Fachstudie No. 146

Comparison of Composition Engines and Identification of Shortcomings with Respect to Cloud Computing

Thomas Bachmann, Lukasz Bialy, Anand Babu

Study Course:	Software Engineering
Examiner:	Prof. Dr. Frank Leymann
Supervisors:	Dr. Vasilios Andrikopoulos, Steve Strauch
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Abstract

Most workflow engines are currently not Cloud-aware. This is due to multiple reasons like no support for transparent scalability, no multi-tenancy support, no ability to store process related data in a Cloud storage, or no support for quality of service enforcements. Recently Cloud based workflow services appeared in the workflow landscape and promise to run workflows in the Cloud. This student reports evaluates current state of the art BPEL and BPMN workflow engines and Cloud based workflow services according to their Cloud-awareness and general workflow functionalities. Identified shortcomings are described and prioritized.

As a result of this evaluation the workflow engine WSO2 Stratos is best suited for running workflows in the Cloud, but it lacks native clustering support and quality of service enforcement.

Keywords: workflow engine, survey, BPEL, BPMN, Cloud computing

Change Log

Version	Date	Chapter	Comment	Author
1 Draft	2012-02-03	1-3	first review done	TB, LB, AB
1 Review	2012-02-04	Abstract, 1-2	added abstract, changed chapter 1 and 2 according to feedback, chapter 1.2 still needs to be updated by AB, chapter 1.4 still needs to be rewritten by TB	TB
1 Review	2012-02-05	1.2	outline updated	AB
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1 Review	2012-02-11	4	added new figures and introduction and fixed comments in chapter 4	AB, TB
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1 Review	2012-02-12	3.4.2	Results of cordys process deployment.	LB
1 Review	2012-02-13	3.2 and 3.3	Made all tables in 3.2 uniform and fixed my engine tables in 3.3	AB
1 Review	2012-02-13	3.2 and 3.3	List of tables and table descriptions	LB
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1 Review	2012-02-14	3.3 and 3.4	Formatted tables in 3.3 and tweaked 3.4 as per advisors comments	AB

List of Tables

List of Figures

Table of Contents

1. Introduction

When designing large distributed software systems the Service-Oriented Architecture (SOA) [432] approach is currently the state of the art. When introducing SOA, proven technologies like Enterprise Service Bus (ESBs) and workflow management systems (WfMSs) are used, which enable distributed systems to communicate, using open standards.

Now Cloud computing is an emerging technology with a high potential in terms of cost efficiency and flexibility [13]. Especially the Platform as a Service (PaaS) delivery model is promising for businesses to rapidly create and run new applications.

Taking this a step further, services can be delivered through the Cloud and workflows can run in the Cloud, but currently only few platforms are available that use the advantages of the Cloud to enable businesses to easily create applications by composing Web Services Description Language (WSDL) [433] services.

As a consequence proven technology like SOA software components need to be adapted to the Cloud. Most software vendor's SOA components like ESBs or WfMSs are not ready for the Cloud since they don't support native multi-tenancy, scalability, or Cloud data persistence layers. Taking data persistence as an example, in the Cloud, data is usually not stored on the disk of a virtual machine but stored somewhere else using a file persistence or database service. This would allow shutting down a workflow engine and starting a new engine without loosing any data and take off from where the workflow engine last dropped out.

As a consequence, the EU project 4CaaSt [14] was started, which builds a PaaS enabling to create new services and applications by composing existing and new services. Therefore a Cloud-aware workflow engine as building block integrated in the PaaS platform is leveraging all Cloud advantages, such as multi-tenancy to maximize the resource utilization for Cloud providers.

This evaluation focuses on workflow engines provided as Cloud services and existing workflow engines not Cloud-aware yet. Other WfMS components or composition engines and SOA software components are out of scope.

1.1. Problem Statement

Most available workflow engines were not built with the Cloud as an execution environment in mind. Nevertheless, there is a need to run workflows in the Cloud and therefore workflow engines also need to be run in the Cloud. Currently we don't know which workflow engines are able to run in the Cloud and which are not. Next to traditional workflow engines, new online services that claim that they are also capable of running workflows in Cloud evolve and need to be evaluated if they are ready for production usage. We call those services "workflow services".

This workflow engine and workflow services evaluation is embedded in the EU project 4CaaSt (www.4CaaSt.eu), which aims to create a PaaS platform in the Cloud that enables

the composition of existing and new components and services, e.g., Web services. It's broader goal is to have "an Internet-scale application platform for design, operation, management, and trading of services and service compositions which can be tailored to different local or global communities" [16].

The task of this "Fachstudie" is to evaluate workflow engines and workflow services in terms of self-defined general workflow engine and Cloud-awareness criteria, identify the shortcomings, and prioritize them according to importance for achieving Cloud-awareness of workflow engines. Also, it is planned to deploy a sample process model on a selection of highly rated workflow services and engines to further validate the products.

The concrete tasks of this evaluation are to first select a limited set of workflow engines and workflow services and then identify and define a catalog of relevant criteria for workflow engines and workflow services in the Cloud context. Next the workflow engines and workflow services are evaluated based on the defined criteria and finally shortcomings concerning running workflow engines in the Cloud or existing workflow services are identified and described.

Within the agreed duration of this student report, a best effort will be made to deploy a sample process model (explained in Chapter 1.4) on a selection of highly rated workflow services and engines and the findings will be documented.

The scope of this workflow engine evaluation is limited to the execution workflows, which are described in the Web Services Business Process Execution Language (WS-BPEL, or short BPEL) or Business Process Model and Notation (BPMN) and therefore use Web services that expose their interface using WSDL. We don't focus on other composition standards and don't take scientific workflows into our considerations.

1.2. Outline

The first chapter is an introduction, which provides the context, describes the problem and goal of this evaluation (Chapter 1.1), our scientific approach (Chapter 1.3), an example scenario (Chapter 1.4), and defines basic terms (Chapter 1.5). The sample scenario is used to have a concrete setting in mind, which is supposed to be deployed on a workflow engine in the Cloud and if time allows, tested as part of the evaluation. In the definitions chapter are the most important terms we use defined as they are understood and meant by the authors.

Chapter 2 describes related work that we found and how it influences this "Fachstudie".

The third chapter evaluates workflow engines by first selecting workflow engines and workflow services (Chapter 3.1), then defining a criteria catalog with measurable capabilities (Chapter 3.2) and finally evaluate the selected workflow engines and workflow services based on the defined criteria (Chapter 3.3). It also provides a documentation (Chapter 3.4) of results and inferences that were found while deploying the sample process model mentioned in Chapter 1.4

Chapter four contains a critical discussion of the results of the evaluation and reflects how the selection of engines and criteria had an impact. It provides a documentation of why some

of the products were ignored (Chapter 4.1) from further evaluation though they were considered at the beginning of this student report. It also lists the capabilities that were left out as not enough information was found on these capabilities after evaluating seven engines (Chapter 4.2). Results of all the evaluations are described in Chapter 4.3 while the shortcomings are described and prioritized in Chapter 4.4.

The fifth chapter takes the findings from the evaluation and discussion in Chapter 3 and four and summarizes them (Chapter 5.1). It also provides an outlook on what to expect in the near future regarding cloud awareness of workflow engines (Chapter 5.2).

1.3. Methodology

The definitions of criteria with their measurable capabilities for evaluating workflow engines and workflow services are developed by analyzing existing criteria catalogs concerning the quality of workflow engines and Cloud capabilities. We use existing evaluation criteria for common features of workflow engine since they also apply to workflow engines that run in the Cloud and workflow services. Since no criteria catalog for evaluating workflow engines in the Cloud exists yet, we adapt Cloud utilization criteria for other software like ESBs to match workflow engine criteria.

The weighting of each criteria and capability is necessary in order to rank the evaluated workflow engines and workflow services. The weighting will be based on our own experience with workflow engines and Cloud computing.

Also, some capabilities are more important than others, especially in a Cloud scenario. For example a workflow engine, which is Cloud ready but which might support lesser number of data sources might not be recognized if both the capabilities are weighted equally. Since we are interested in Cloud-aware engines, we award different weightage for different capabilities so a more appropriate workflow engine is selected for the Cloud scenario. Every Cloud related criteria is weighted three times (marked as *** in the document). The features which are critical but not directly Cloud-related are weighted two times (marked as **). In general the weightings are:

** - 2 times the weightage associated (feature of moderate significance)
*** - 3 times the weightage associated (feature of utmost significance)

In the middle of the evaluation (about half the evaluated engines) we will decide which capabilities will be further ignored, because there is not enough information to do a meaningful points assignment. This step is done in the middle of the evaluation, because we have only a limited time in the "Fachstudie" and can save time when having to evaluate and research less capabilities for each workflow engine and workflow service.

The selection of workflow engines and workflow services to evaluate will be a mixture of commercial and open source products. We need to evaluate open source products since the 4CaaSt project want to adapt one for their PaaS environment. In contrast there are commercial products already exist that state that they are Cloud-aware, therefore, these commercial products are also considered. In general we prefer workflow engines and workflow services with a profound user base.

The ranking of each workflow engine and workflow service for each capability is based on the measurable capability description. Using that evaluation and ranking the most important

shortcomings of current workflow engines and workflow services for Cloud usage are described and possible solutions to overcome them are suggested.

The evaluation will be based on information, which the software vendors or service providers provide on their websites, product documentation, developer blogs, forums, and mailing lists. Further information resources like external websites or blogs could not be evaluated, because of the time limits for a "Fachstudie". Next to this evaluation, the sample scenario from Chapter 1.4 will be tested with some of the evaluated workflow engines and workflow services. The selection of those workflow engines and workflow services is based on their public availability, either as a trial version in case of workflow services or as a virtual machine image in case of workflow engines.

The points assignment for each capability and workflow engine or workflow service will be done according to points scale for each capability, which describe the minimal required features to get zero to four points. If a source states something about a feature, but is not very explicit about it and the authors have doubt that the feature is available, then the points assignments are put in parenthesis.

1.4. Sample Scenario

This evaluation of workflow engines and services is mostly based on the vendor's documentation. In order to get an idea how the workflow engines and services behave in practice we decided to try to deploy a non-trivial sample business process to some of the workflow engines and services. This chapter describes the later on used sample process in principle.

