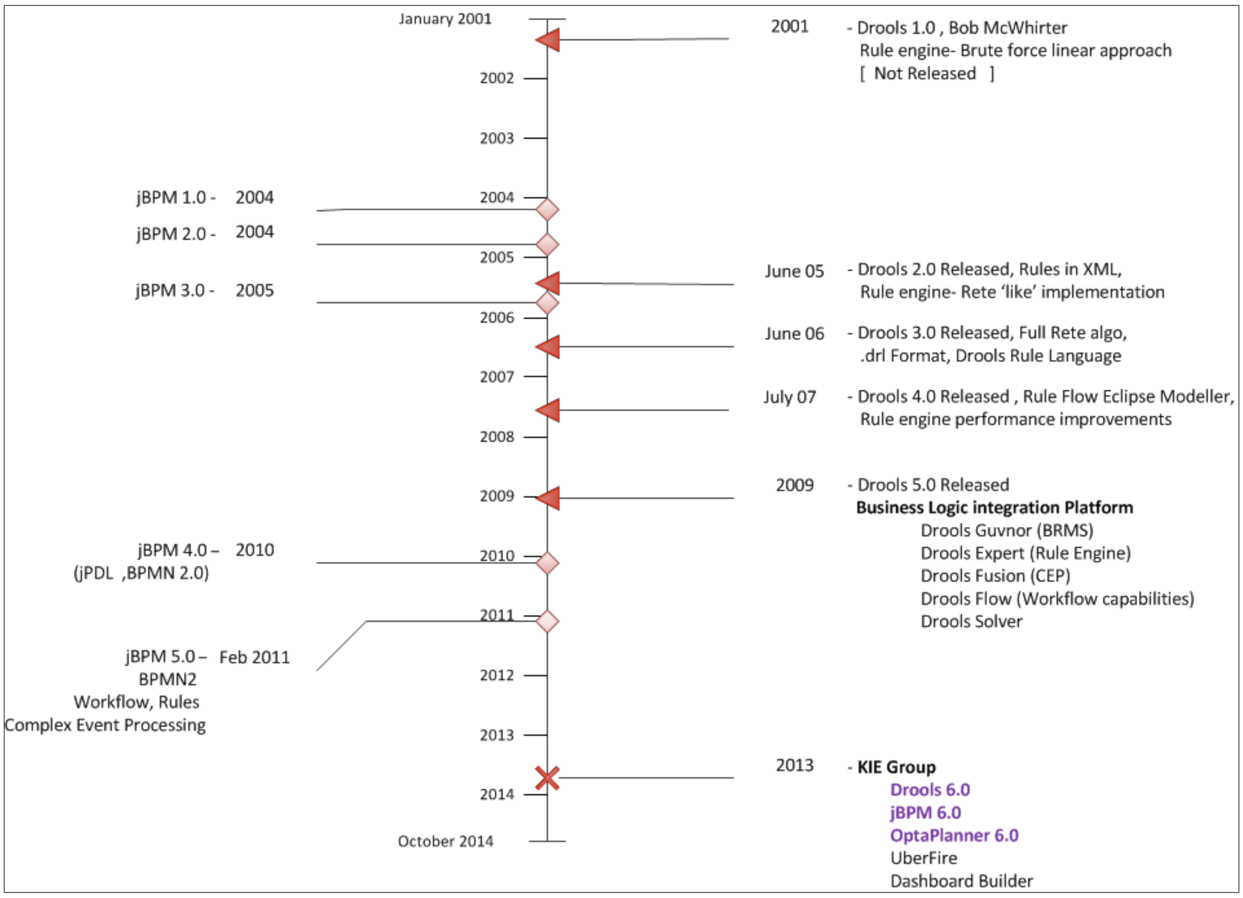

January 2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
October 2014
2001 - Drools 1.0 , Bob McWhirter
Rule engine- Brute force linear approach
[Not Released]
jBPM 1.0 - 2004
jBPM 2.0 - 2004
jBPM 3.0 - 2005
June 05 - Drools 2.0 Released, Rules in XML,
Rule engine- Rete 'like' implementation
June 06 - Drools 3.0 Released, Full Rete algo,
.drl Format, Drools Rule Language
July 07 - Drools 4.0 Released , Rule Flow Eclipse Modeller,
Rule engine performance improvements
2009 - Drools 5.0 Released
Business Logic integration Platform
Drools Guvnor (BRMS)
Drools Expert (Rule Engine)
Drools Fusion (CEP)
Drools Flow (Workflow capabilities)
Drools Solver
jBPM 4.0 – 2010
(jPDL ,BPMN 2.0)
jBPM 5.0 – Feb 2011
BPMN2
Workflow, Rules
Complex Event Processing
2013 - KIE Group
Drools 6.0
jBPM 6.0
OptaPlanner 6.0
UberFire
Dashboard Builder

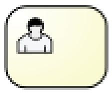
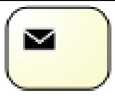
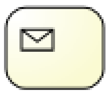
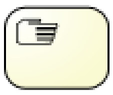
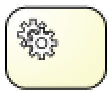
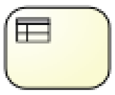
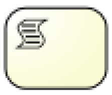
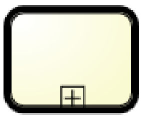
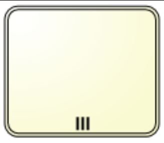
Figure 25: Timeline showing evolution of Drools, jBPM and OptaPlanner

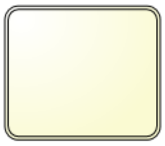
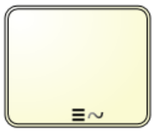
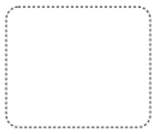
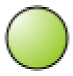
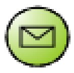
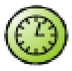
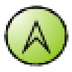
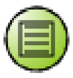
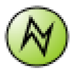
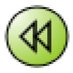
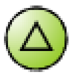
Appendix B. BPMN 2.0 Notations

B.1. BPMN 2.0 notations supported in jBPM 6

A list of the various BPMN 2.0 notations supported by jBPM can be seen in Table 3, along with their description [51] and those notations present in jBPM 5 as well.

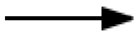
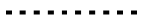
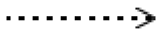
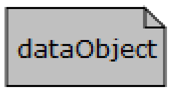
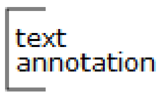
Table 3: BPMN 2.0 notations supported in jBPM 6

	Tasks	
	**User** *A User Task is performed by a human actor with the assistance of a software application and is scheduled through a task list manager.*	jBPM 5 check
	**Send-** *A Send Task is used to send a message to an external participant.*	jBPM 5 check
	**Receive** *A Receive Task is used to wait for a message to arrive from an external participant.*	jBPM 5 check
	**Manual** *A Manual Task is to be performed without the aid of the business process execution engine or any application.*	jBPM 5 check
	**Service** *A Service Task relies on an external Web service or an automated application for completing its unit of work.*	jBPM 5 check
	**Business Rule** *A Business Rule Task provides a mechanism for the process to provide input to a Business Rules Engine and to get the output of calculations that the Business Rules Engine might provide.*	jBPM 5 check
	**Script** *A Script Task is an automatic task in which a script is executed by the process engine.*	jBPM 5 check
	Sub Processes	
	**Reusable** *The reusable sub process is used to invoke another process through the 'Called Element 'property.*	jBPM 5 check
	**Multiple Instances** *A multiple instance sub process contains process segments that can be executed multiple times.*	jBPM 5 check

	**Embedded** *An embedded sub process acts a container for a process segment. It must contain a process with a start and end node.*	jBPM 5 check
	**Ad-Hoc** *An ad-hoc sub process contains a group of tasks that does not require a sequenced relationship.*	jBPM 5 check
	**Event** *An event sub process is placed within another sub process. It becomes active when its start event gets triggered and can interrupt the sub process context or run in parallel (non-interrupting), depending on the start activity.*	
	Start Events	
	**None** *Un-typed start event that triggers a new process instance.*	jBPM 5 check
	**Message** *The start of a process is triggered when a message is received from another process.*	jBPM 5 check
	**Timer** *A process instance is started on cyclic timer events, points in time, after time spans or timeouts.*	jBPM 5 check
	**Escalation** *Reacts on an escalation to another role in the organization. This event is only used inside of an event sub process.*	jBPM 5 check
	**Conditional** *A process instance is started based on changed business conditions or matching business*	jBPM 5 check
	**Error** *Catches named errors. This event is only used inside of an event-sub process. An event-sub process with an error trigger will always interrupt its containing process.*	jBPM 5 check
	**Compensation** *Compensation handling. This event is only used inside of an event sub process.*	jBPM 5 check
	**Signal** *A process instance is started based on signaling across different processes.*	jBPM 5 check

	End Events	
●	**None** *The un-typed end event typically marks the standard end of a process.*	jBPM 5 check
✉	**Message** *At the end of the process, a message is sent.*	jBPM check
⋀	**Escalation** *The case is escalated with the end of the process.*	jBPM 5 check
ϟ	**Error** *The process ends in an error state. As result a named error is thrown*	jBPM 5 check
✖	**Cancel** *Triggering cancellation of a transaction.*	jBPM 5 check
⏪	Compensation *Triggering compensation as final process step.*	jBPM 5 check
▲	Signal *At the end of the process, a signal is thrown*	jBPM 5 check
●	Terminate *Triggering the immediate termination of a process instance. All steps still in execution in parallel branches are terminated.*	jBPM 5 check
	Catching Intermediate Events	
✉	**Message** *This event reacts on the arrival of a message.*	jBPM 5 check
🕒	**Timer** *Process execution is delayed until a certain point in time is reached or a particular duration is over.*	jBPM 5 check
⋀	**Escalation** *This event reacts on the escalation of a case. It needs to be attached to the boundary of an activity.*	jBPM 5 check
☰	**Conditional** *Process execution is delayed until a changed business condition or business rule matches.*	jBPM 5 check
ϟ	**Error** *An Intermediate Error Catch Event can only be attached to the boundary of an activity. The Error Event always interrupts the activity to which it is attached.*	jBPM 5 check
⏪	**Compensation** *Compensation handling in case of partially failed operations. This event needs to be attached to the boundary of an activity.*	
△	**Signal** *A signal that has been thrown will be caught.*	jBPM 5 check