The used sample process is called "WatchMe" and is taken from the COMPAS project. The process deals with mobile clients that want to watch movies or TV. The mobile clients only have a contract with an intermediary party, called Mobile Virtual Network Operator (MVNO), which in turn has contracts with different media providers. When a mobile client wants to watch a movie, he authorizes himself at the MVNO, then searches for a movie title, retrieves a list of results and selects one to be streamed to him. The MVNO composes audio and video streams from the media providers and streams this result to the mobile client. He also has to ensure that all contracts with the third party media providers are fulfilled, because some require a time-based billing, other a pay-per-view. Additionally the MVNO has to guarantee his clients a certain quality of service. The basic process is shown in Figure 1 [17, p. 11].
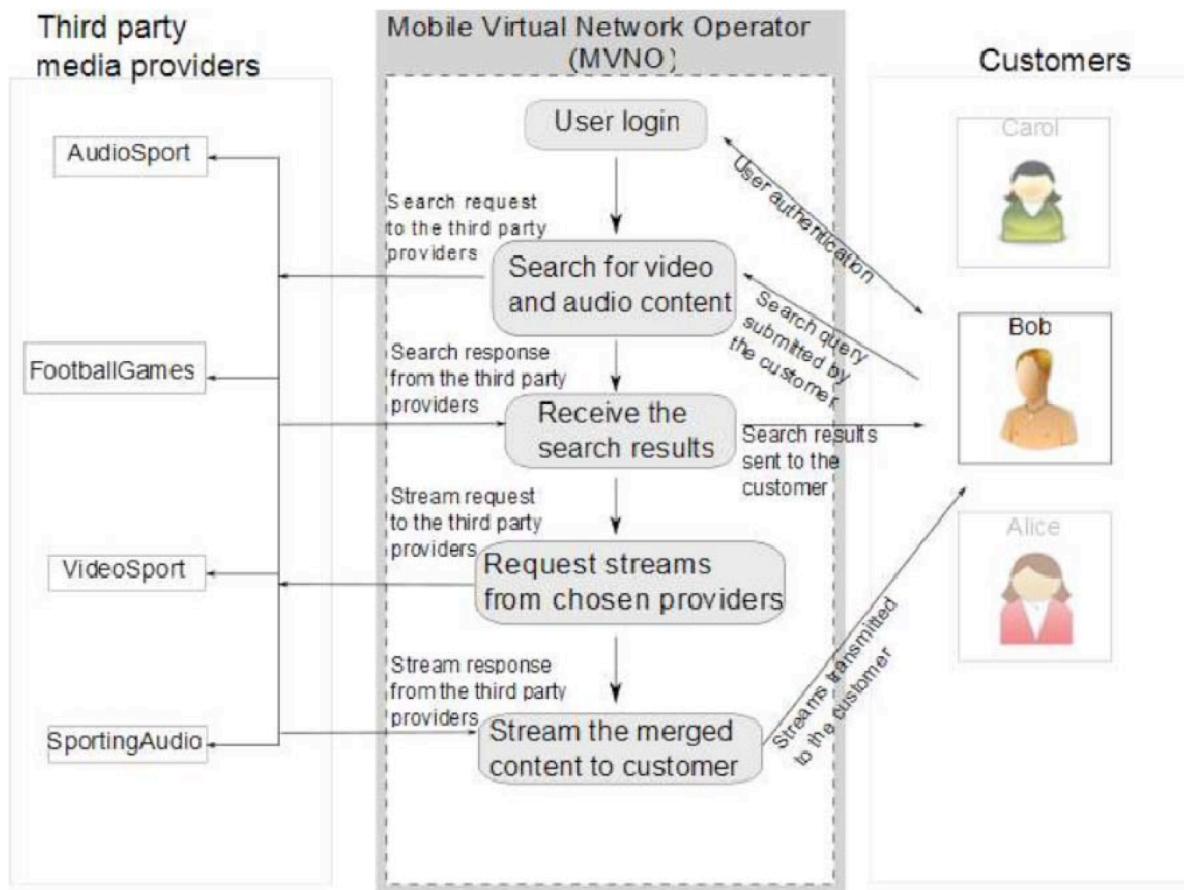
Figure 1. Use Case Scenario – "WatchMe" Process [17, p. 11]

For a deeper understanding of the "WatchMe" process, this is a list of services that are used: a bank service for payment, an assembly service to merge audio and video streams, an audio sport service and a video sport service which stream audio and video content, a football games service which streams football games, a session id generation service which returns a session id once the client is authorized, and an user data check service that authorizes clients. All these services are composed in the "WatchMe" process in order to let clients watch movies. The process also contains fault handlers in case request time out or resources are not available.

1.5. Definitions

Workflow [83]
"Workflow is a technology for realizing of inter-/intra-enterprise (business) processes" and "Workflow constructs allow to implement business process aspects like logical decision points, sequential as wells as parallel work routs, as well as managing of exceptional situations. This is realized by the means of control flow constructs of a workflow language. The business rules (complex transition conditions) specify in reusable manner the way to process the workflow specific data."

Workflow Management System (WfMS) [18]

"A system that completely defines, manages and executes 'workflows' through the execution of software whose order of execution is driven by a computer representation of the workflow logic."

Workflow Engine

"A software service or 'engine' that provides the run time execution environment for a workflow instance." [18]

"The main purpose of the runtime component of the workflow management system is to proactively drive processes. The runtime component navigates through a process model and interacts with users and applications [...]." [45, p. 97]

Cloud Computing [19]

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.

This Cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models."

"Essential Characteristics: On-demand self-service, Broad network access, Resource pooling, Rapid elasticity, Measured Service"

"Service Models: Cloud Software as a Service (SaaS), Cloud Platform as a Service (PaaS), Cloud Infrastructure as a Service (IaaS)"

"Deployment Models: Private Cloud, Community Cloud, Public Cloud, Hybrid Cloud"

2. Related Work

Similar work has been done by Binz et al. [28] for the migration of relational database management systems (RDBMSs), application servers, composition frameworks and engines, and ESBs to the Cloud. This work influences the criteria and capability catalog concerning Cloud-awareness. We will also consider the evaluated BPEL or BPMN capable composition engines, but additionally take a more detailed look at the composition features. Additionally we are evaluating further commercial workflow engines and workflow services.

Previous research from Vandenberg et al. [3] looked at runtime environments, licenses and supported workflow languages, which we did as well. TEC [21] identified a list of features which contain very detailed workflow engine functionalities like "Task-driven engine", "Goal-driven engine", or "Workflow steps can be activated based on time". These are out of scope of our evaluation since they go too much into the workflow execution internals. Eswaran et al. [22] identified evaluation categories like "Data Management", "Security", or "Scalability", but had no measurable capabilities assigned. We used some of their categories, since they were in scope of our evaluation. Laszlo et al. [23] also provided criteria like "long term state-full and long term stateless task execution", "GUI is web based and it has API to replaced the GUI with a customised version", or "Perform proper logging for auditing and tracking purpose", which we used as well, since they were in our scope.

Anstett et al. already discovered security problems when running BPEL workflows in the Cloud, which will play a role in the criteria catalog [25].

Pandey et al. [24], discussed how to run scientific workflows in the Cloud using Aneka. This work is helpful, because it describes a possible architecture of a workflow engine in the Cloud, which helps to find possible solutions to resolve shortcomings of existing workflow engines that are not Cloud-aware. Pandey et al. also stated that "Traditional WfMSs were designed with a centralized architecture and were thus tied to a single machine. Moving workflow engines to Clouds requires: (a) architectural changes and (b) integration of Cloud management tools." [15]
Architectural changes are needed to better scale the WfMS to its usage, e.g. by distributing components of WfMS to multiple machines. The integration into Cloud management tools requires data management and monitoring of the now distributed components [15].
Possible problems for existing workflow engines are therefore "scalability and on-demand access", whereas scalability is needed for effective Cloud services and enables "real-time provisioning of resources" [15].

Currently we could not find any published research on how to technically move on-premise applications to the Cloud without just running the applications in a virtual machine in the Cloud. Most Cloud providers like Microsoft [26] and Amazon Web Services [27] only describe a more generic and conceptual approach that describes what needs to be considered when moving applications to the Cloud, but don't provide technical assistance. What we were looking for, is how to convert an on-premise application to a Cloud service that can be composed with other services and uses the whole Cloud infrastructure including Cloud data stores and transparent scalability or elasticity.

3. Evaluation of Workflow Engines for Usage in Cloud Computing

3.1. Selected Workflow Engines and Cloud Composition Services

The list of 67 workflow engines and workflow services (see Appendix A) is the result of the literature research for potential candidates to considered in the survey. The list was composed by studying [28, 29, 20] and 4CaaSt D7.1.1 [12]. Criteria for exclusion (KO criteria) were BPEL or BPMN support. The selection of the 19 engines and workflow services to be considered in the survey and evaluation was based on 4CaaSt D7.1.1 [12], "Gartner's Magic Quadrant for BPM Suites" [29] and input from our advisors. We preferred software from big companies and software that is already adapted to or made for the Cloud. One exception is the Ericsson Composition Engine, which does neither support BPEL or BPMN but is mentioned in 4CaaSt D7.1.1 [12].

The 19 selected workflow engines and workflow services were categorized into two pairs. The first one is open source and commercial and the second one is workflow engine and workflow service.

In the following chapters a selection of commercial workflow engines is briefly described. Most products are not only workflow engines, but also workflow management systems, in which case only the workflow engine part is evaluated.

Since some engines were already described in 4CaaSt D7.1.1 [12], we only describe additional findings that were not included in the evaluation in 4CaaSt D7.1.1 [12] and rate the capabilities according to our findings and the ones in 4CaaSt D7.1.1 [12]. The engines from 4CaaSt D7.1.1 [12] are evaluated first in the following chapter.

When we talk about "BPEL" we mean WS-BPEL in general, which can be version one or two of the standard. If we talk about "BPEL 2.0" we mean WS-BPEL 2.0.

3.1.1. Commercial and Open Source Workflow Engines from 4CaaSt D7.1.1

ActiveVOS Data Center Edition by ActiveEndpoints
ActiveVOS was already described in 4CaaSt D7.1.1 [12, p. 76]. The following description focuses on the Data Center Edition of ActiveEndpoints.

ActiveVOS Data Center Edition's workflow engine called, BPM Engine [30], is a commercial product, currently in version 10 and BPMN 2.0 and fully BPEL 2.0 compliant [30, 103]. Additionally it supports standards like BPEL4People & WS HumanTask, WS *, including WS Policy, representational state transfer (REST), Java Message Service (JMS), Enterprise Java Beans (EJB) and others [30]. It's features include "modeling, simulation, testing, debugging, monitoring, reports, instance repair console", next to multi-tenant support [30].

ActiveVOS is relatively new in the BPM market and competes with Intalio BPMS Enterprise [29]. The workflow engine is a Java Platform, Enterprise Edition (Java EE) product, which focuses on the IT side of business process management (BPM), like SOA and integration, and is also low-cost [29].

It "has a good Eclipse-based SOA service development environment that is well-respected in the Java development community", "includes a good Web services directory" and has a "business-friendly human workflow environment" [30].

Composition Engine by Ericsson

Ericsson Composition Engine was already described in 4CaaSt D7.1.1 [12, p. 85]. The following description explains a couple more details.

The Ericsson Composition Engine is a commercial product with a GUI based [35] workflow management system for service providers, e.g. telco operators [35], specially for all-IP networks [36]. One sample scenario would be sending a SMS (communication) to all online (available, via Internet) friends in the neighborhood (GPS) [35].

It uses "industry-standard technology", telephony protocols and Web 2.0 services like Facebook and last.fm [36]. It is based on JEE [36] and has some sort of multi-tenancy support, where partners of a telco operator can use the engine as well. Supported standards for service invocation are "SIP services, CAP/INAP-based IN services, SOAP/Web services, and JSON RESTful services" [37].

There is no BPEL or BPMN support because their process based approach does not fit the data or event driven approach of Session Initiation Protocol (SIP) services [100]. The Ericsson Compositions Engine is nevertheless evaluated, because it plays a major role in the blueprint resolution approach of 4CaaSt.

Apache ODE

Apache ODE Engine was already described in 4CaaSt D7.1.1 [12, p. 78]. Further, in our evaluation, we used version 1.3.5 [45]. In this version, there is no in-built support for multi-tenancy and hence isolation of data is not possible. However, it is evaluated because
1. Its is one of the premier open source engines and
2. WSO2 (another evaluated open source engine) was built on top of this provides features, which are Cloud-aware.

ODE Supports the following standards: WS-BPEL 2.0, BPEL4WS1.1, Axis2, Java Business Integration (JBI), REST [45], and OpenJPA [46] as database abstraction, which supports many more RDBMSs.

OW2 Orchestra

OW2 Orchestra Engine was already described in 4CaaSt D7.1.1 [12, p. 88]. Further, in our evaluation, we used version 4.8.0. Unlike the other open source offering like Apache ODE, this engine supports both WS-BPEL and BPMN. Due to its Open Services Gateway initiative framework (OSGi) packaging, Orchestra is well suited to integrate with other PaaS components. It is delivered integrated with the ESB camel and therefore provides out of the box communication using several protocols: JMS, Mail, EJB, File, Java Management

Extensions (JMX), Java Persistence API (JPA). It Uses Hibernate for persistence and support migration of process models and instances between Orchestra engine instances.