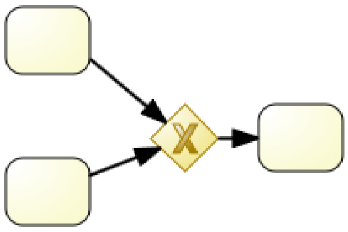
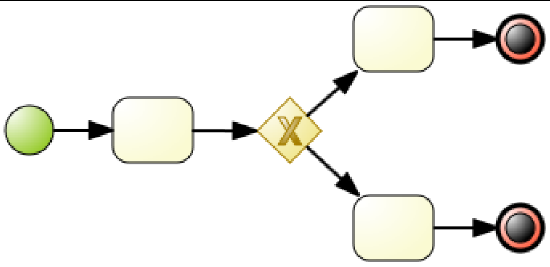
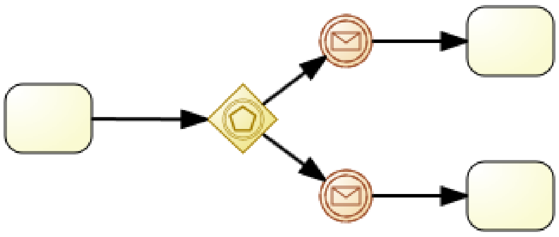
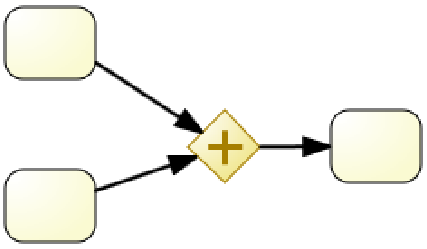
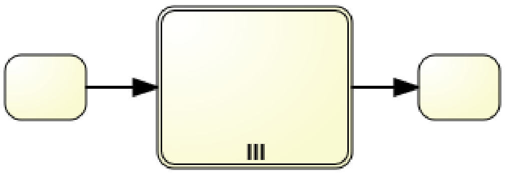
Throwing Intermediate Events		
	Message *A Message Intermediate Event can be used to either send a Message or receive a Message.*	jBPM 5 check
	Escalation *This event triggers the escalation of the case to another role in the organization.*	jBPM 5 check
	Signal *A signal event will be thrown*	jBPM 5 check
Gateways		
	Data-based Exclusive (XOR) *When splitting, it routes the sequence flow to exactly one of the outgoing branches based on conditions. When merging, it awaits one incoming branch to complete before triggering the outgoing flow.*	jBPM 5 check
	Event-based *It is always followed by catching events or receiving tasks. It is used to represent deferred choices within a process.*	jBPM 5 check
	Parallel *It is used to split a sequence flow or merge parallel sequence flows. When a sequence flow is split, all outgoing branches are executed simultaneously. When it is used to merge parallel sequence flows, it waits for all incoming branches to be completed before triggering the outgoing flow.*	jBPM 5 check
	Inclusive *When splitting, one or more branches are activated based on branching conditions. When merging, it awaits all active incoming branches to complete.*	jBPM 5 check
Service Tasks		
Log	**Log**	jBPM 5 check
Email	**Email**	jBPM 5 check
REST	**REST**	
WS	**Web Service**	

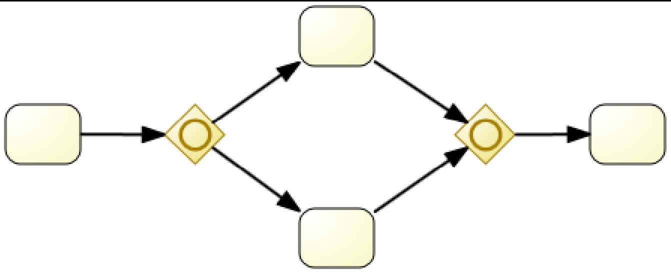
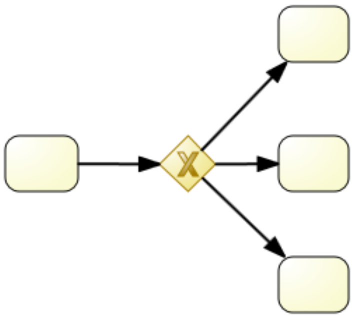
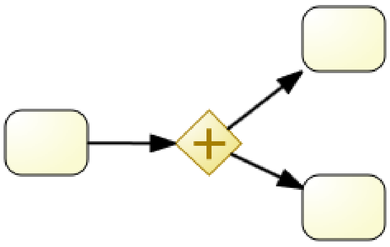
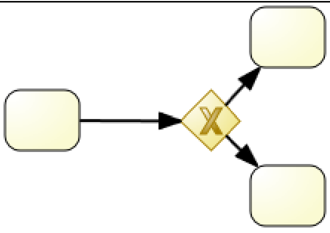
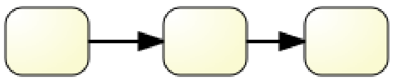
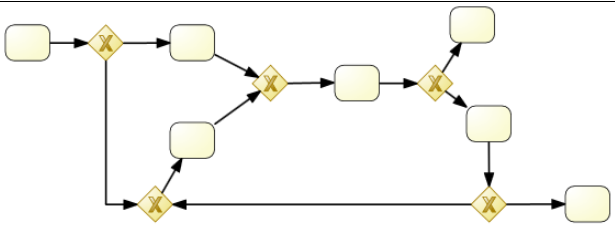
	Connecting Objects	
	**Sequence Flow** *It is used to define the order in which activities will be executed.*	jBPM 5 check
	**Association (un directed)** *It is attached to a sequence flow and a data object. It is used to represent the transfer of information between the activities involved.*	jBPM 5 check
	**Association (uni directional)** *It is used to represent the flow of information between two activities. A data object is created at the end of one activity and read at the beginning of the other activity*	jBPM 5 check
	Data Object	
	**Data Object** *It is used to represent the information flowing within the process.*	jBPM 5 check
	Swimlanes	
	Lane *It is used to represent the participants of a process and the different activities they are responsible for.*	jBPM 5 check
	Artifacts	
	Group *It is used to represent a set of nodes that logically belong together*	jBPM 5 check
	**Text Annotation** *It is used to provide additional documentation within the process*	jBPM 5 check

B.2. Workflow patterns in jBPM 6

A list of the different workflow patterns supported by jBPM 6 can be seen in Table 4

Table 4: Workflow patterns supported in jBPM 6

Workflow Patterns	
	Simple Merge
	Implicit Termination
	Deferred Choice
	Synchronization
	Multiple Instances without synchronization

	Synchronizing Merge
	Exclusive Choice
	Parallel Split
	XOR Split
	Sequence
	Arbitrary cycles

Appendix C. Business Process Simulation

C.1. Business Process Simulation in jBPM 6

Since the release of jBPM 5.4, simulation capabilities have been introduced in the web-based designer. This process simulation tool is compatible with the Business Process Simulation Interchange Standard (BPSim) which is a WfMC standard [52]. The simulation relies on the different possible execution paths rather than process data.

In order to run simulations in jBPM, the business process must be correctly modeled using the BPMN 2.0 semantics. Further each BPMN 2.0 notation in the process model has specific simulation properties which must be specified. A list of the different simulation properties for each BPMN 2.0 constructs can be seen in Table 5. It is possible to visually validate the process model to check if the BPMN 2.0 semantics has been correctly used. In case, certain nodes contain validation errors, then those nodes are highlighted and by clicking on the node, a description of the error can be seen.

Before running the simulation, certain simulation session details must also be specified, namely the number of process instances to be created and triggered, and the specific interval time (inter-arrival time) between each process instance. The results of the simulation can be seen in a simulation tab within the web-based designer. The results can be viewed from 3 different perspectives – the process perspective, activity perspective and path perspective.

In the process perspective, various simulation graphs (bar charts and pie charts) can be seen showing the execution time (minimum, maximum, average)of the process , the number of activity instances and the total cost (minimum , maximum ,average) involved for executing the process. Moreover the data in these charts can also be filtered. There is also a Timeline feature which allows us to move forward in time, and see the execution times of various activities for all process instances.

In the activity perspective, the minimum, maximum and average execution time, wait time , resource utilization and resource cost can be seen for each activity.

Finally in the path perspective, all possible paths are highlighted and the number of instances traversing a particular path can be seen as a pie chart. A path is a set of activities followed sequentially from the start event to the end event, and it may include loops.
A sample model can be seen in Figure 26, along with its simulation results at the process perspective in Figure 27. The timeline feature at the process perspective can also be seen in Figure 28. Simulation results for the activity perspective and path perspective can be seen in Figure 29 and Figure 30 respectively.

Table 5: Simulation properties for the various BPMN 2 constructs supported by jBPM

BPMN2 construct		Simulation Properties
Tasks	User	Cost per time unit Distribution Type Processing Time Staff availability Working hours
	Send/Receive Service Business Rule Manual Script	Cost per time unit Distribution Type Processing Time
Sub Processes	Reusable Multiple Instances Embedded Ad-Hoc Event	Cost per time unit Distribution Type Processing Time
Start Events	Message Timer Escalation Conditional Error Compensation Signal	Distribution Type Processing Time
End Events	Message Escalation Error Cancel Compensation Signal Terminate	Distribution Type Processing Time
Catching Intermediate Events	Timer	Distribution Type Processing Time Wait Time
	Message Escalation Conditional Error Compensation Signal	Distribution Type Processing Time
Throwing Intermediate Events	Message Escalation Signal	Distribution Type Processing Time
Connecting Objects	Sequence Flow	Probability