WSO2 Stratos / Business Process Server

WSO2 Orchestra Engine was already described in 4CaaSt D7.1.1 [12, p. 91]. Further, in our evaluation, we used Version: 2.1.2. Its powered by Apache ODE [58]. It provides a complete Web-based graphical console to deploy, manage and view processes. It can be used to integrate applications in the Cloud with a full ESB-as-a-Service [57]. It provides single sign-on to applications deployed on WSO2 Stratos as well as other Cloud services such as SalesForce.com and Google using open standard Security Assertion Markup Language 2 (SAML2) tokens [57]. It supports multi-tenancy and has built-in monitoring and metering capabilities [58]. It also provides Message broker as a service, which supports message queuing and publish/subscribe feature [59]. It supports the following standards: JMS, Mail, File and HTTP transport, WS-Trust, WS-Security and WS-SecureConversation and an instant access to a complete middleware PaaS with messaging, data, business and presentation services, as well as common identity, security, governance, monitoring and management services [57]. It must be noted that we are not evaluating Stratos Live which is available as a SaaS offering.

BonitaSoft Bonita Open Solution

The Bonita Open Solution was already described in 4CaaSt D7.1.1 [12, p. 81]. In the following description we will explain couple more details about the current version 5.6 of the open source product Bonita Open Solution.

Additionally to the engine a modelling tool is provided, which can be used to model the process in BPMN 2.0. It is also possible to import process models from JBPM3 and the XML Process Definition Language (XPDL) format.
Bonita Open Solution provides a great amount of features around process modeling, development, execution, and monitoring. Also cloud relevant features are provided like multi-tenancy, scalability [80].

3.1.2. Commercial Workflow Engines

IBM Business Process Manager

IBM Business Process Manager Advanced, formerly named WebSphere Dynamic Process Edition (WDPE) is currently in version 7.5. It supports BPEL as well as BPMN 2.0 [38] and is compatible to WebSphere Lombardi Edition and WebSphere Process Server [38].

"Many IBM customers view WDPE is a "natural" option, since they have already invested in WebSphere Application Server, WebSphere Portal and other products of the family." [29]
Also IBM Business Process Manager is made for business people and not only IT staff [38].

BPMS Enterprise by Intalio

BPMS Enterprise's workflow engine, called Intalio BPMS Server, is currently in version 6.2.4. It competes with ActiveEndpoints and is low-cost, since it uses open source components [29]. Next to the on-premise solution, Intalio also has cloud delivery (SaaS) model for BPM [29].

Intalio is a "strong advocate for open standards and open source" and supports standards like "BPEL, BPEL4People, BPMN (1.2 in Enterprise Edition and 2.0 natively in Intalio/BPM) and the WS-Human Task life cycle" [29].

BPMS Enterprise is a JEE application, which works on almost all Java application servers, but Enterprise Edition 6.0 is also dependent on products like "Ajax General Interface, Eclipse BIRT, Alfresco, JBoss Community Drools, MuleSoft, Apache ServiceMix and WSO2", which might get replaced over time [29].

Intalio's BPMS is multi-tenant capable, has user management features, allows role-based access control, audit trail, and much more [39].

Windows Workflow Foundation (.NET) by Microsoft

Originally we wanted to evaluate the .Net library Windows Workflow Foundation (WF) by Microsoft, but we found out that BPEL was only supported in a Community Technology Preview (CTP) from March 2007 for .NET 3 [46], which is now outdated. Therefore the WF is not part of this evaluation any more.

BPM Suite 11g by Oracle

Oracle's BPM Suite version 11g has a workflow engine called Oracle BPEL Process Manager Runtime [40], which is a native BPEL engine [40]. It supports standards like XML, WSDL and Web services, XSLT, XPATH, JMS, JCA [40], and BPMN 2.0 [29].

"The Oracle BPEL Process Manager executes standard BPEL processes and provides a 'dehydration' capability so that the state of long-running flows is automatically maintained in a database, enabling clustering for both fail-over and scalability" [40].

Further features are human workflow support, monitoring, auditing, advanced exception management, side-by-side versioning, high performance, and scalability [40].

BPM Suite is also available in the SaaS delivery model [29].

NetWeaver BPM Process Server by SAP

NetWeaver BPM Process Server is part of SAP NetWeaver Business Process Management, which in turn is part of SAP's NetWeaver Composition Environment (CE) 7.2. It supports the BPMN standard [41, 29] and is a "JEE-based runtime execution engine", which is also BPMN-native [41].

In order to get BPEL support, one needs another product, called SAP NetWeaver Process Integration [41]. NetWeaver BPM Process Server is especially good for SAP ERP integration [29].

webMethods BPMS by Software AG

webMethods BPMS is currently in version: 8.2 [42] and supports standards like SOAP, WSDL, UDDI, Web services, XML and HTTP, Electronic Data Interchange (EDI) [42], BPEL [43], BPMN 2.0 [44]. The workflow engine component is called "Process Engine" and is currently in version 8.2 SP2 [174].

Further features are supports for Ad-hoc workflows, dynamic workflows, human-workflow management, and a metadata library [42]. webMethods BPMS is made for "a collaborative environment, [where] business and IT can work together to design, simulate, test and deploy processes — then in real-time monitor those processes. They can optimize processes by integrating whatever resource is required across your enterprise — people, systems and documents." [42].

webMethods BPMS allows Eclipse based design, rich simulations, and integrated business rules management [42]. It is enterprise suited due to support for complex processes and "high-volume performance and scalability" [42].

3.1.3. Commercial Workflow Services

Business Operations Platform (BOP) by Cordys
Business Operations Platform is currently in version 4.1 [31] and is part of Cordy's Business Process Management Suite (BPMS). It is available as a PaaS (BOP) and SaaS (Cordys Process Factory) Cloud delivery model, with partners that host the SaaS solution [32, 29].

BOP supports standards like BPMN 1.1 (partial), WSDL, XSD, XML, SOAP, WS-I Basic Profile 1.0, XPDL 2.0, WS-Security 1.1 [33] and BPEL [34].

Gartner states that "Cordys' best innovations recently are in its cloud offerings and partnerships for process content" and that "BOP is one of the few natively cloud-enabled, full multitenant cloud platforms" [29].

BOP has only an average ease of use and the UI is not appealing, as of version 4.0 [29]. Also BOP internally is heavily based on XML [122].

After the evaluation we found out that, although Cordys states that BOP is made for the Cloud, it seems that the platform is only made for a cluster. It has no Cloud-awareness, no dynamic node instantiation and no reference that it can be run on, e.g. Azure or AWS. At least not yet as a public product on the market [144].

Business Suite by Polymita
Business Suite is currently part of Polymita version 6 and has a "BPMN, Web-based modeler, a cloud-based platform-as-a-service (PaaS) package, and a new tool (FreeFlow) to manage unstructured processes and to discover process patterns" [29]. Next to the SaaS delivery model, Polymita is also available as a hosted solution [51].

Polymita allows "online composition, configuration, execution and management of process-based enterprise solutions and end-to-end business processes" [49],
"supports unstructured and structured processes" and "self-adjusting processes based on personalization and behavioral patterns" [29]. It is "one of the strongest approaches to case management" [29].

Business Suite is a Java offering [29] with a "100% on-line, from a Web browser" [48], focuses on model driven development [49, 29] and provides a "combination of SOA, Web 2.0, Cloud Computing, Data Management and Model-Driven Development" [49]. It supports standards like BPMN, XPDL, XSLT, WSDL, XML, SOAP, Web services, JDBC, JMS, FTP,

POP3, IMAP, SMTP and runs on many database systems, application servers, operating systems and Firefox & Internet Explorer [50].

Interstage BPM / Cloud BPM by Fujitsu

Interstage BPM is currently in version 11 and available as SaaS and on-premise solution [52]. It allows to "define, refine, automate, analyze and optimize processes" as well as "process discovery and visualization through to modeling and simulation, automation, analysis and process optimization" [52].

Fujitsu's BPM product supports standards like BPMN, XPDL, BPEL, WebDAV, Wf-XML 2.0, Universal Description, Discovery and Integration (UDDI) and Web services [53]. It is Java based, supports multiple JEE application servers, has ARIS and Microsoft Visio import and is 100% browser based [53]. Interstage BPM also has good discovery and optimization facilities [29].

"InterstageBPM.com can help automate processes that span multiple applications and organizations." [52] It's multi-tenancy capability is optional: "Each client gets its own instance and can run multiple applications within each instance.", "solution providers" get a multi-tenancy edition [52] and "Fujitsu Interstage BPM [...] can be used for private cloud services, or as a platform for external SaaS or cloud offerings" [29].

BPM by Intalio

Intalio describes his BPM-Service as an well designed, collaboration friendly service, build for the use in the Cloud. Cloud-awareness is created by "providing Web-based user interfaces, native multi-tenancy, a small memory footprint optimized for virtualization, and support for the most popular cloud deployment options, including VMware vCloud, Microsoft Azure, and Amazon EC2, both on premises and on demand" [55].

The Service is providing a collection of features for each of the twelve steps in the Intalio Process Life Cycle. The life cycle contains steps like analyzing, designing, building, executing, monitoring etc. For example for the Building-step features like debugging, package management, life cycle management and case management are provided.

On Intalio's Web site we can read: "Intalio|BPMS is Intalio's traditional BPM product. While remaining available as a standalone Java application that can be deployed on virtually any application server, Intalio BPMS is being integrated into Intalio Cloud and forms the foundation of IntalioBPM[55], Intalio's cloud-based BPM product." [177] In the e-mail conversation with Intalio's representative Roberto Pasti [421], we learn that's not the case. In the conversation it is said that the two products are very different. It was also mentioned that Intalio's BPM is still in the beta phase, and there is no public release. The publication of the stable release is planed at end of January 2012.

RunMyProcess by RunMyProcess

RunMyProcess is a Cloud-based platform, which allows design, execution and management of business processes [61]. This pay-per-use Web-based workflow service provides a set of features, which can be described as the most important ones [62]. This way RunMyProcess provides an intuitive interface for building processes and process examples to make the process designing easier [62]. Also a BPM modeling tool is provided, which uses BPMN 2.0 [62].

With perspective to Cloud computing RunMyProcess also focuses on the essential features. The service is built on an multi-tenant architecture, which allows tenants to use a shared infrastructure [62]. It provides security and reliability using a 4-layer protection containing physical security, data encryption, user authentication, and application security [62]. Also a very essential point is the on-the-fly scalability. RunMyProcess provides the possibility to scale up or down at any moment as required [62].

An other advantage of RunMyProcess is the powerful integration. Via over 1,200 pre-configured connectors it is possible to interact with other applications like Google Apps, Salesforce, Zoho, Oracle CRM and many more [62, 170].

3.1.4. Open Source Workflow Engines

BPMN Process Engine by JBoss
JBoss BPMN Process Engine is based on Java Technology, which makes it platform independent [230]. The current version is of the engine is 5.2. The engine supports only BPMN 2.0 [224], and provides a tools for graphical modeling. One tool is Web-based the other one id based on the Eclipse IDE. The process engine provides a set of useful features, for example "Pluggable persistence and transactions based on JPA" [225] or WS-HumanTask. Also a great feature is the integration with spring, seam and OSGi. The engine is published under Apache Software License 2.0 [243].

Activiti
Activiti version 5.8 is published under the Apache License V2. It's workflow engine is called ProcessEngine [54] and supportes BPMN 2.0 and JPA [54]. It has an Eclipse integration to inspect the database and BPMN files [54]. Activiti supports six different database systems [54] and can optional be integrated into Spring or other Java applications [54]. The engine is manageable through a Java and REST API [54]. Activiti supports Web service calls, human tasks, script tasks, Java tasks, Emails etc. [54].

3.2. Feature/Usage Criterion

3.2.1. Functionality
Functionality is one of most important properties of a software system. In this category the criteria that evaluate this property are summarized. It is validated, if the set of functions provide enough abilities for the comfortable efficient management of workflows.

Capability	Explanation
Workflow Languages	Each workflow engine needs to support a basic set of workflow definition languages. It's important that the most popular languages like BPEL or BPMN can be used with the engine. The output of this capability is a list of supported workflow languages.
Workflow Management Functionality	A workflow engine has to provide basic functions to manage the workflows running on it. The output of this capability is a

	set of statements describing the workflow management functions. Those statements answer questions like if a basic function is missing. Basic function like a proper deploying mechanism or a good way to see what workflows are deployed, how much of them are running or if there is enough information about the state of the workflow. Is it possible to interact with the workflow during runtime? [21, 23]
Advanced Functionality	Are there advanced functionalities for the execution of workflows. There are functionalities that are very useful but not every workflow engine provides them. For example the support for pause/hold states or the possibilities to link workflows to a status change of other workflows. The output of this capability is a list of advanced features of the engine or few words about their usefulness. [5, 23]
Suitability for Long-Term Workflows	Not all workflow engines are suitable for the execution of long-term workflows, which are needed in many businesses. In this criteria we will evaluate if the engine is qualified to execute workflows on a long term. [23]

Table 1. Capabilities of Functionality

Workflow Languages (**)

Points	Support
0	The workflow engine does niether support BPEL nor BPMN.
2	The engine supports BPEL or/and BPMN.
4	The engine supports additionally to BPEL/BPMN other languages like XPDL, which allows to import processes from this languages.

Table 2. Points Assignment Scheme for Capability Workflow Languages

Workflow Management Functionality (**)

Points	Support
0	The engine is missing a basic functionality like monitoring, a user-friendly deployment and management interface, a proper controlling mechanism for the workflows. Or it does not provide the information about the deployed and running workflows necessary for administration.
4	The engine provides all basic functions and information to run and administer the workflows on it.

Table 3. Points Assignment Scheme for Workflow Management Functionality

Advanced Functionality (**)

Points	Support
0	The engine does not provide any additional functionality or there is not much of it and it's not really useful.
2	The engine provides some additional functionality, but it is not much practical or it won't be used that often.

4	There is additional functionality that is useful and makes the engine more powerful in handling of workflows or helps the user administrate the workflows.

Table 4. Points Assignment Scheme for Advanced Functionality

Suitability for Long-Term Workflows (**)

Points	Support
0	There are no statements about the execution of long term workflow or boundaries for the maximal duration of a workflow execution.
4	It is specified that the engine can run workflows on a long term.

Table 5. Points Assignment Scheme for Suitability for Long-Term Workflows

3.2.2. Theoretical Foundation

Workflows can be internally represented in different ways, e.g. as graphs, state machines, or petri nets. Depending on the internal representation there might be formal ways to check the validity of the workflow model.

Capability	Explanation
Formal Model	This capability only collects information on the internal representation used to describe the workflow, e.g. graph (which type), state machine or petri net. There is no ranking implied.
Syntax Checking	Is there a possibility to check the syntax of a workflow model (e.g. BPMN, BPEL)?
Verification Options	Can workflow models undergo a formal verification check, e.g. unreachable states, unreachable paths, lifeness, dead-locks, or compliance with semantic (meta) model?

Table 6. Capabilities of Theoretical Foundation

Syntax Checking (**)

Points	Support
0	There is no syntax check of workflow models.
4	A syntax check for workflow models is provided.

Table 7. Points Assignment Scheme for Syntax Checking

Verification Options (**)

Points	Support
0	No verification for workflows is provided.
4	There is a verification function for workflows.

Table 8. Points Assignment Scheme for Verification Options

3.2.3. Integration and Communication Standards

Workflow engines need to support multiple communication and integration standards to work with different Cloud components (e.g cloud db, cloud storage) as well as different in-house components (e.g. storage, ESB, and network components) that are required in different workflows.

Capability	Explanation
Communication Protocols	The communication protocols supported by the workflow engine (Non-WS protocols: RMI / IIOP, RPC, Web service protocols: SOAP, REST, WSDL, UDDI, WS-*, Messaging protocols: JMS, SOAP Over JMS, Amazon SQS) [12]
Supported Databases	Does the composition engine use a database abstraction mechanism (e.g. Hibernate)? Which DBMSs are officially supported (by the composition engine or the database abstraction mechanism) and in which versions? Which DBMSs are capable running the composition solution, but are not officially supported? [12]
Platforms Able to Run on	What are the operating systems (and supported application servers are listed) on which the engine can be run?
Interoperability with other Cloud Systems	The workflow engine would ideally be developed so that it can be deployed across different Clouds with zero or minimal changes. Not relevant for workflow services.

Table 9. Capabilities of Integration and Communication Standard

Communication Protocols (**)

Points	Support
0	The engine doesn't support WS-Standards, REST, RMI and JBI.
2	The engine offers to a limited set of the above mentioned integration technologies.
4	The engine offers an extensive support of the above mentioned technologies.

Table 10. Points Assignment Scheme for Communication Protocols

Supported Databases. (*)

Points	Support
0	The engine doesn't support the most popular databases (e.g. MySQL, DB2, Oracle, Microsoft SQL Server), it only supports 1-2 databases.
2	The engine supports to a limited set (3) of databases.
4	The engine supports an extensive support to all relevant databases (4 or more, e.g. MySQL, DB2, Oracle, Microsoft SQL Server).

Table 11. Points Assignment Scheme for Supported Databases

Platforms able to run on (*)

Points	Support
0	The engine is not available on all major operating systems, e.g. Windows, Solaris and major Linux distributions like RedHat.
2	The engine is available on most of the major operating systems.
4	The engine can be run on all of the relevant operating systems.

Table 12. Points Assignment Scheme for Platform Able to Run On

Interoperability with other Cloud Systems (***)

Points	Support
0	It is nearly impossible to port the engine to different cloud infrastructure providers.
2	The engine can be ported to other cloud platforms with substantial effort.
4	The engine can be ported with minimal effort.

Table 13. Points Assignment Scheme for Interoperability with Other Cloud Systems

3.2.4. Extensibility

Often a software system is missing some functions or is just not optimal implemented to fulfil its purpose to the full extent. That is why it is important to have the possibility to extend the system and improve it if needed. In this category the extensibility of the workflow engine is evaluated.

Capability	Explanation
Plug-in Interface	In this capability we evaluate to see if there is a plug-in mechanism to add new or changed functionality to the default workflow engine. The output of this capability is a statement if there is an interface for plug-ins and few words describing it [24].
Modular Architecture	In this capability the architecture of the workflow engine will be evaluated, regarding its modularity and the possibility to extend it [12].
APIs and GUI-Replacement	There are a lot of ways how the GUI for a system can be designed. In this capability it will be checked if there is an interface to control the workflow engine and if it is possible to replace the GUI with an own custom version. [23]
License	How is the engine licensed? If changes are allowed, do they have consequences like losing rights or forced publications? [12]

Table 14. Capabilities of Extensibility

Plug-in Interface (**)

Points	Support
0	The engine has no plug-in interface to extend its functionality.
2	There is a plug-in mechanism to add new or changed functionality to the

	workflow engine, but it's not well documented or there aren't any examples for plug-in implementation.
4	There is a well documented/described plug-in mechanism to add new or changed functionality to the workflow engine.

Table 15. Points Assignment Scheme for Plug-in Interface

Modular Architecture (**)

Points	Support
0	The architecture of the engine is not modular or it's not shown.
2	The architecture is modular, but it is not likely to extend it or to split the components to multiple computers.
4	The engine has an modular architecture, and it's suited for extension or for work on multiple computers.

Table 16. Points Assignment Scheme for Modular Architecture

APIs and GUI-Replacement (**)

Points	Support
0	There is no workflow control interface or other API through which external components can communicate with the system. Also it's not possible to connect a custom GUI via an API.
2	There is a workflow control interface or few other APIs, but its not suited for an external GUI-component. For exymple only console interface.
4	A workflow control interface and enough other APIs are provided and its easy to integrate a custom GUI-component. For example there could be libraries provided.

Table 17. Points Assignment Scheme for APIs and GUI-Replacement

License (**)

Points	Support
0	The License is proprietary. All rights are reserved. No changes on the software is allowed.
2	The software can be modified, but the license needs to be kept (e.g. GPL).
4	The software can be modified, distributed, can be used for any purpose under the terms of the license. (Apache License)

Table 18. Points Assignment Scheme for License

3.2.5. Tools and Development

For the usage in the 4CaaSt project the ability to easily extend the composition engines is important to implement new functionalities. This also includes the ecosystem of tools, IDE, documentation and training that are available for developers when working on extending the different engines. [12]

Capability	Explanation
Tools Availability	Does the engine provide graphical modelling capabilities? Is

	the modelling tool integrated into the composition solution, for example by providing one-click deployment from the modelling tool, start, and analyse execution of composition instances from within the tool? [12]
Availability of IDE Plugins for Modelling and Managing Workflows	Are there IDE plug-ins to alter the state of composition or deploy compositions from the IDE itself?
Debugger Support	Does the composition engine provide a mechanism to test and debug compositions? Is it possible to suspend and resume compositions? Is there a Web interface or Web service to check the state of composition instances, state of each activity and content of variables? [12]
Developer Support	What is the quality of the documentation targeting developers: is it accessible, readable, complete, and up-to-date? Who are the main contributors of the projects? What is the size of the developer and contributor community on the mailing lists and forums? When using search engines to find further resources, how many results are there? Does the company provide consulting and enough training support if required? [12]

Table 19. Capabilities of Tools and Developement

Tools Availability (*)

Points	Support
0	There are no additional tools available for the engine.
2	There is a small set of tools available, but they are not very useful or raw regarding their usability.
4	There is a set of tools provided that can be also small. But the tools are useful and well implemented.

Table 20. Points Assignment Scheme for Tools Availability

Availability of IDE plugins for modelling and managing workflow (*)

Points	Support
0	The engine provides no IDE plug-ins.
2	The engine offers a limited set of IDE plug-ins.
4	The engine provides an extensive set of IDE plug-ins.

Table 21. Points Assignment Scheme for Availability of IDE plugins for modelling and managing workflow

Debugger Support (*)

Points	Support
0	The engine provides none of the debugging options mentioned above.

2	The engine offers a limited set of debugging options.
4	The engine provides a very good level of debugging options.

Table 22. Points Assignment Scheme for Debugger Support

Developer Support (*)

Points	Support
0	There seems to be no active community or good documentation and training.
1	The community is small or there is no commercial support, no training, limited documentation.
2	Small but active community or commercial support, no training and limited documentation.
3	The community is numerous and active or there is commercial support, documentation and training limited.
4	The community is numerous or there is commercial support, active, good documentation and training.

Table 23. Points Assignment Scheme for Developer Support

3.2.6. Management and Operation

When a system is running, it is essential that in can be managed and maintained properly. To ensure this, the system has to provide access to all needed information and provide a efficient way for the administration. The criteria in this category validate the capabilities to manage the workflow engine and operate with it.