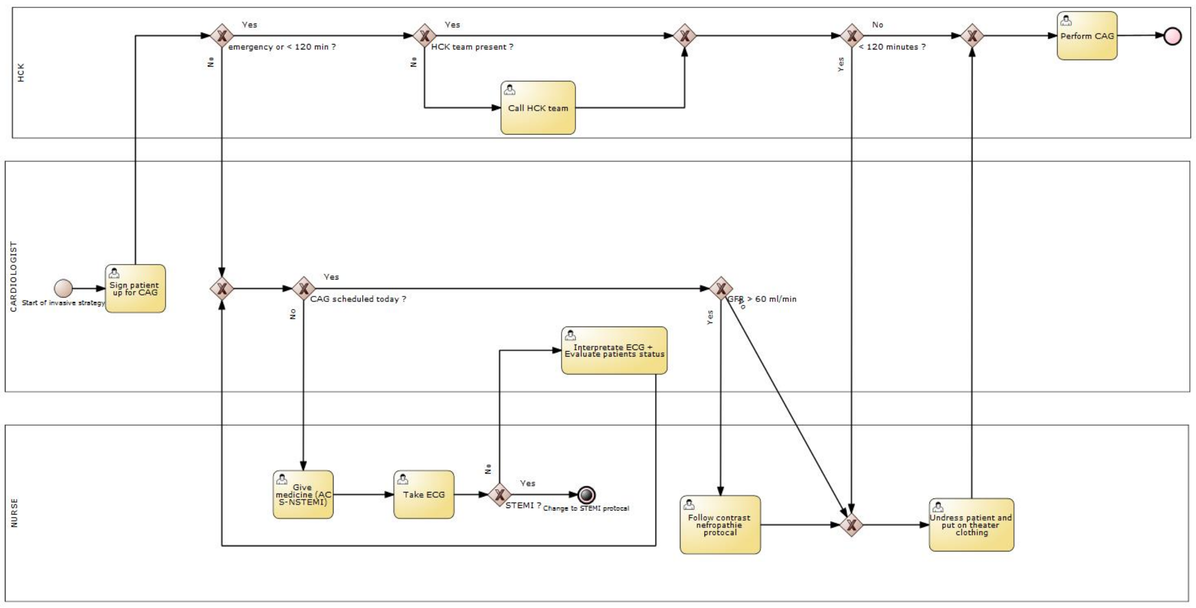


Figure 26: Sample model

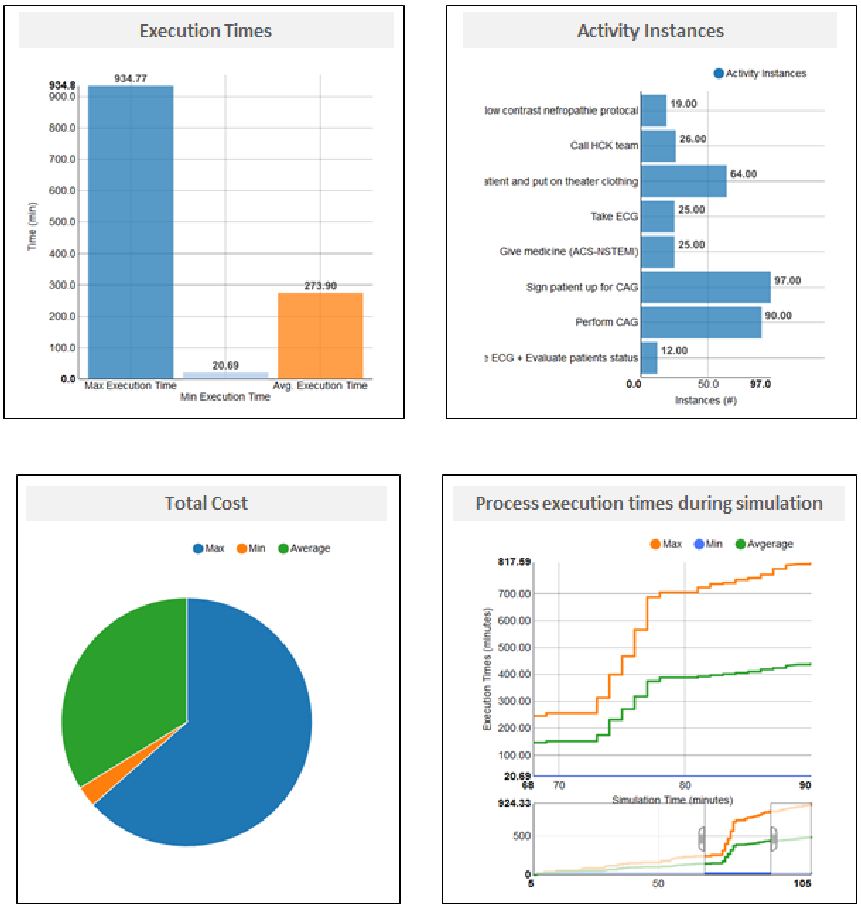


Figure 27: Simulation results at the process perspective

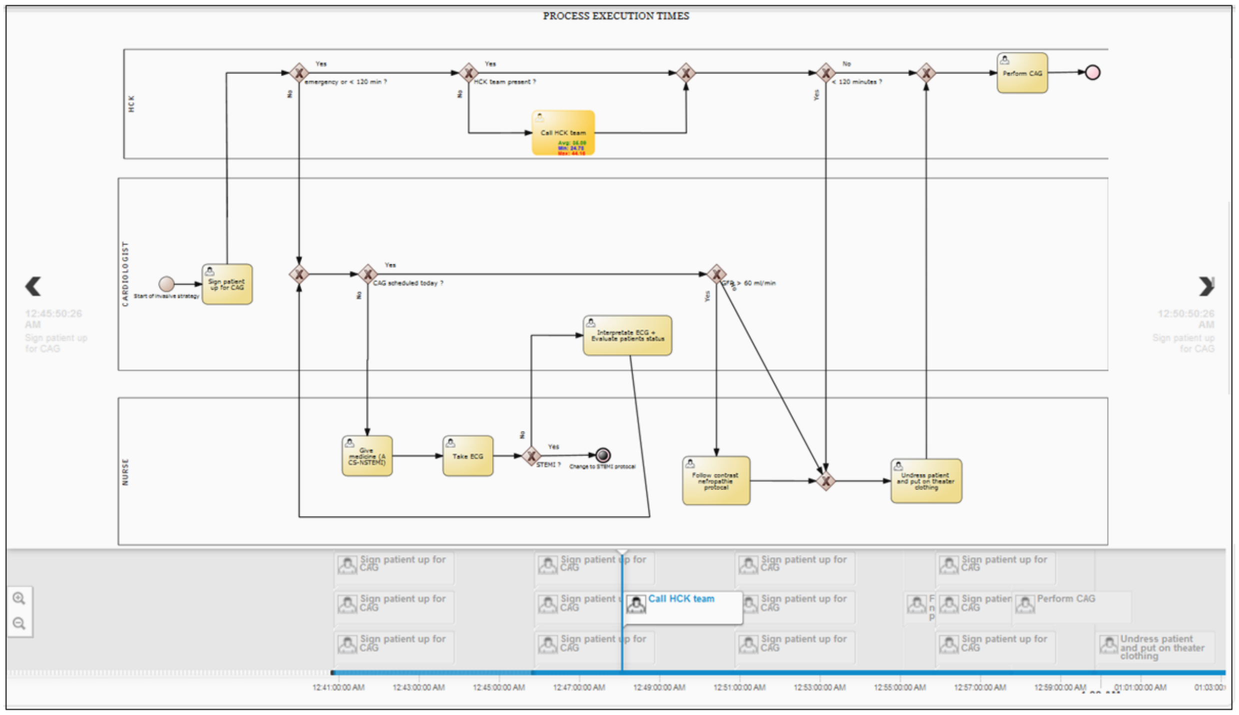


Figure 28: Simulation results at the process perspective -Timeline feature

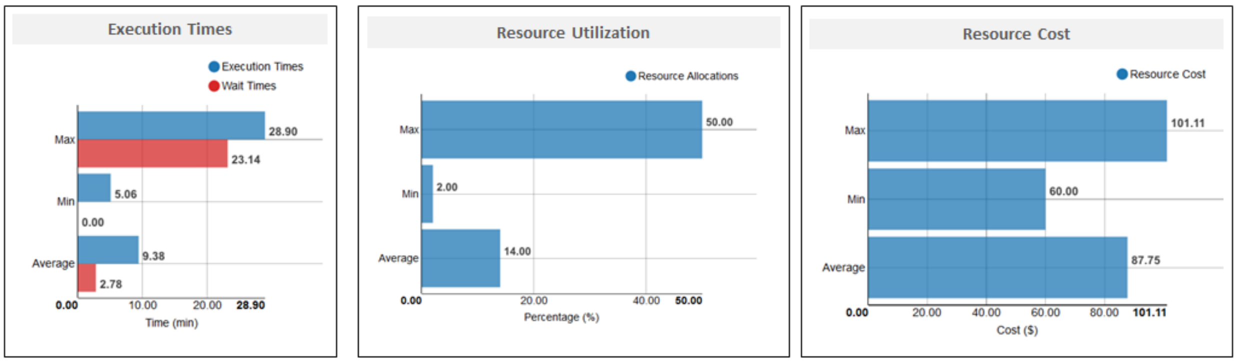


Figure 29: Simulation results at the activity perspective

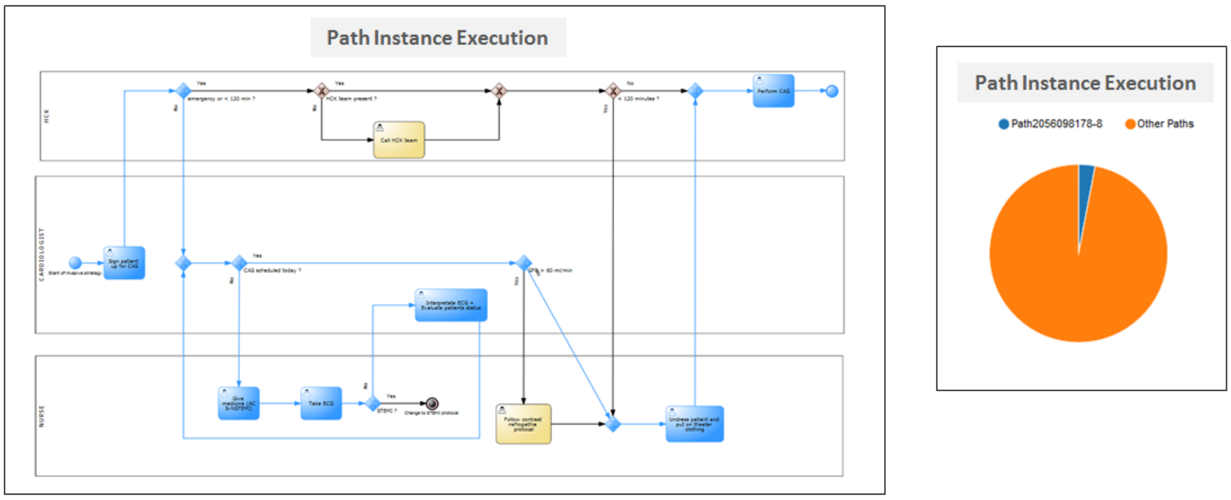


Figure 30: Simulation results at the path perspective

C.2. Problems and limitations in jBPM Business Process Simulations

1. The simulation engine does not run for some models or when the simulation scenario properties have a large number of process instances to be created and triggered. Figure 31 and Figure 32 shows two models, where the simulation engine did not run.

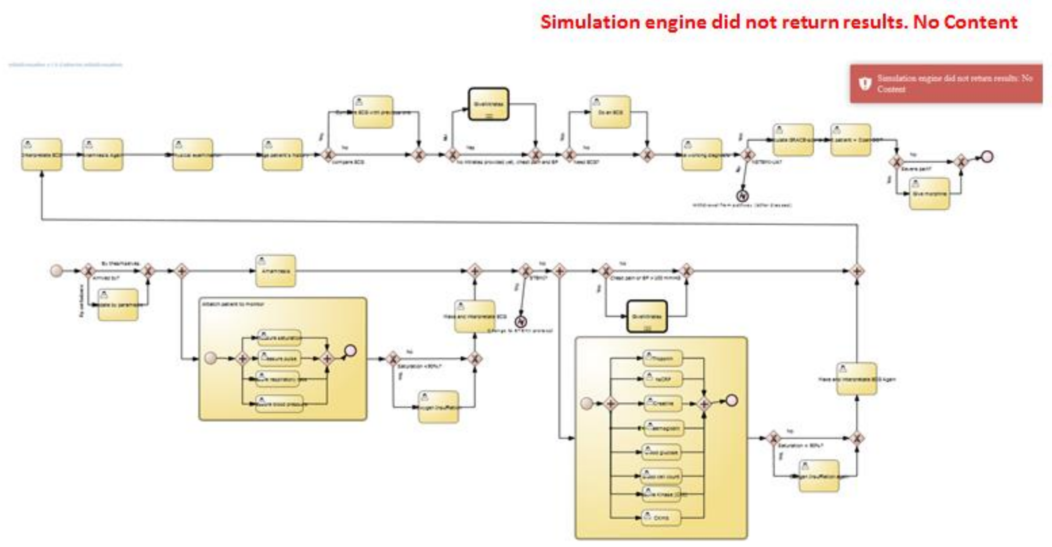

Simulation engine did not return results. No Content
Simulation engine did not return results: No Content

Figure 31: Simulation engine does not run for the model (1)

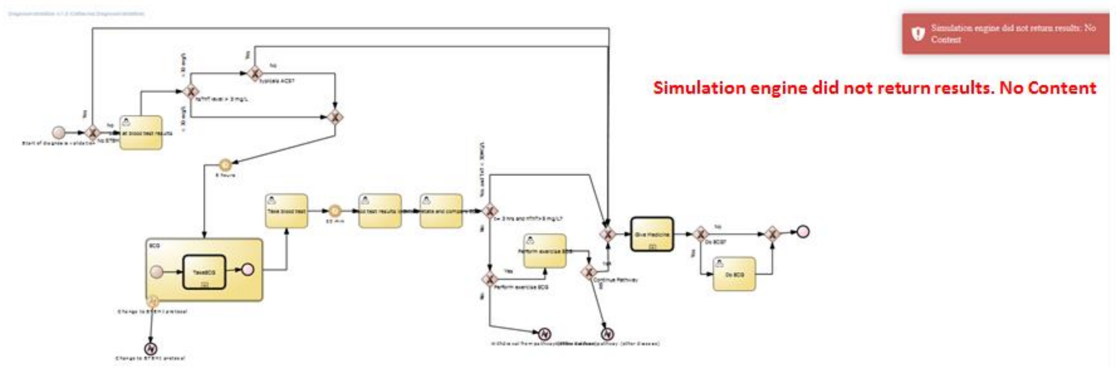

Simulation engine did not return results: No Content
Simulation engine did not return results. No Content

Figure 32: Simulation engine does not run for the model (2)

2. When there are 15-20 paths in a process model, all paths cannot be visually shown.

3. Simulation supports only a limited number of distribution types- namely Poisson, uniform and normal distributions as shown in Table 6.

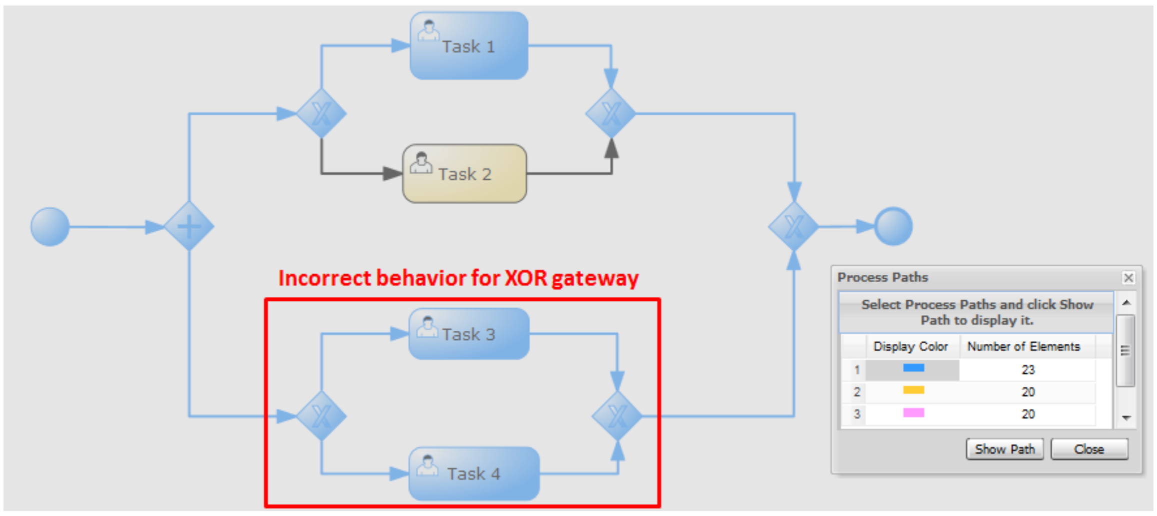
Table 6: Distribution types and their processing time

Distribution Types	Processing Time
Poisson distribution	Mean processing time
Normal distribution	Mean processing time and standard deviation
Uniform distribution	Maximum, minimum processing times

4. The inter–arrival rate of process instances has to be a constant value. In reality it usually follows a particular distribution type.

5. For sub processes (embedded, reusable tasks), it is not possible to drill down and analyze simulation results of the activities within.

6. Incorrect behavior of BPMN semantic sometimes. For instance, Figure 33, shows a model where a process path includes both Task 3 and Task 4 from an XOR gateway.


Task 1
Task 2
Incorrect behavior for XOR gateway
Task 3
Task 4
Process Paths
Select Process Paths and click Show Path to display it.
Show Path
Close

	Display Color	Number of Elements
1	🟦	23
2	🟨	20
3	🟪	20

Figure 33: Incorrect behavior for XOR gateway

7. Currently resource utilization is calculated for **each** human task based on the number of staff available for the given task and the wait time. The simulation does not support the concept of pooled resources when calculating resource utilization.

   For instance, consider a sample model as shown in Figure 34. In the process there are 3 tasks done in parallel. Task 1 and Task 3 can be done by doctors and Task 2 can be done by nurses. Let's assume there are 5 doctors available to do Task 1 and Task 3, and 5 nurses available to do Task 2. The number of doctors and nurses will be specified in the Staff Available simulation property of the respective human task nodes.

For each human task node, the execution time is set to follow a Normal distribution, with a mean processing time of 10 minutes, and a standard deviation of 1. Additionally the simulation scenario properties include 100 process instances to be created and triggered, with an inter-arrival time of 20 minutes.

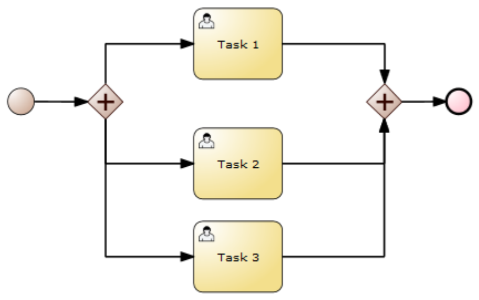


Figure 34: Sample model 1 for checking resource utilization

Table 7 shows the resource utilization for each task, after running the simulation. Here we can observe that the resource utilization for task 1 and task 3 are nearly the same.

Table 7: Resource utilization at the activity perspective for Sample model 1(in Figure 34)

Resource Utilization	**Maximum (%)**	**Minimum (%)**	**Average (%)**
Task 1	47	0	11.64
Task 2	36	0	9.02
Task 3	46	0	11.45

If the model is further extended by adding two more human task nodes- task 4 and task 5 as shown in Figure 35 and then setting the simulation properties of the two nodes to have 5 staff available.

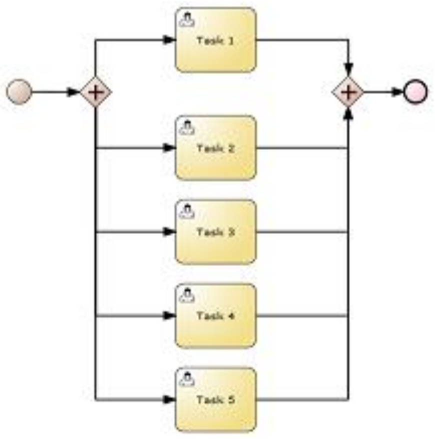


Figure 35: Sample model 2 for checking resource utilization

Then the resource utilization found after running simulations can be seen in Table 8. Once again, we can observe that the resource utilization is nearly the same for tasks 1, 2, 4 and 5.

Table 8: Resource utilization at the activity perspective for Sample model 2(in Figure 35)

Resource Utilization	**Maximum (%)**	**Minimum (%)**	**Average (%)**
Task 1	52	0	12.94
Task 2	37	0	9.21
Task 3	38	0	9.49
Task 4	40	0	10.01
Task 5	42	0	10.36

When running simulations, the resource utilization should be calculated based on the roles. For instance, if there are 5 employees who have the role of a doctor, the resource utilization should give a single value for the role doctor. Currently this concept of pooled resources is not supported in jBPM simulations.

Appendix D. Business Activity Monitoring

jBPM 6 also provides a Business Activity Monitoring module (also called a Dashboard Builder) which is used to create dashboards. These dashboards are used to display key performance indicators relevant to a business process. Two types of Dashboards can be built using this module – Business Dashboards which can use data retrieved from any relational database through SQL queries; and a Process Dashboard which uses data retrieved from the jBPM database (the database where the jBPM engine will persist data) [25]. In Figure 36, we can some process dashboards.