Capability	Explanation
Web-based GUI	It is important that there is an easy, OS independent way for managing the workflow engine. In this capability it will be validated if the engine has an own Web-based GUI for this purpose.
Proper Logging for Auditing and Tracking Purpose	Each system should provide a good logging mechanism that allows auditing and tracking it's behavior. As output for this capability we will provide information on the logging mechanism and if the logged information allows easy tracking and auditing. [23]
Access to Engine Status Information	In this capability it will be evaluated if the administrator has access to information about the state of the engine. Also a statement will be taken about how precise and valuable the information is.

Table 24. Capabilities of Management and Operation

Web-based GUI (**)

Points	Support
0	There is no Web-based GUI for managing the workflow engine.
4	The Web-based GUI provides enough capabilities for operating with the system.

Table 25. Points Assignment Scheme for the Web-based GUI

Proper Logging for Auditing and Tracking Purpose (**)

Points	Support
0	The logging function provides only hardly readable information or there is no logging function.
2	The logging function provides well readable information, but there are no additional functions for searching, sorting, or filtering.
4	The engine provides a good logging function and also functions for easy search and dealing with the provided information.

Table 26. Points Assignment Scheme for Proper Logging for Auditing and Tracking Purpose

Access to Engine Status Information (**)

Points	Support
0	There is no access to information about the state of the engine.
2	The administrator can access the state information of the engine, but the information are not precise or not valuable.
4	The engine provides precise information about the state of the engine and the information are good readable and valuable.

Table 27.Points Assignment Scheme for Access to Engine Status Information

3.2.7. Scalability & Elasticity

Elasticity is the ability to provide (scale up) and release (scale down) resources dynamically with respect to dynamic workloads to maintain agreed service levels. Scalability is the ability to endure increasing workloads without decreasing an agreed service level when underlying resources are also increased. (Taken from the IAAS lecture Foundation Of Architecture Of Application Systems)

Scalability is a subset of Elasticity, because it only implies that the solution can scale up [12].

Capability	Explanation
Clustering	Does the composition engine support clustering, i.e. multiple instances on different nodes can be connected, so they are seen as a single composition engine from the client side? Does the composition engine support dynamic (at run-time) evolution of the cluster, according to some load indicators? [12]
Utilization of Flexible Storage Services	Does the workflow engine support usage of on-demand flexible storage services like Amazon Web Service S3, as well as to physical servers through normal FTP? [7]

Component Architecture Allows to Distribute Workflow Engine Components	The ability to run different components across different machines rather than running the whole WfMS on a single machine. So scaling of the engine is possible depending on the workload of the clients. [7]
Available Tools Allowing Cloud Administration	Ability to control different Cloud components from the workflow engine. For example reconfiguring nodes in a Cloud, monitoring the performance and power usage of applications (Green IT), managing users.
Transparent Scalability	Is the workflow engine capable of transparently provisioning additional resources by acquiring new resources in third party Cloud services such as Amazon EC2 to meet application demands.
Data Transfer and Access Efficiency	The workflow engine must efficiently and reliably handle the flow of data. For example the workflow engine must be able to connect with tools that allow having large amount of data flowing across different machines in a workflow. [7]

Table 28. Capabilities of Scalability and Elasticity

Clustering (***)

Points	Support
0	The engine provides no clustering support as well as no dynamic scalability.
2	The engine provides clustering support but no dynamic scalability.
4	The engine provides both clustering support and dynamic scalability.

Table 29. Points Assignment Scheme for Clustering

Utilization of Flexible Storage Services (***)

Points	Support
0	The engine provides no support of flexible storage services.
2	The engine provides limited support of flexible storage services.
4	The engine provides extensive support for flexible storage services.

Table 30. Points Assignment Scheme for Utilization of Flexible Storage Services

Component Architecture Allows Distribute Usage (**)

Points	Support
0	The engine's components can't be run across different machines.
4	The engine's components can be run across different machines.

Table 31. Points Assignment Scheme for Component Architecture Allows Distribute Usage

Available Tools allowing Cloud Administration (***)

Points	Support
0	The engine provides no special Cloud-specific features to measure/configure Cloud components.
2	The engine provides limited Cloud-specific features to measure/configure

	Cloud components.
4	The engine provides extensive Cloud-specific features to measure/configure Cloud components.

Table 32. Points Assignment Scheme for Available Tools allowing Cloud Administration

Transparent Scalability (**)

Points	Support
0	The engine doesn't provide transparent scalability.
4	The engine provides transparent scalability.

Table 33. Points Assignment Scheme for Transparent Scalability

Data Transfer and Access Efficiency (***)

Points	Support
0	The engine doesn't provide special tools to support large data transfers in a composition engine.
4	The engine does provide tools to support large data transfers between different activities in a workflow.

Table 34. Data Transfer and Access Efficiency

3.2.8. Reliability

Since software is taking more important tasks every day its reliability has become more significant. To provide reliability a system has to ensure correct behavior even when facing exceptional circumstances. This category contains a set of criteria, which evaluate if the system has the necessary properties to be reliable.

Capability	Explanation
Transactional Behavior	In this capability it will be determined if the engine is suited to run critical operations. It will be evaluated if the workflow engine supports transactions and thereby ensure ACID properties namely atomicity, consistency, isolation, and durability.[12]
Dynamic Service Selection / Service Discovery	In scope of this capability it will be validated, if the engine is capable of choosing new available bindings or even services to continue the work, when the previous service is out of function.
Central Exception Handling	This capability will evaluate how the workflow engine is handling exceptions. Is there a central component for this purpose and is this solution reliable?
Behavior under Heavy Load	To ensure reliability it is important to know how a system behaves when it has to deal with large workloads. As output of this capability it will be determined if there are any statements about the behavior of the system in this case and how the engine deals with (D)DoS Attacks.
Persistent Data Storage	A very important part of a reliable system is a permanent data storage, which can save the valuable data and can ensure its consistency, integrity, and persistence. In this capability it will be verified, how the data is handled, where it is stored. Especially for workflow services it is

	important to know where the data is stored, since that is an external data storage form your point of view. For the engines data is the connected data base responsible.

Table 35. Capabilities of Reliability

Transactional Behavior (**)

Points	Support
0	There is no support for transactions.
4	The engine supports transactions.

Table 36. Points Assignment Scheme for Transactional Behavior

Dynamic Service Selection / Service Discovery (**)

Points	Support
0	The engine is able to choose neither a new service nor a other available binding after the previous one failed.
2	The engine is able to choose other available bindings, but not new services.
4	The engine is capable to choose a new service provider on demand. So that the work can be continued.

Table 37. Points Assignment Scheme for Dynamic Service Selection / Service Discovery

Central Exception Handling (**)

Points	Support
0	The engine doesn't have central exception handling.
4	There is a central exception handling system.

Table 38. Points Assignment Scheme for Central Exception Handling

Behavior under Heavy Load (**)

Points	Support
0	There are no statements about behavior under heavy loads nor information about how the engine deals with (D)DOS attacks. Or the information is not satisfying.
4	The engine has been tested under heavy loads or the behavior is specified and the result is satisfying.

Table 39. Points Assignment Scheme for Behavior under Heavy Load

Persistent Data Storage(**)

Points	Support
0	No statements about how and where the data is stored are provided or the presented solution is not trustworthy.
2	There are statements about the data storage, but the developer company does not guarantee data safety.
4	The developer company guarantee data safety. It is described how the data is handled and where it is stored.

Table 40. Points Assignment Scheme for Persistent Data Storage

3.2.9. Security

Security is critical especially in a Cloud environment. This category evaluates which security mechanisms are needed in the workflow engine.

Capability	Explanation
User Authentication	How are users authenticated? What standards (Java Authentication and Authorization, Windows Authorization, Single Sign-on (SSO)) are used and how strong are they in comparison to existing technologies implemented by other state of the art composition engines.
Role Based Access	What standards are implemented by the engine to ensure role based access within a client as well as in a multi-tenant Cloud usage?
Data Encryption	What are the encryption methods that the engine supports to store data on servers as well as in the Cloud? How do we ensure data privacy in case of recovery of data in the Cloud?
Encrypted Data Transmission	What protocols are implemented to ensure safe data transmission across different components in private as well as public Clouds? Whether the workflow engine supports HTTPS, WS-Security or VPC protocol to communicate with Cloud service providers and among different components.
Compliance with Data-Access Rules from a Region	When distributing workloads to nodes in the Cloud, does the workload provide functionality to implement region-based data policy of the client?

Table 41. Capabilities of Security

User Authentication (**)

Points	Support
0	The engine's authentication and authorization support is not up to the latest standards (e.g. no/weak encryption during authorization, no SSO, no LDAP).
2	The engine provides limited authentication and authorization support.
4	The engine provides state of the art authentication and authorization.

Table 42. Points Assignment Scheme for User Authentication

Role Based Access (**)

Points	Support
0	The engine doesn't provide role based access.
4	The engine provides role based access.

Table 43. Points Assignment Scheme for Role Based Access

Data Encryption (**)

Points	Support
0	The engine does not provide complete data encryption and therefore data privacy.
4	The engine provides complete data privacy due to complete data encryption even during data loss.

Table 44. Points Assignment Scheme for Data Encryption

Encrypted Data Transmission (***)

Points	Support
0	The engine doesn't provide state of the art security for data transmission.
4	The engine provides state of the art security standards for data transmission.

Table 45. Points Assignment Scheme for Encrypted Data Transmission

Compliance with Data-Access Rules from a Region (***)

Points	Support
0	The engine doesn't have logic to implement regulatory guidelines.
2	The engine provides an agreement but its not verifiable by the client.
4	The engine provides verifiable mechanisms to ensure regulatory guidelines.

Table 46. Points Assignment Scheme for Compliance with Data-Access Rules from a Region

3.2.10. Multi-Tenancy

In the "Immigrant PaaS Technologies:Scientific and Technical Report" [12] we can read:"Multi-tenancy is the ability of transparent and dynamic usage of one application server instance by several tenants. To facilitate multi-tenancy, multiple capabilities are needed." In this category we evaluate if the workflow engine have this ability.

Capability	Explanation
Customize Configuration for different Tenants	In this capability it will be evaluated, if it is possible for each tenant, to individually configure the workflow engine [12].
Data Isolation	Isolation of data is critical to ensure privacy and security for each tenant and prevent users and tenants from accessing information that belong to others. In this capability it will be reviewed, if all necessary steps were taken, to ensure the secrecy of tenant information. [12]
Performance Isolation	Performance isolation is an important aspect regarding isolation of tenants. Everyone of the tenants should be able to use the same amount of processing power that the others can do. In scope of this criteria we check if there is any information about this in the workflow engine specification. [23]
Tenancy based Identity and Access Management	For the efficient administration of tenants and users its significant to have an identity and access management component. In this capability it will be reviewed if there is such an component. [12]

Management Portal for Tenants	A comfortable way for a tenant to manage his configuration on the engine is a Web-based management portal. In this capability it will be evaluated if a portal for managing tenant configuration is provided.

Table 47. Capabilities of Multi-Tenancy

Customize Configuration for different Tenants (***)

Points	Support
0	The engine can't be configured individually for each tenant.
4	Each tenant has the possibility to configure the engine for him self.

Table 48. Points Assignment Scheme for Customize Configuration for different Tenants

Data Isolation (***)

Points	Support
0	The engine does not ensure data isolation or there are no specifications about it.
4	The author of the engine guarantees data isolation, privacy, and security for each tenant.

Table 49. Points Assignment Scheme for Data Isolation

Performance Isolation (***)

Points	Support
0	There are no statements about performance isolation or the engine does not ensure it.
4	There are statement that performance isolation is guaranteed.

Table 50. Points Assignment Scheme for Performance Isolation

Tenancy based Identity and Access Management (***)

Points	Support
0	There is no tenant identity or access management functionality for this engine.
4	Each tenant has his own identity and it is possible to give tenants access rights or to forbid some actions.