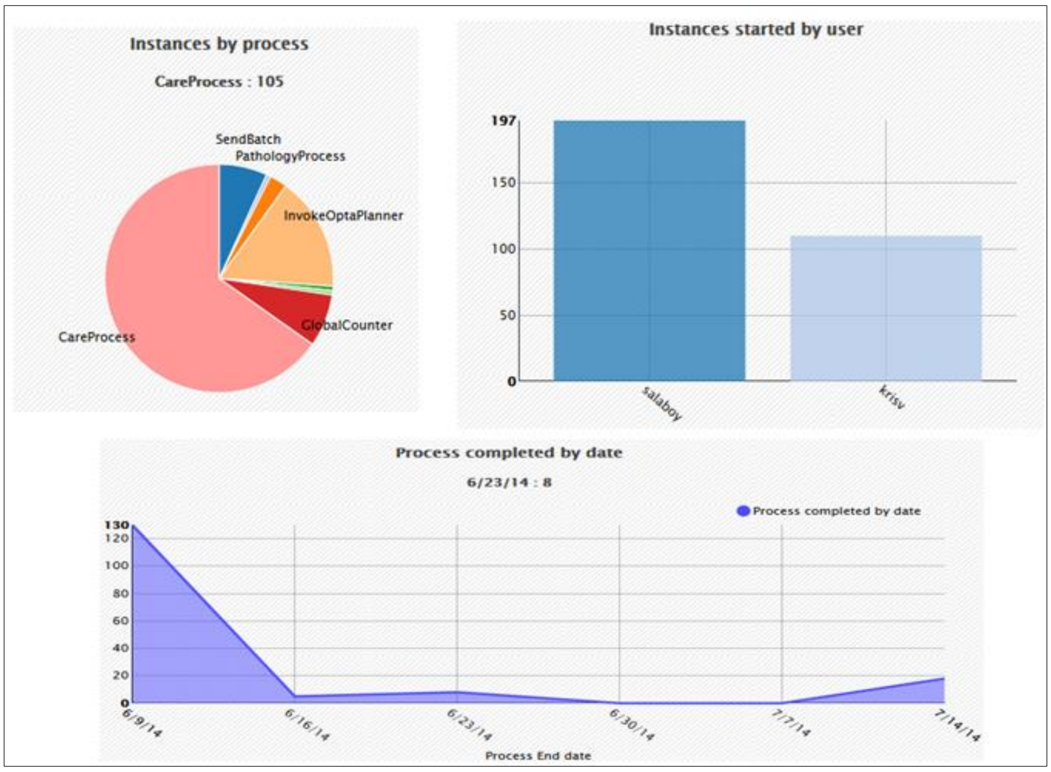


Figure 36: Process dashboards

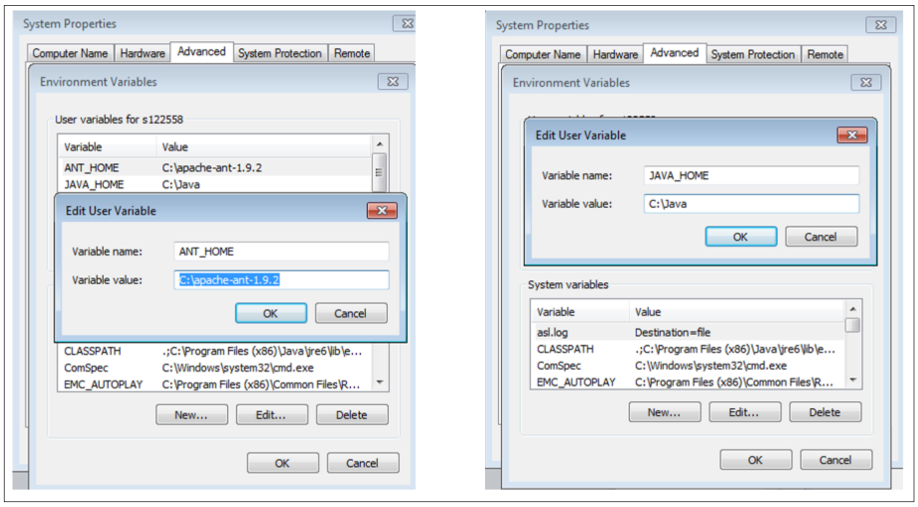
Appendix E. Installation and setup of jBPM 6.0.1

jBPM 6.0.1 is installed and a demo setup will be created, which will include the core engine (rule engine and workflow engine) and a web console deployed on JBoss Application Server 7. The Drools and jBPM plugins for the Eclipse IDE will also be installed along with an Eclipse based BPMN2 modeler. Additionally, jBPM 6.0.1 has been configured to use the PostgreSQL database for persisting runtime data.

E.1. Steps to install jBPM 6.0.1

1) Download and install Java JDK 1.5+ and Ant 1.7+
   They can be downloaded from -
   Java: http://java.sun.com/javase/downloads/index.jsp
   Ant: http://ant.apache.org/bindownload.cgi

2) Open the *Advanced System Settings*, and click on the *Environment Variables* tab, then
   a. Set ANT_HOME, JAVA_HOME to the path where ANT and Java was installed respectively, as shown in Figure 37.



System Properties
Computer Name | Hardware | Advanced | System Protection | Remote
Environment Variables
New... | Edit... | Delete
OK | Cancel

User variables for s122558

Variable	Value
ANT_HOME	C:\apache-ant-1.9.2
JAVA_HOME	C:\Java

Edit User Variable
Variable name: ANT_HOME
Variable value: C:\apache-ant-1.9.2

Variable	Value
CLASSPATH	.;C:\Program Files (x86)\Java\jre6\lib\e...
ComSpec	C:\Windows\system32\cmd.exe
EMC_AUTOPLAY	C:\Program Files (x86)\Common Files\R...

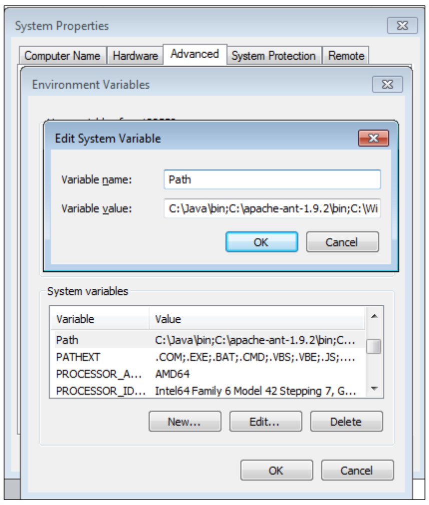
Edit User Variable
Variable name: JAVA_HOME
Variable value: C:\Java

System variables

Variable	Value
asl.log	Destination=file
CLASSPATH	.;C:\Program Files (x86)\Java\jre6\lib\e...
ComSpec	C:\Windows\system32\cmd.exe
EMC_AUTOPLAY	C:\Program Files (x86)\Common Files\R...

Figure 37: Setting system properties (1)

   b. Add the location of the *bin* folder of ANT and Java, to the Path in System Variables, as shown in Figure 38.



Variable name: Path
Variable value: C:\Java\bin;C:\apache-ant-1.9.2\bin;C:\Wi

Variable	Value
Path	C:\Java\bin;C:\apache-ant-1.9.2\bin;C...
PATHEXT	.COM;.EXE;.BAT;.CMD;.VBS;.VBE;.JS;....
PROCESSOR_A...	AMD64
PROCESSOR_ID...	Intel64 Family 6 Model 42 Stepping 7, G...

Figure 38: Setting system properties (2)

3) Download jbpm-6.0.1.Final-installer-full.zip from - http://sourceforge.net/projects/jbpm/files/

4) Unzip jbpm-6.0.1.Final-installer-full.zip to a folder at a particular path

5) Now open the Command Prompt, and point the cursor to the path where jbpm-6.0.1.Final-installer-full.zip was unzipped.

6) Then type command - ***ant install.demo***
This will do the following: -

- Download JBoss Application Server 7
- Download Eclipse
- Install the jBPM Console into JBoss AS
- Install the jBPM Eclipse plugin
- Install the Drools Eclipse plugin

Alternatively if you do not wish to install Eclipse, then type command –
ant install.demo.noeclipse

7) Then to start the setup, type the following command in the Command Prompt - ***ant.start.demo***

This will do the following -

- Starts the H2 database
- Starts the JBoss Application Server
- Start Eclipse
- Start the jBPM Human Task Service

Alternatively, if you wish not to start Eclipse, then type the command - ***ant.start.demo.noeclipse***

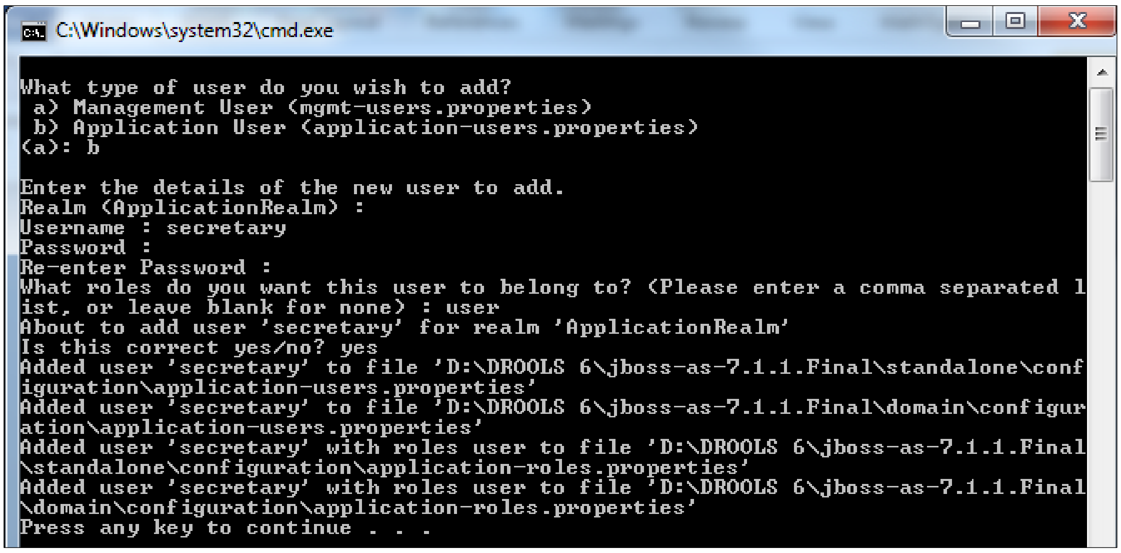
8) The **KIE Workbench** can then be opened at http://localhost:8080/jbpm-console
It is recommended to use Mozilla Firefox web browser.

9) Once the work has been completed, type the following command in the command prompt- ***ant stop.demo***

E.2. Steps to create users in jBPM

1) In the folder where *jbpm-6.0.1.Final-installer-full* is installed, then go to folder *jboss-as-7.1.1.Final\bin ,* and open the file - *add-user.bat*

   Opening the Batch file, will show a Command Prompt window as shown in Figure 39.



```
What type of user do you wish to add?
 a) Management User (mgmt-users.properties)
 b) Application User (application-users.properties)
(a): b

Enter the details of the new user to add.
Realm (ApplicationRealm) :
Username : secretary
Password :
Re-enter Password :
What roles do you want this user to belong to? (Please enter a comma separated l
ist, or leave blank for none) : user
About to add user 'secretary' for realm 'ApplicationRealm'
Is this correct yes/no? yes
Added user 'secretary' to file 'D:\DROOLS 6\jboss-as-7.1.1.Final\standalone\conf
iguration\application-users.properties'
Added user 'secretary' to file 'D:\DROOLS 6\jboss-as-7.1.1.Final\domain\configur
ation\application-users.properties'
Added user 'secretary' with roles user to file 'D:\DROOLS 6\jboss-as-7.1.1.Final
\standalone\configuration\application-roles.properties'
Added user 'secretary' with roles user to file 'D:\DROOLS 6\jboss-as-7.1.1.Final
\domain\configuration\application-roles.properties'
Press any key to continue . . .
```

Figure 39: Creating users in jBPM (1)

Then in order to create users, do the following:-

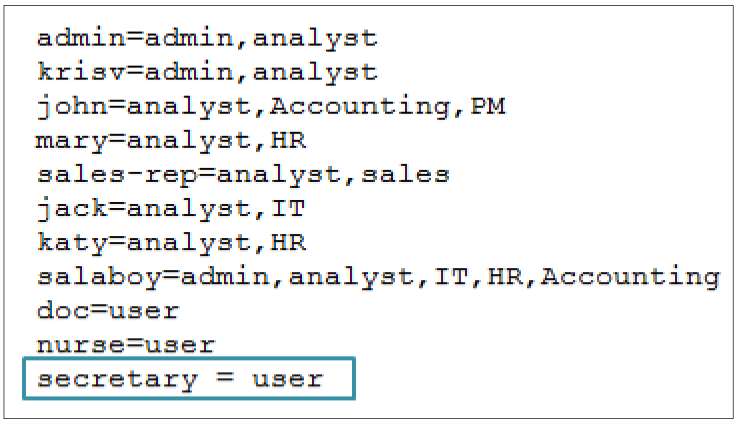
- Choose option b for creating an application user
- Leave Realm empty
- Enter a username and password ,which must be different
  (For instance – *Username* is *secretary* and *Password* is *abcd*)
- Enter the role which this user belongs to (For instance- role is *user*).
  The different roles provided by jBPM can be seen in Table 9

Table 9: Predefined roles in jBPM 6 [25]

Role	Description
admin	*Administrates the BPMS system. Have full access rights to make any changes necessary. Also has the ability to add and remove users from the system.*
analyst	*Creates rules, models, process flows, forms, dashboards and handles process change requests.*
developer	*Implements code required for process to work. Mostly uses the JBoss Developer Studio connection to view processes, but may use the web tool occasionally.*
manager	*Viewer of the system that is interested in statistics around the business processes and their performance, business indicators, and other reporting of the system and people who interact with the system.*
user	*Daily user of the system to take actions on business tasks that are required for the processes to continue forward. Works primarily with the task lists*

2) Then go to *jboss-as-7.1.1.Final\standalone\configuration* folder, and open the *roles.properties* file

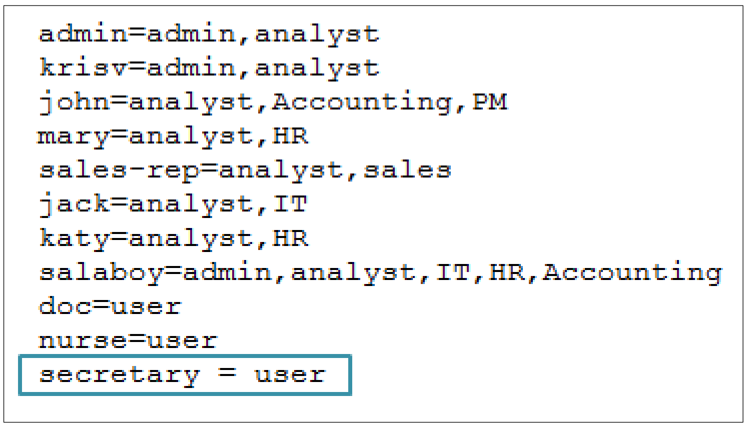
   Append to the list the username and its respective role (*secretary=user*) as shown in Figure 40.



```
admin=admin,analyst
krisv=admin,analyst
john=analyst,Accounting,PM
mary=analyst,HR
sales-rep=analyst,sales
jack=analyst,IT
katy=analyst,HR
salaboy=admin,analyst,IT,HR,Accounting
doc=user
nurse=user
secretary = user
```

Figure 40: Creating users in jBPM (2)

3) In the same folder, open the *users. properties* file, and enter the username and password (secretary= abcd) as shown in Figure 41.

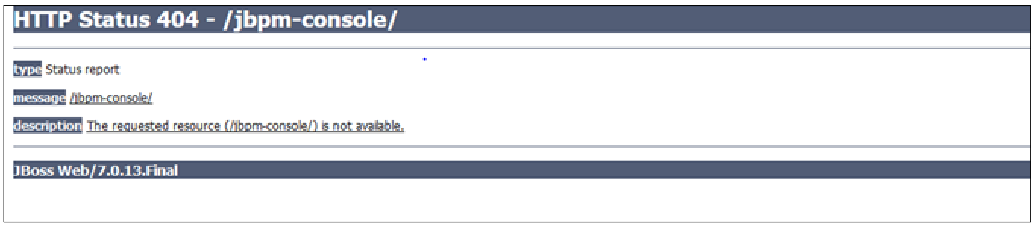


```
admin=admin,analyst
krisv=admin,analyst
john=analyst,Accounting,PM
mary=analyst,HR
sales-rep=analyst,sales
jack=analyst,IT
katy=analyst,HR
salaboy=admin,analyst,IT,HR,Accounting
doc=user
nurse=user
secretary = user
```

Figure 41: Creating users in jBPM (3)

E.3. Problems in jBPM

1) After starting the demo setup using ant.start.demo, and then going to http://localhost:8080/jbpm-console, the error shown in Figure 42 comes on screen , although JBoss Application Server is still running



HTTP Status 404 - /jbpm-console/

type Status report

message /jbpm-console/

description The requested resource (/jbpm-console/) is not available.

JBoss Web/7.0.13.Final

Figure 42: Startup error

This is a startup time lag. Wait for 1-2 minutes and refresh screen.

2) After modeling a process and executing the process definition and then if you delete the process model before performing the tasks in the process, then the active process instance cannot be deleted.

3) When modeling a process in the jBPM web based designer,

- The model often gets disturbed at gateways, especially when trying to edit gateway properties.
- Sometimes it becomes impossible to connect an object to another object (connection arrow to object does not work).
- Sometimes you cannot place objects on the editor/workspace.

5) Sometimes the project explorer may disappear (for instance, after deleting a repository) as shown in Figure 43. Then it is not possible to author a process. (http://drools.46999.n3.nabble.com/Project-Explorer-has-dissappeared-in-KIE-Workbench-td4027767.html)

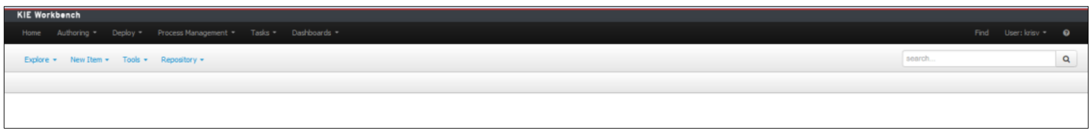
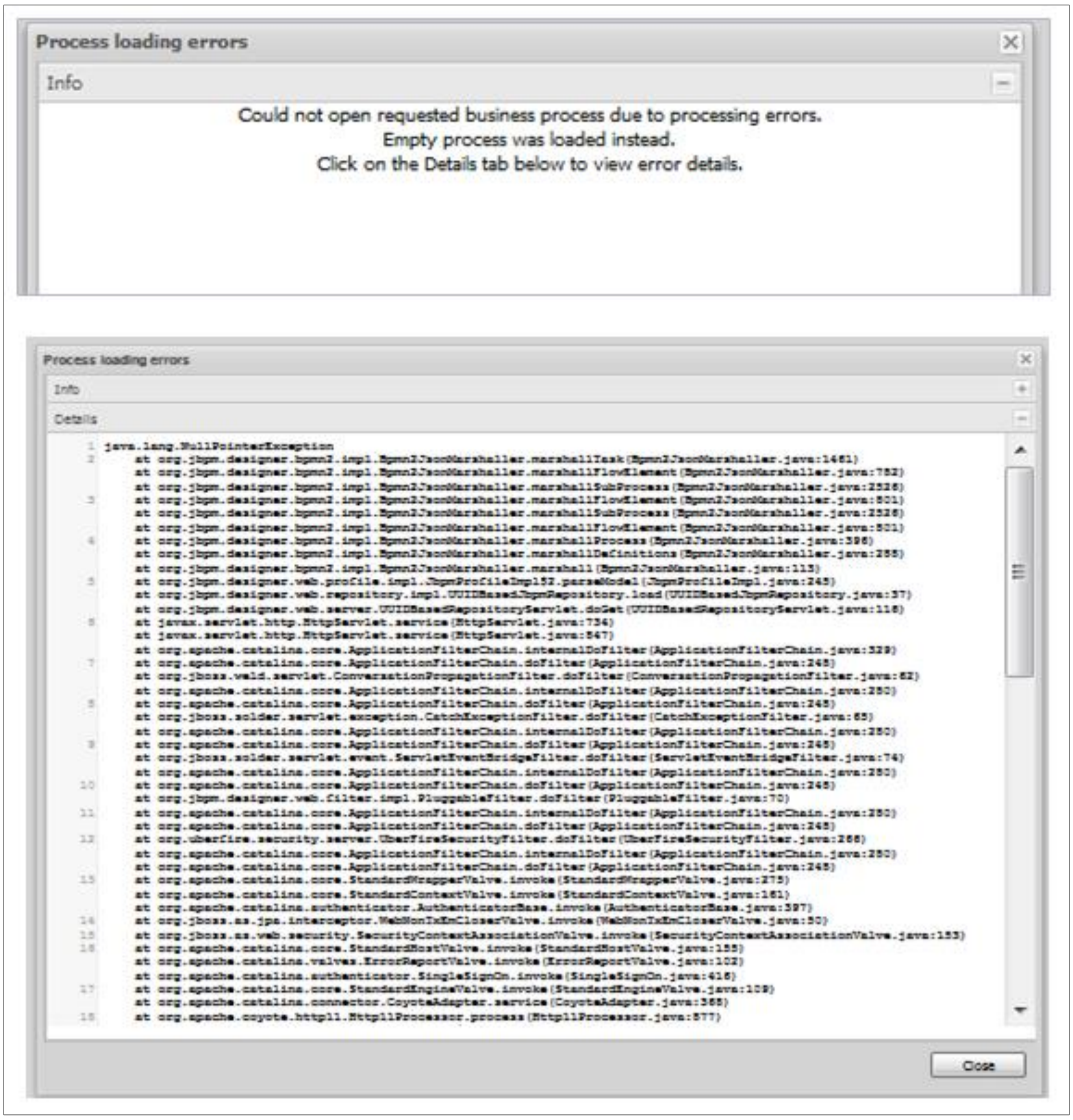


Figure 43: Project explorer has disappeared in the KIE workbench

4) Sometimes when reopening a previously saved model in the jBPM web based designer, the error shown in Figure 44 occurs. If this error occurs to any one process in the project then you cannot, build and deploy the process definition. Moreover you cannot see the option to delete the process as well. (https://issues.jboss.org/browse/JBPM-4203)



Could not open requested business process due to processing errors.
Empty process was loaded instead.
Click on the Details tab below to view error details.