Table 51. Points Assignment Scheme for Tenancy based Identity and Access Management

Management Portal for Tenants (***)

Points	Support
0	No Web-based portal for tenants is provided.
4	The engine provides a Web-based portal where the tenant can administrate his configurations.

Table 52. Points Assignment Scheme for Management Portal for Tenants

3.2.11. Quality of Service

SLA is a critical aspect in Cloud computing. The engine needs to have the logic implemented to be able to estimate the current workload and scale-up or down resources to meet QoS levels guaranteed to users.

Capability	Explanation
QoS Enforcement	The workflow engine must ensure that it meets the SLA that is requested in the composition. What are the self-repair, self-scaling, self-optimizing capabilities that are supported? Does it offer QoS by best effort? [12]
Metrics and Billing System	Deploying workloads across the Cloud requires an accurate metrics measurement and billing system. The metrics include both resource utilization as well as energy consumption.
Cloud-aware QoS Enforcement	Based on user choice, the workflow engine or workflow service should have the possibility to instantiate different Cloud components (e.g. computing or storage nodes) either with respect to cost or performance.

Table 53. Capabilities of Quality of Service

QoS Enforcement (***)

Points	Support
0	The engine doesn't have self-repair capabilities implemented.
2	The engine provides limited self-repair capabilities.
4	The engine provides self-repair capabilities to meet SLA's nearly 100%.

Table 54. Points Assignment Scheme for QoS Enforcement

Metrics and Billing System (***)

Points	Support
0	The engine doesn't provide Metrics and Billing data about cloud components.
2	The engine provides limited Metrics and Billing data about cloud components.
4	The engine provides extensive Metrics and Billing data about cloud components.

Table 55. Points Assignment Scheme for Metrics and Billing System

Cloud-aware QoS Enforcement (***)

Points	Support
0	The engine provides no flexibility of cloud components usage.
2	The engine provides limited flexibility of cloud components usage.
4	The engine provides extensive flexibility of cloud components usage.

Table 56. Points Assignment Scheme for Cloud-aware QoS Enforcement

3.3. Evaluation of Selected Composition Engines

3.3.1. ActiveVOS Data Center Edition by ActiveEndpoints

Functionality

Capability	Evaluation	Pts.
Workflow	see 4CaaSt D7.1.1 [12, p. 76], XPDL was only supported until	2

Languages	version 7 [102]	
Workflow Management Functionality	workflows can be easily deployed and migrated, e.g. via Eclipse [101], monitored and controlled, e.g. via Web Interface	4
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 76]	N/A
Suitability for Long-Term Workflows	yes, "You can start crucial, long-running work – including human tasks – that might represent weeks or even months of work at one site and continue or complete it at another site in the event of a failure at the source." [47]	4

Table 57. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	see 4CaaSt D7.1.1 [12, p. 76], plus: Axis2, JBI, OpenJPA, RMI, WS-Reliable Messaging, XML, POJO, EJB, WSIO [30, 60]	4
Supported Databases	see 4CaaSt D7.1.1 [12, p. 78]	4
Platforms able to run on	see 4CaaSt D7.1.1 [12, p. 78], plus: Microsoft Windows 2003/2008 Server, Linux, Solaris 10 (x86/Sparc), AIX 5.3 and 6.1, HP-UX 11 v3, Mac OS 10.6 64-bit or higher	4
Interoperability with other Cloud Systems	only needs Java 6 with JEE application server and a database, runs on many operation systems and therefore can be easily ported to other IaaS Clouds [71]	4

Table 58. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	the engine itself cannot be extended, only BPEL extensions can be defined, see 4CaaSt D7.1.1 [12, p. 77]	0
Modular Architecture	modular architecture, custom activities, receive and invoke handlers can be added [75]	2
APIs and GUI Replacement	see 4CaaSt D7.1.1 [12, p. 78], Admin SDK (process level, not node/tenant/server level) [76], no information on GUI replacement ability	2
License	see 4CaaSt D7.1.1 [12, p. 78]	0

Table 59. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	see 4CaaSt D7.1.1 [12, p. 77]	2
Availability of IDE	extensive Eclipse integration [30, 60, 101]	4

Plug-ins		
Debugger Support	see 4CaaSt D7.1.1 [12, p. 77]	2
Developer Support	see 4CaaSt D7.1.1 [12, p. 77], extensive online video training, sample applications, professional training and consulting, big and active forum, not 4CaaSt member, 165.000 Google hits for "ActiveVOS"	4

Table 60. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	see 4CaaSt D7.1.1 [12, p. 78]	4
Proper Logging for Auditing and Tracking Purpose	see 4CaaSt D7.1.1 [12, p. 78]	4
Access to Engine Status Information	administrator can look into every detail of the processes [65], drill down status from server to cluster node to process to task [74]	4

Table 61. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	see 4CaaSt D7.1.1 [12, p. 77]	4
Utilization of Flexible Storage Services	none, it seems attachments are stored in the database	0
Available Tools Allowing Cloud Administration	"multi-cloud clustering, which provides seamless replication and scaling of business processes across multiple data centers and clouds" [77], partly with multi site deployment (fail-over, synchronization of configuration), but no Cloud-awareness	0
Data Transfer and Access Efficiency	N/A, seems everything is stored in the database, except the keystore for WS-Security	0

Table 62. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	database transactions, distributed (XA) transactions with JMS [67]	4
Dynamic Service Selection / Service Discovery	dynamic service selection only based on message data or WS-Policy rules [101], no information on dynamic binding selection or UDDI service discovery found (as failure compensation)	0
Central Exception Handling	yes, through "Administration Console" and "ActiveVOS Designer" debug view (Eclipse IDE plugin) [68]	4

Behavior under Heavy Load	configurable throttling and queuing, monitoring and management of dispatcher (pause, resume, purge queued requests) ("Dispatch Service") [66], no information on attack scenarios (DDoS), infinite threads possible, configurable thread pools per "Work manager" and process [69], configurable dispatcher [66]	4
Persistent Data Storage	configurable from all data (incl. journaling) to no data is persisted in databases [70], databases in gereral can store data persistent	4

Table 63. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	yes, features depending on application server (e.g. LDAP), SSO via CAS [104], no further information found	4
Role Based Access	yes, relies on features of application server, roles for system admin, tenant admin, task client, developer, deployer, service consumer and identity list consumer [78]	4
Encrypted Data Transmission	WS-Security (incl. SAML) [79], keystore has to be on disk	4

Table 64. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	"each client organization works with a customized virtual application instance"	4
Data Isolation	"Each tenant creates and manage his on processes in complete isolation." [63]	4
Performance Isolation	"Each tenant creates and manage his on processes in complete isolation." [63]	4
Tenancy based Identity and Access Management	"Each tenant creates and manage his on processes in complete isolation." [63], configurable tenant users (admin groups and consumer groups), tenant security roles [64], system admins can log in to tenant context [65]	4
Management Portal for Tenants	yes [64]	4

Table 65. ActiveEndpoints ActiveVOS Data Center Edition – Evaluation of Category Multi-Tenancy

3.3.2. Composition Engine by Ericsson

Functionality

Capability	Evaluation	Pts.
Workflow Languages	see 4CaaSt D7.1.1 [12, p. 86]	0
Workflow Management	see 4CaaSt D7.1.1 [12, p. 86]	N/A

Functionality		
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 86]	2
Suitability for Long-Term Workflows	N/A	N/A

Table 66. Ericsson Composition Engine – Evaluation of Category Functionality

Integration and Communication Standards

Capability	**Evaluation**	**Pts**.
Communication Protocols	see 4CaaSt D7.1.1 [12, p. 86]	2
Supported Databases	see 4CaaSt D7.1.1 [12, p. 88]	0
Platforms able to run on	see 4CaaSt D7.1.1 [12, p. 88], Glassfish Application Server, needs [107], no information on supported operating systems found	N/A
Interoperability with other Cloud Systems	N/A	N/A

Table 67. Ericsson Composition Engine – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	**Evaluation**	**Pts**.
Plug-in Interface	see 4CaaSt D7.1.1 [12, p. 87]	2
Modular Architecture	N/A	N/A
APIs and GUI Replacement	see 4CaaSt D7.1.1 [12, p. 88]	2
License	see 4CaaSt D7.1.1 [12, p. 87]	0

Table 68. Ericsson Composition Engine – Evaluation of Category Extensibility

Tools and Development

Capability	**Evaluation**	**Pts**.
Tools Availability	see 4CaaSt D7.1.1 [12, p. 87]	0
Availability of IDE Plug-ins	Eclipse plug-in for modeling, monitoring, inspecting and debugging [105], Netbean plug-in [106]	2
Debugger Support	see 4CaaSt D7.1.1 [12, p. 87]	2
Developer Support	see 4CaaSt D7.1.1 [12, p. 87]	0

Table 69. Ericsson Composition Engine – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	see 4CaaSt D7.1.1 [12, p. 88]	0
Proper Logging for Auditing and Tracking Purpose	see 4CaaSt D7.1.1 [12, p. 88]	2
Access to Engine Status Information	"inspect all state information stored in the composition engine" [105]	4

Table 70. Ericsson Composition Engine – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	see 4CaaSt D7.1.1 [12, p. 87]	2
Utilization of Flexible Storage Services	N/A	N/A
Available Tools Allowing Cloud Administration	N/A	N/A
Data Transfer and Access Efficiency	N/A	N/A

Table 71. Ericsson Composition Engine – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	N/A	N/A
Dynamic Service Selection / Service Discovery	yes [108]	4
Central Exception Handling	N/A	N/A
Behavior under Heavy Load	low latency [107]	0
Persistent Data Storage	N/A	N/A

Table 72. Ericsson Composition Engine – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	N/A	N/A
Role Based Access	N/A	N/A

Encrypted Data Transmission	N/A	N/A

Table 73. Ericsson Composition Engine – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	see 4CaaSt D7.1.1 [12, p. 86]	0
Data Isolation	see 4CaaSt D7.1.1 [12, p. 86]	4
Performance Isolation	see 4CaaSt D7.1.1 [12, p. 86]	0
Tenancy based Identity and Access Management	N/A	N/A
Management Portal for Tenants	N/A	N/A

Table 74. Ericsson Composition Engine – Evaluation of Category Multi-Tenancy

3.3.3. Apache ODE

Functionality

Capability	Evaluation	Pts.
Workflow Languages	see 4CaaSt D7.1.1 [12, p. 78], no BPMN support	2
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows.	4
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 79]	N/A
Suitability for Long-Term Workflows	both long and short running process executions [82]	4

Table 75. Apache ODE – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	see 4CaaSt D7.1.1 [12, p. 79], REST [84]	4
Supported Databases	see 4CaaSt D7.1.1 [12, p. 81]	4
Platforms able to run on	see 4CaaSt D7.1.1 [12, p. 81], supported application servers: As a simple Web service in Axis 2, ODE is bundled in a WAR than can	4

	be deployed in any application server and is invoked using plain SOAP/HTTP.	
Interoperability with other Cloud Systems	Its available as WAR or JBI package and therefore can be easily ported to other IaaS Clouds [85].	4

Table 76. Apache ODE – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	see 4CaaSt D7.1.1 [12, p. 80]	4
Modular Architecture	modular architecture, minimal dependencies between modules that can be reassembled [86]	4
GUI Replacement and APIs	see 4CaaSt D7.1.1 [12, p. 81], a very basic Web interface is included with many functionalities still need to be developed, no information on GUI replacement ability	2
License	see 4CaaSt D7.1.1 [12, p. 80]	4