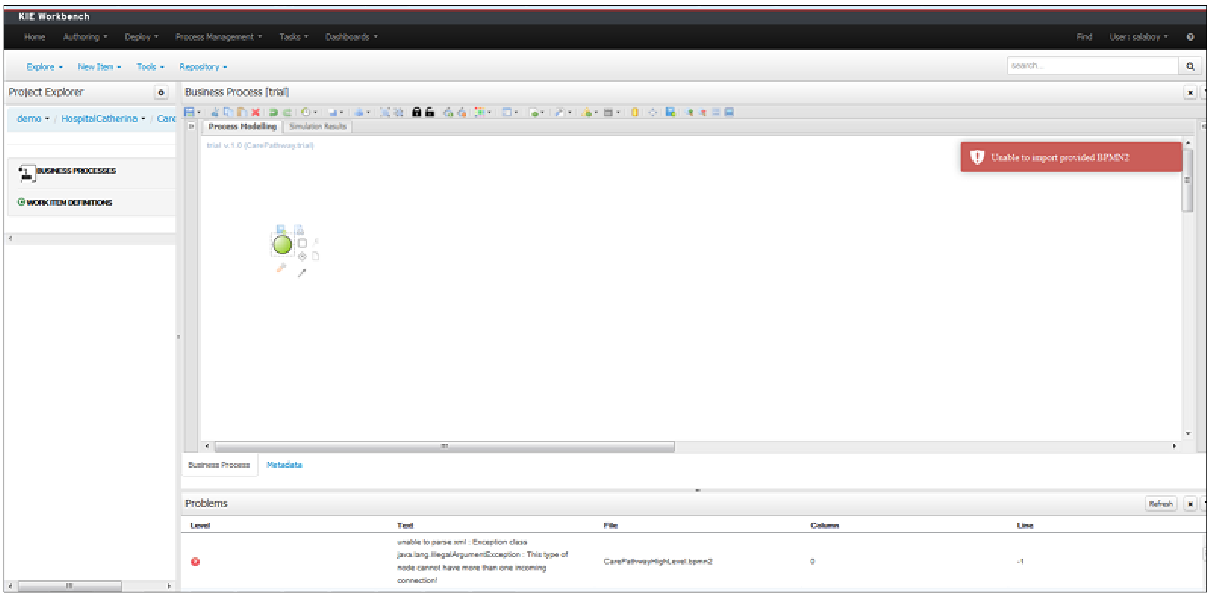
```
java.lang.NullPointerException
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallTask(Bpmn2JsonMarshaller.java:1461)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallFlowElement(Bpmn2JsonMarshaller.java:752)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallSubProcess(Bpmn2JsonMarshaller.java:2526)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallFlowElement(Bpmn2JsonMarshaller.java:801)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallSubProcess(Bpmn2JsonMarshaller.java:2526)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallFlowElement(Bpmn2JsonMarshaller.java:801)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallProcess(Bpmn2JsonMarshaller.java:396)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshallDefinitions(Bpmn2JsonMarshaller.java:255)
    at org.jbpm.designer.bpmn2.impl.Bpmn2JsonMarshaller.marshall(Bpmn2JsonMarshaller.java:113)
    at org.jbpm.designer.web.profile.impl.JbpmProfileImpl$2.parseModel(JbpmProfileImpl.java:245)
    at org.jbpm.designer.web.repository.impl.UUIDBasedJbpmRepository.load(UUIDBasedJbpmRepository.java:37)
    at org.jbpm.designer.web.server.UUIDBasedRepositoryServlet.doGet(UUIDBasedRepositoryServlet.java:116)
    at javax.servlet.http.HttpServlet.service(HttpServlet.java:734)
    at javax.servlet.http.HttpServlet.service(HttpServlet.java:847)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:329)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.jboss.weld.servlet.ConversationPropagationFilter.doFilter(ConversationPropagationFilter.java:62)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:280)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.jboss.solder.servlet.exception.CatchExceptionFilter.doFilter(CatchExceptionFilter.java:65)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:280)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.jboss.solder.servlet.event.ServletEventBridgeFilter.doFilter(ServletEventBridgeFilter.java:74)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:280)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.jbpm.designer.web.filter.impl.PluggableFilter.doFilter(PluggableFilter.java:70)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:280)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.uberfire.security.server.UberFireSecurityFilter.doFilter(UberFireSecurityFilter.java:266)
    at org.apache.catalina.core.ApplicationFilterChain.internalDoFilter(ApplicationFilterChain.java:280)
    at org.apache.catalina.core.ApplicationFilterChain.doFilter(ApplicationFilterChain.java:248)
    at org.apache.catalina.core.StandardWrapperValve.invoke(StandardWrapperValve.java:275)
    at org.apache.catalina.core.StandardContextValve.invoke(StandardContextValve.java:161)
    at org.apache.catalina.authenticator.AuthenticatorBase.invoke(AuthenticatorBase.java:397)
    at org.jboss.as.jpa.interceptor.WebNonTxEmCloserValve.invoke(WebNonTxEmCloserValve.java:50)
    at org.jboss.as.web.security.SecurityContextAssociationValve.invoke(SecurityContextAssociationValve.java:153)
    at org.apache.catalina.core.StandardHostValve.invoke(StandardHostValve.java:155)
    at org.apache.catalina.valves.ErrorReportValve.invoke(ErrorReportValve.java:102)
    at org.apache.catalina.authenticator.SingleSignOn.invoke(SingleSignOn.java:416)
    at org.apache.catalina.core.StandardEngineValve.invoke(StandardEngineValve.java:109)
    at org.apache.catalina.connector.CoyoteAdapter.service(CoyoteAdapter.java:368)
    at org.apache.coyote.http11.Http11Processor.process(Http11Processor.java:877)
```

Figure 44: Error in loading the process

Workaround:

a. After validating model, download the source code to your local file system. And only then save it in the web editor.
b. Restart the JBoss application server.

6) It is easier to build larger processes using the Eclipse BPMN2.0 modeler. However sometimes it is not possible to upload those models into the web based designer as shown in Figure 45 .



Unable to import provided BPMN2

Problems

Level	Text	File	Column	Line
●	unable to parse xml : Exception class java.lang.IllegalArgumentException : This type of node cannot have more than one incoming connection!	CarePathwayHighLevel.bpmn2	0	-1

Figure 45: Cannot import BPMN models into the jBPM web based designer

Appendix F. Optimization algorithms in OptaPlanner

In Table 10, the various optimization algorithms supported by OptaPlanner is shown.

Table 10: Optimization algorithms supported by OptaPlanner [17]

Algorithm	Scalable	Optimal	Ease of use	Tweakable	Requires CH
Exact algorithms					
Brute force	0/5	5/5	5/5	0/5	No
Depth- first search	0/5	5/5	4/5	1/5	No
Construction heuristics (CH)					
First Fit	5/5	1/5	5/5	1/5	No
First Fit Decreasing	5/5	2/5	4/5	2/5	No
Best Fit	5/5	2/5	4/5	2/5	No
Best Fit Decreasing	5/5	2/5	4/5	2/5	No
Cheapest Insertion	3/5	2/5	5/5	2/5	No
Regret Insertion	3/5	2/5	5/5	2/5	No
Metaheuristics					
Local Search					
Hill-Climbing	5/5	2/5	4/5	3/5	Yes
Tabu Search	5/5	4/5	3/5	5/5	Yes
Simulated Annealing	5/5	4/5	2/5	5/5	Yes
Late Acceptance	5/5	4/5	3/5	5/5	Yes
Step Counting Hill Climbing	5/5	4/5	3/5	5/5	Yes
Evolutionary Algorithms					
Evolutionary Strategies	4/5	3/5	2/5	5/5	Yes
Genetic Algorithms	4/5	3/5	2/5	5/5	Yes

Appendix G. Rules for Pathologist Case Assignment problem

Figure 46: Negative constraints (Hard and Soft score)

Figure 47: Scenario where there are 4 cases and 2 pathologists - for Rule 1

Figure 48: Representing scoring logic for rule 1

Figure 49: Scenario where there are 4 cases and 2 pathologists – for Rule 2

Figure 50: Representing scoring logic for rule 2

Figure 51: Scenario where there are 10 cases and 3 pathologists- for Rule 3

Figure 52: Standard deviation of complexity of cases assigned to pathologists is zero

Appendix H. Creating the OptaPlanner Work Item

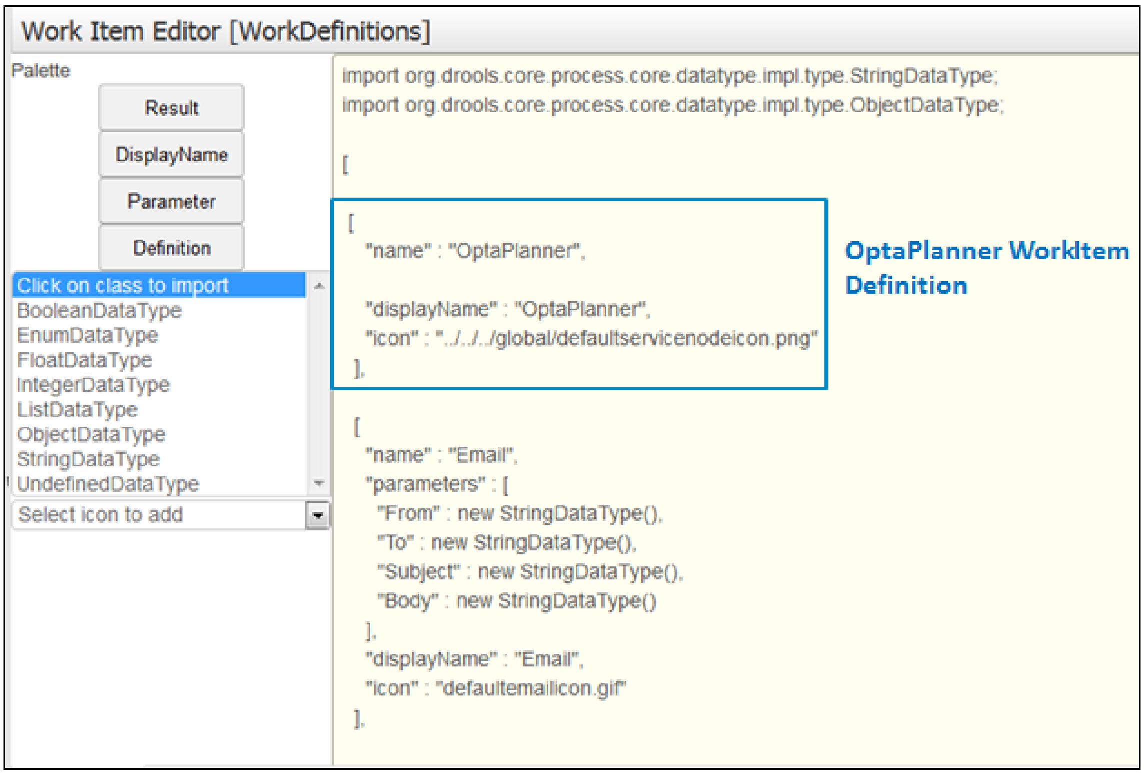
The following steps have to be followed in order to create the OptaPlanner WorkItem.

Step 1) Create a work item definition using the MVEL language

1.1 Create a project in the KIE workbench from the project authoring perspective

1.2 Then open the default file called WorkDefinitions. wid, which contains some default WorkItems (Email, Log, Web Service, Rest).
It is in this file, we will add the new work item definition as shown in the Figure 53. Since the work item is being defined in an existing file (WorkDefinitions. wid) from the KIE workbench, it is already registered with the process engine.

Then the new work item will appear in the palette of the process modeler for a new process



```
import org.drools.core.process.core.datatype.impl.type.StringDataType;
import org.drools.core.process.core.datatype.impl.type.ObjectDataType;

[
  [
    "name" : "OptaPlanner",

    "displayName" : "OptaPlanner",
    "icon" : "../../../global/defaultservicenodeicon.png"
  ],

  [
    "name" : "Email",
    "parameters" : [
      "From" : new StringDataType(),
      "To" : new StringDataType(),
      "Subject" : new StringDataType(),
      "Body" : new StringDataType()
    ],
    "displayName" : "Email",
    "icon" : "defaultemailicon.gif"
  ],
```

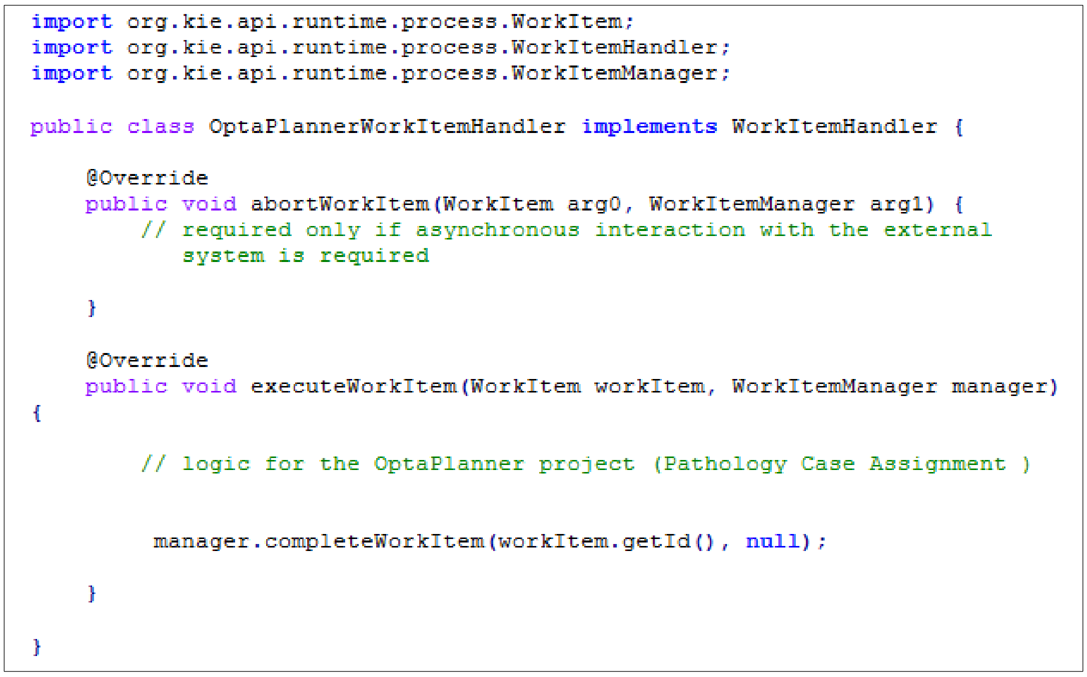
Figure 53: Creating the WorkItem definition for the OptaPlanner WorkItem

Step 2) Create a java work item handler in Eclipse

2.1 Create a maven project and add the kie-api artifact with the 6.0.0.redhat version value as the project dependency.

2.2 The custom work item handler to be created will implement the interface class WorkItemHandler.

2.3 In the executeWorkItem method, we will implement the logic for the OptaPlanner project (Pathology Case Assignment) as shown in Figure 54. Additionally make sure that the *completeWorkItem()* function is called to notify the process engine that the work item is completed.



```java
import org.kie.api.runtime.process.WorkItem;
import org.kie.api.runtime.process.WorkItemHandler;
import org.kie.api.runtime.process.WorkItemManager;

public class OptaPlannerWorkItemHandler implements WorkItemHandler {

    @Override
    public void abortWorkItem(WorkItem arg0, WorkItemManager arg1) {
        // required only if asynchronous interaction with the external
           system is required

    }

    @Override
    public void executeWorkItem(WorkItem workItem, WorkItemManager manager)
{

        // logic for the OptaPlanner project (Pathology Case Assignment )


         manager.completeWorkItem(workItem.getId(), null);

    }

}
```

Figure 54: Creating the OptaPlanner WorkItem Handler

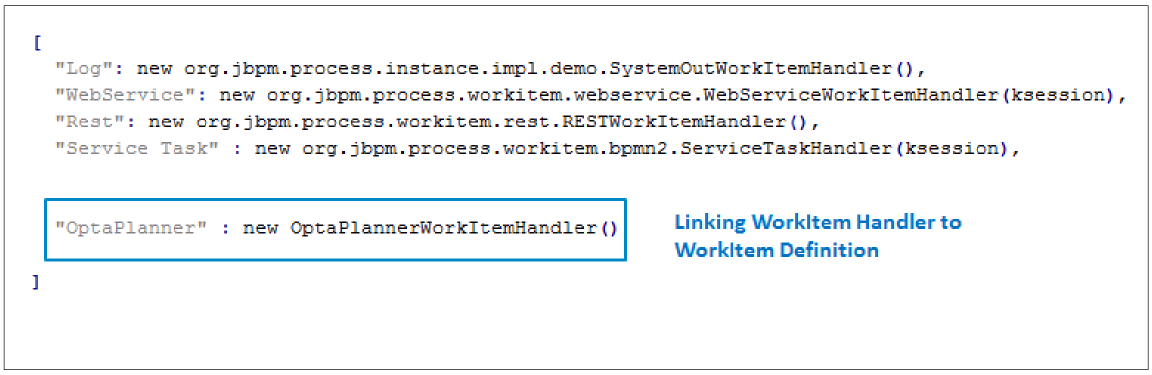
Step 3) Register the work item handler

3.1 Export the custom work item implementation as a jar file to the lib folder located at installation directory\jboss-as-7.1.1.Final\standalone\deployments\jbpm-console.war\WEB-INF\lib\.

3.2 Make sure that if your work item implementation requires other external libraries (jar files), copy them as well to the lib folder in the location shown in step 3.1.

3.3 Map the workitem handler to the work item definition.
This mapping has to be done in the CustomWorkItemHandlers.config file which is located at
installationdirectory\jboss-as 7.1.1.Final\standalone\deployments\jbpm-console.war\WEB-INF\classes\META-INF\

Figure 55 shows how this mapping has been done.



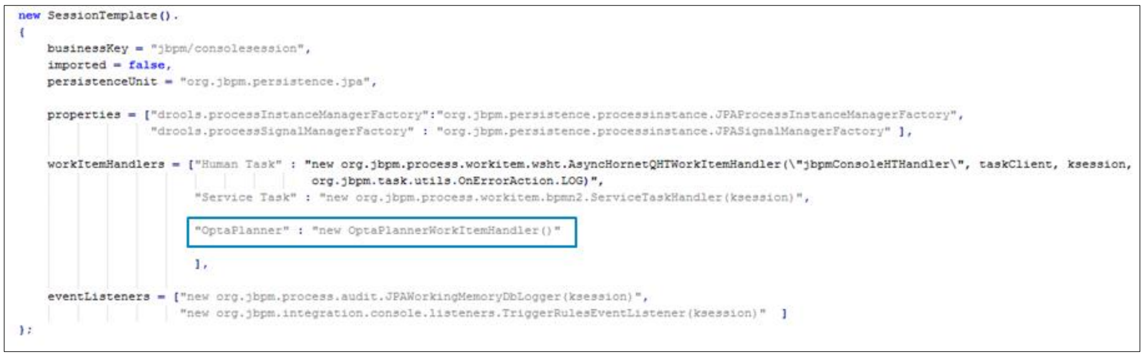
```
[
  "Log": new org.jbpm.process.instance.impl.demo.SystemOutWorkItemHandler(),
  "WebService": new org.jbpm.process.workitem.webservice.WebServiceWorkItemHandler(ksession),
  "Rest": new org.jbpm.process.workitem.rest.RESTWorkItemHandler(),
  "Service Task" : new org.jbpm.process.workitem.bpmn2.ServiceTaskHandler(ksession),

  "OptaPlanner" : new OptaPlannerWorkItemHandler()
]
```

Figure 55: Mapping OptaPlanner WorkItem Handler to respective WorkItem definition

3.4 Copy default.session.template file from installationdirectory \jboss-as-7.1.1.Final\standalone\deployments\jbpm-console.war\WEB-INF\classes\to the configuration folder located at installationdirectory \jboss-as-7.1.1.Final\standalone\

And rename the file as session.template with and it should include some modifications as shown in Figure 56.



```
new SessionTemplate().
{
    businessKey = "jbpm/consolesession",
    imported = false,
    persistenceUnit = "org.jbpm.persistence.jpa",

    properties = ["drools.processInstanceManagerFactory":"org.jbpm.persistence.processinstance.JPAProcessInstanceManagerFactory",
                  "drools.processSignalManagerFactory" : "org.jbpm.persistence.processinstance.JPASignalManagerFactory" ],

    workItemHandlers = ["Human Task" : "new org.jbpm.process.workitem.wsht.AsyncHornetQHTWorkItemHandler(\"jbpmConsoleHTHandler\", taskClient, ksession,
                                        org.jbpm.task.utils.OnErrorAction.LOG)",
                        "Service Task" : "new org.jbpm.process.workitem.bpmn2.ServiceTaskHandler(ksession)",

                        "OptaPlanner" : "new OptaPlannerWorkItemHandler()"

                        ],

    eventListeners = ["new org.jbpm.process.audit.JPAWorkingMemoryDbLogger(ksession)",
                      "new org.jbpm.integration.console.listeners.TriggerRulesEventListener(ksession)"  ]
};
```

Figure 56: Modifying the session template

Step 4) Restart the server

Now the custom work item can be executed from the KIE workbench