Table 77. Apache ODE – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	see 4CaaSt D7.1.1 [12, p. 80], BPEL Designer	2
Availability of IDE Plug-ins	Eclipse integration [87], plugins are available but workload distribution across cloud components is not possible.	2
Debugger Support	see 4CaaSt D7.1.1 [12, p. 81]	2
Developer Support	See 4CaaSt D7.1.1 [12, p. 80], limited documentation	2

Table 78. Apache ODE – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	see 4CaaSt D7.1.1 [12, p. 81], a very basic Web GUI	2
Proper Logging for Auditing and Tracking Purpose	see 4CaaSt D7.1.1 [12, p. 81], using log4j	4
Access to Engine Status Information	[89, p.13] a high-level overview of Apache ODE traceability is explained.	4

Table 79. Apache ODE – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	see 4CaaSt D7.1.1 [12, p. 80]	0
Utilization of Flexible Storage Services	An example of this implementation is given in [90].	4
Available Tools Allowing Cloud Administration	It's possible to allocate/administer Cloud resources. However no Cloud administration tools available now. [90]	2
Data Transfer and Access Efficiency	can connect with tools like gridFTP [91]	4

Table 80. Apache ODE – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	ODE uses transaction management and relies on transactional data stores to ensure data consistency in the event of failure	4
Dynamic Service Selection / Service Discovery	yes [93, 94]	4
Central Exception Handling	a BPEL extension handles this [95]	4
Behavior under heavy Load	N/A	0
Persistent Data Storage	ODE relies on a relational databases to provide persistent storage [92]	4

Table 81. Apache ODE – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	HTTP Basic Authentication [96], process contexts [97]	2
Role Based Access	everyone can access the administration Web interface and use all processes see 4CaaSt D7.1.1 [12, p.79]	0
Encrypted Data Transmission	WS-Security (incl. SAML) , HTTPS[422], are supported	4

Table 82. Apache ODE – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize	everyone can access the administration Web interface and use all	0

Configuration for different Tenants	processes see 4CaaSt D7.1.1 [12, p.79]	
Data Isolation	see 4CaaSt D7.1.1 [12, p.79]	0
Performance Isolation	see 4CaaSt D7.1.1 [12, p.79]	0
Tenancy based Identity and Access Management	see 4CaaSt D7.1.1 [12, p.79]	0
Management Portal for Tenants	see 4CaaSt D7.1.1 [12, p.79]	0

Table 83. Apache ODE – Evaluation of Category Multi-Tenancy

3.3.4. OW2 Orchestra

Functionality

Capability	Evaluation	Pts.
Workflow Languages	WS-BPEL and BPMN support [430] + see 4CaaSt D7.1.1 [12, p. 89]. WS-BPEL 2.0 elements not supported: Isolated Scope, variable validation (validate), extension activity Support of only basic BPMN 2.0 structures in the designer.	2
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows. see 4CaaSt D7.1.1 [12, p. 89]	4
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 89]	4
Supported Workflow Execution Patterns	handles long-running, service-oriented processes [430]	4

Table 84. OW2 Orchestra – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	see 4CaaSt D7.1.1 [12, p. 89], SOAP, Axis1.4, CXF 2.2.5 [233], no information on REST support.	2
Supported Databases	see 4CaaSt D7.1.1 [12, p. 91]	4
Platforms able to run on	Delivered as a Tomcat distribution and Felix OSGi distribution [233]. Apache Tomcat Servlet Container, JonAS, Apache Felix OSGI platform are the containers supported. Aplications Servers/Servlet Container Supported are: Apache Tomcat,JOnAS / JBoss AS, Apache Felix.	4

Interoperability with other Cloud Systems	Its available embedded inside a Tomcat or Felix package distribution and therefore can be easily ported to other IaaS Clouds[233]	4

Table 85. OW2 Orchestra – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	see 4CaaSt D7.1.1 [12, p. 90]	4
Modular Architecture	It's based on the OSGi technology that allows to be built modular [407].	4
GUI Replacement and APIs	see 4CaaSt D7.1.1 [12, p. 91]. No information on GUI replacement ability is available. APIs are provided as JMX interfaces see 4CaaSt D7.1.1 [12, p. 91]	2
License	see 4CaaSt D7.1.1 [12, p. 90]	4

Table 86. OW2 Orchestra – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	see 4CaaSt D7.1.1 [12, p. 90]+ issues with Eclipse BPEL Designer are identified[233]. Work in progress on Web2.0 designer(a preview is available)	2
Availability of IDE Plug-ins	Eclipse integration [87] Plugins are available but workload distribution across cloud components is not possible.	2
Debugger Support	see 4CaaSt D7.1.1 [12, p. 90] . Only through API and not through console.	2
Developer Support	see 4CaaSt D7.1.1 [12, p. 90] , small community, training from Bull is possible, limited documentation.	2

Table 87. OW2 Orchestra – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	see 4CaaSt D7.1.1 [12, p. 91] + a Web2.0 console is included [233]	4
Proper Logging for Auditing and Tracking Purpose	see 4CaaSt D7.1.1 [12, p. 91]	4
Access to Engine Status Information	For each instance, its state, last updated date, start date are available on the console. Also a set of possible actions are also listed in the console. Using these actions, Its possible to get details and activities of the selected instance. Inside an instance, one can check which activities are already completed and running [234].	4

Table 88. OW2 Orchestra – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	see 4CaaSt D7.1.1 [12, p. 56] + In a clustered environment, reply activities are not supported. The Web services exported by Orchestra are only one-way Web services[234]	2
Utilization of Flexible Storage Services	No information found.	N/A
Available Tools Allowing Cloud Administration	Though the road-map is well documented in [265], no implementation detail is found.	0
Data Transfer and Access Efficiency	No information found though this has been explored as an idea to be implemented.	0

Table 89. OW2 Orchestra – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	only simple 2 phase commit transaction support found [263]	2
Dynamic Service Selection / Service Discovery	A novel method has been just simulated using OW2 for dynamic service selection [264].	2
Central Exception Handling	handled by Dead Job handler [234]	4
Behavior under heavy Load	see 4CaaSt D7.1.1 [12, p. 90]	4
Persistent Data	Orchestra is persistable. This means that all the data concerning	4

Storage	your processes definition and instances execution is stored in a database using a persistence framework (Hibernate by default) [234].	

Table 90. OW2 Orchestra – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	No information found	N/A
Role Based Access	The roles are defined in web.xml file. By default, you can log with user and admin as role but this version doesn't implement the role mechanism [234].	0
Encrypted Data Transmission	CXF supports WS-Security, HTTPS [423]	4

Table 91. OW2 Orchestra – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	see 4CaaSt D7.1.1 [12, p. 89]	0
Data Isolation	see 4CaaSt D7.1.1 [12, p. 89]	0
Performance Isolation	see 4CaaSt D7.1.1 [12, p. 89]	0
Tenancy based Identity and Access Management	see 4CaaSt D7.1.1 [12, p. 89]	0
Management Portal for Tenants	see 4CaaSt D7.1.1 [12, p. 89]	0

Table 92. OW2 Orchestra – Evaluation of Category Multi-Tenancy

3.3.5. WSO2 Stratos / Business Process Server

Functionality

Capability	Evaluation	Pts.
Workflow Languages	see 4CaaSt D7.1.1 [12, p. 92] no BPMN support.	2
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows. see 4CaaSt D7.1.1 [12, p. 92]	4
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 92]	N/A

	WSO2 BPS is recommended for long running processes [148]	4
Supported Workflow Execution Patterns	WSO2 BPS is recommended for long running processes [148]	4

Table 93. WSO2 Stratos – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	Everything based on Apache Axis2, See 4CaaSt D7.1.1 [12, p. 96] and BPEL4WS 1.1 , WS-BPEL 2.0 , SOAP 1.1/1.2 , WSDL 1.1, WS-Addressing, WS-Security 1.0/1.1,WS-*, XKMS, etc.[150]	4
Supported Databases	See 4CaaSt D7.1.1 [12, p. 94] + H2 [150]	4
Platforms able to run on	Binary Distribution includes binary files for both MS Windows and Linux operating systems [151]. Application Servers supported:Apache Tomcat, WSO2 Carbon, JBoss	4
Interoperability with other Cloud Systems	It avoids vendor lock-in as its platform independent [152]	4

Table 94. WSO2 Stratos – Evaluation of Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	See 4CaaSt D7.1.1 [12, p. 93] + Eclipse BPEL support, including the ability to work with Eclipse BPEL tooling and the availability of a plug-in to deploy Eclipse-developed processes in WSO2 BPS [152]	4
Modular Architecture	modular, componetized, OSGi standard [149]	4
GUI Replacement and APIs	See 4CaaSt D7.1.1 [12, p. 94,95] + All admin functions and all the low level services are available as SOAP APIs.[149]	4
License	See 4CaaSt D7.1.1 [12, p. 93]	4

Table 95. WSO2 Stratos – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	See 4CaaSt D7.1.1 [12, p. 94] + BPS BPEL Exporter to export a deployable artifact[157]	4
Availability of IDE Plug-ins	See 4CaaSt D7.1.1 [12, p. 94] + Service Archive Generator Wizard + Code Generator Wizard [158] [160]	4
Debugger Support	See 4CaaSt D7.1.1 [12, p. 94] + debug Web services + test Web services [160]	2
Developer Support	See 4CaaSt D7.1.1 [12, p. 94] [145] [146] limited documentaion, yet tutorials and training options are good	2

Table 96. WSO2 Stratos – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	See 4CaaSt D7.1.1 [12, p. 94]	4
Proper Logging for Auditing and Tracking Purpose	See 4CaaSt D7.1.1 [12, p. 95]	4
Access to Engine Status Information	activate or retire the process from Process Information page, Activity Information and State of the instance from Instance Information page [162]	4

Table 97. WSO2 Stratos – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	See 4CaaSt D7.1.1 [12, p. 93]	0
Utilization of Flexible Storage Services	the WSO2 team uses Amazon Simple Storage System (Amazon S3) to store configurations and code images, Amazon Elastic Block Storage (Amazon EBS) to manage the underlying databases, and Elastic IP addresses to preserve a consistent public IP and DNS view.[163]	4
Available Tools Allowing Cloud Administration	See [90] It's possible to allocate/administer cloud resources. However no Cloud administration tools available now	2
Data Transfer and Access Efficiency	N/A	0

Table 98. WSO2 Stratos – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	see [164] One can specify external or custom transaction factory class to take care of transactions	4
Dynamic Service Selection / Service Discovery	WSO2 BRS let users to expose the business logic written in such rule files as a Web service so that any SOA system can consume it.[165]	4
Central Exception Handling	N/A	N/A
Behavior under heavy Load	Auto scales (up & down) by monitoring the load and creating/shutting down new nodes. Load balancer routes the requests.[190]	4
Persistent Data Storage	events are persisted in BPS embedded H2 database and can be queried using the BPS Management API [191]	4

Table 99. WSO2 Stratos – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User	It supports XMPP based Multifactor Authentication, Federated	4

Authentication	authentication mechanisms such as OpenID provider and SAML2, SAML2 based Single Sign On among all the services in SLive, Authentication delegations mechanisms such as OAuth [192]	
Role Based Access	Role based permission model as well as powerful, fine grained and flexible Policy Based Access Control with XACML are supported [192]	4
Encrypted Data Transmission	Data communication from the browser to back-end Admin Services happens over HTTPS which provides transport level protection[192]	4

Table 100. WSO2 Stratos – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	See 4CaaSt D7.1.1 [12, p. 93]	4
Data Isolation	Data isolation in registry is achieved with the tenant domain id, in a shared schema, shared database pattern, while the registry data storage is hosted in a DMZ[192]	4
Performance Isolation	See 4CaaSt D7.1.1 [12, p. 92]	2
Tenancy based Identity and Access Management	Each tenant is given a separate security domain such that each domain is isolated and does not have access to other domains [192]. Also See 4CaaSt D7.1.1 [12, p. 92]	4
Management Portal for Tenants	Bulk User import and provisioning users from google app domain for user administration[192]. Also See 4CaaSt D7.1.1 [12, p. 91]	4

Table 101. WSO2 Stratos – Evaluation of Category Multi-Tenancy

3.3.6. BonitaSoft Bonita Open Solution

Functionality

Capability	Evaluation	Pts.
Workflow Languages	see 4CaaSt D7.1.1 [12, p. 82], also JBPM3 is supported [193].	4
Workflow Management Functionality	All basic functionalities are given [193].	4
Advanced Functionality	see 4CaaSt D7.1.1 [12, p. 82], also simulation, graphical process design tool, process optimization and templates are provided [193].	4
Suitability for Long-Term Workflows	N/A	N/A

Table 102. BonitaSoft Bonita Open Solution – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	see 4CaaSt D7.1.1 [12, p. 82]. Also it is possible to use build-in or to develope own connectors [197, 198].	4
Supported Databases	see 4CaaSt D7.1.1 [12, p. 85]. Also see [219]. A large set of connectors is provided for different databases [198, p. 53].	4
Platforms able to run on	Windows, Linux, Mac, JBoss 5.1.0, Tomcat 6.0.3	4
Interoperability with other Cloud Systems	With version 5.3 functionalities were added like "multi-tenancy and REST services to better adapt to cloud computing environments."[200] The Bonita Engine was successfully deployed "on Windows Azure but also implemented it on other private and public cloud platforms such as Amazon EC2." But the effort for this was substantial.[202]	2

Table 103. BonitaSoft Bonita Open Solution – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	see 4CaaSt D7.1.1 [12, p. 83]	4
Modular Architecture	N/A	N/A
APIs and GUI Replacement	A respectful set of APIs is provided [202, 214].	2
License	see 4CaaSt D7.1.1 [12, p. 83], GNU General Public License V2 (January 2012)	4

Table 104. BonitaSoft Bonita Open Solution – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	There are good tools provided. A graphical workflow designing tool that also has some additional functionalities like the "connector wizard" for creating connectors. [204]	4
Availability of IDE Plug-ins	N/A	N/A
Debugger Support	"Using Bonita Studio's new debugger, developers can now test their applications more easily by choosing not to use connectors with external systems with a simple click." [205], testing connectors in a pre-run excecution [193]	2
Developer Support	see 4CaaSt D7.1.1 [12, p. 83]. Good community [206], Training [203]	4

Table 105. BonitaSoft Bonita Open Solution – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	"Bonitasoft User Experience: Provides a user and administration portal designed for managing and deploying running processes, cases and reports." [207] Also see [208, 223].	4
Proper Logging for Auditing and Tracking Purpose	see 4CaaSt D7.1.1 [12, p. 85], see also [209]	4
Access to Engine Status Information	A great amount of status information is provided [210].	4

Table 106. BonitaSoft Bonita Open Solution – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	see 4CaaSt D7.1.1 [12, p. 83]	2
Utilization of Flexible Storage Services	There are same processes, which interact with Windows Azure storage [212, 213].	2
Available Tools Allowing Cloud Administration	N/A	N/A
Data Transfer and Access Efficiency	N/A	N/A

Table 107. BonitaSoft Bonita Open Solution – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	"The Bonita Execution Engine is a fully transactional engine, which allows grouped calls and unit definition to manage failures." [193, 215, 216, 217]	4
Dynamic Service Selection / Service Discovery	N/A	N/A
Central Exception Handling	There is connector exceptions management [218]. Error management [193].	4
Behavior under Heavy Load	N/A	N/A
Persistent Data Storage	Depends on the configured database. On default its set on H2 [219]. Bonita doesn't guarantee data safety. See accuracy and security on Bonitasoft's privacy page [222].	2

Table 108. BonitaSoft Bonita Open Solution – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	There is user authentication mentioned [220], Java Authentication and Authorization Service is used [221].	4
Role Based Access	"Organizations with complex requirements may want to define rules to ensure certain processes can only be started by authorized people. This feature is especially valuable at runtime when you need to make dynamic assignments based on business conditions." [193]	4
Encrypted Data Transmission	Only information about Secure Web services found[211]	0

Table 109. BonitaSoft Bonita Open Solution – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	see 4CaaSt D7.1.1 [12, p. 83]	4
Data Isolation	see 4CaaSt D7.1.1 [12, p. 83]	4
Performance Isolation	see 4CaaSt D7.1.1 [12, p. 83]	0
Tenancy based Identity and Access Management	see 4CaaSt D7.1.1 [12, p. 83]	4
Management Portal for Tenants	A administration portal for tenants is provided [223,208]. Also see [207] under "User Experience".	4

Table 110. BonitaSoft Bonita Open Solution – Evaluation of Category Multi-Tenancy

3.3.7. IBM Business Process Manager

Functionality

Capability	Evaluation	Pts.
Workflow Languages	IBM Business Process manager supports BPMN and BPEL and migration from other WebSphere products [81].	2
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows [81, 88, 126].	4
Advanced Functionality	The engine provides a process center, with which it is possible to use some additional functions, e.g. in the Performance Data Warehouse data is stored, which can be used "for testing and playback purposes" [88, p. 2].	4
Suitability for long-term workflows	"When building a BPM 7.5 Advanced Integration Service, developers choose between a Java component, a long-running BPEL process or a short-running transactional process called a microflow." [126, p. 10]	4

Table 111. IBM Business Process Manager – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	Bindings: HTTP/SOAP, JAX-WS, EJB, JMS, SCA, JAX-RPC, WSDL [88, p. 45, 63, 98, 156-158]	4
Supported Databases	Microsoft SQL Server, DB2, Oracle [123; 88, p. 10]	2
Platforms able to run on	AIX, HP-UX, Linux, Solaris, Windows [124]	4
Interoperability with other Cloud Systems	N/A	N/A

Table 112. IBM Business Process Manager – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	"Importing services from an external EJB implementation allows users to plug their business logic into the IBM Business Process Manager environment and participate in a business process." [88, p. 95], also "Build-in enterprise service bus(ESB)" [88, p. 4]	2
Modular Architecture	The architecture of the engine is shown [81, p. 3]. It's possible to add some IBM products to the engine like IBM Forms Server or WebSphere Application Server [125]. Since it's possible to connect other products (SOA, ESB) to the engine, they don't have to be on the same machine.	2
GUI Replacement and APIs	Worklists, coaches, and other BPM runtime components are exposed as REST-based UI fragments called widgets that can be assembled by end users in their Business Space. Alternatively, through optional add-on components, BPM 7.5 users can perform process tasks directly from Microsoft Outlook and Microsoft SharePoint. [126, p. 12]	2
License	IBM International Program License Agreement [127], "Licensee may copy and modify Source Components and Sample Materials for internal use only provided such use is within the limits of the license rights under this Agreement, provided however that Licensee may not alter or delete any copyright information or notices contained in the Source Components or Sample Materials." [128]	0

Table 113. IBM Business Process Manager – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	There is a respectful set of tools provided, e.g. IBM Process Designer, IBM Integration Designer, IBM Performance Admin Console [88, p. 2].	4

Availability of IDE Plug-ins	Integration Designer is a Eclipse plug-in	2
Debugger Support	"For a selected instance, see the currently executing step and then move forward through the process, evaluating process execution step by step. A tree display of the process combined with indicators [...]" [88, p. 15] and the variables are also visible for every step.	4
Developer Support	Training is provided [129], good documentation and few samples [130]. Active community [418] and also different kinds of support. For example IBM Support Assistant [419] or remote assistance [420].	4

Table 114. IBM Business Process Manager – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	The engine provides a Web-based process portal [126, p. 11]. Also there is the Business Space. It is a Web portal where users can access the Business Process Manager via widgets [154].	4
Proper Logging for Auditing and Tracking Purpose	A great deal of logging capabilities is provided [131,132].	4
Access to Engine Status Information	Access to all necessary information is given. "A tree display of the process combined with indicators called tokens in the process diagram make it easy to understand where you are in the process. "[88, p. 15].	4

Table 115. IBM Business Process Manager – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	IBM Business Process Manager in standard and advanced versions supports clustering [88, table 2].	4
Utilization of Flexible Storage Services	N/A	N/A
Available Tools Allowing Cloud Administration	N/A	0
Data Transfer and Access Efficiency	"If one or more activities require access to large backend systems or service [...] you can meet that need using Integration Designer. [...] That service can use mediation flows to transform, route, and enhance data and adapters to get to many backend systems in standard way. [88. p. 6], see for example HTTPStreamDataBinding [88. p. 94]	4

Table 116. IBM Business Process Manager – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	The IBM Business Process Manager Advanced supports transactions. [88, Table 2]	4
Dynamic Service Selection / Service Discovery	Dynamic endpoint selection is provided [137; 88, p. 20, 156, 163].	2
Central Exception Handling	No central exception handling [88].	0
Behavior under heavy Load	"If one server is unavailable to perform the task, it is assigned to another cluster member. This reassignment capability has obvious advantages over running a single application server that can become overloaded if too many requests are made." [88, p. 35]	4
Persistent Data Storage	data handling described in section "Data sources for IBM Business Process Manager" [88, p. 151], backup options [153]	4

Table 117. IBM Business Process Manager – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	Internal IBM security based on WebSphere Application Server is provided [141]. Possible to use "in conjunction with an external security provider" [142].	4
Role Based Access	Engine provides role based access [141]. It's possible to manage rights for some operations based on user groups [159].	4
Encrypted Data Transmission	WS-Security [88, p. 66], encryption of message contents in the integrated ESB [88, p. 149]	4

Table 118. IBM Business Process Manager – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	There is a customizable UI called Business Space that can be configured for each user individually, but it cannot be called multi-tenancy [154]. No additional information found.	0
Data Isolation	Only statements about Business Space (UI) access limitations [155] and limitations by user groups [156].	0
Performance Isolation	N/A	N/A
Tenancy based Identity and Access Management	N/A	N/A
Management Portal for Tenants	N/A	N/A

Table 119. IBM Business Process Manager – Evaluation of Category Multi-Tenancy

3.3.8. BPMS Enterprise by Intalio

Functionality

Capability	Evaluation	Pts.
Workflow Languages	BPMN[327], BPEL[327]	2
Workflow Management Functionality	All required workflow management functionality is provided [368].	4
Advanced Functionality	Great amount of additional functions is provided. For each step of the workflow lifecycle, e.g. consistency checking, activity based costing, or ESB [368].	4
Suitability for Long-Term Workflows	Long running workflows are supported [373].	4

Table 120. BPMS Enterprise by Intalio – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	WSDL [367], REST, SOAP, JMS [378], ESB [380], WS-HumanTask [389]	2
Supported Databases	Derby (default), MySQL, PostgreSQL, IBM DB2, Ingres Database, MS SQL Server, Oracle, Sybase ASE [327]	4
Platforms able to run on	Red Hat Linux, Suse Linux, Windows 2003 Server, Windows 2008 Server, HP-UX, IBM AIX, Sun Solaris, Tomcat, Jetty, JBoss Application Server, WebLogic Application Server [327]	4
Interoperability with other Cloud Systems	On one source [177] its said that Intalio's open source engine (Intalio BPMS) is the base of Intalio's Cloud product (Intalio BPM). On the other hand we received information from a different source that contradicts with the previous information [421].	N/A

Table 121. BPMS Enterprise by Intalio – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	N/A	N/A
Modular Architecture	The architecture of BPMS is shown, but is not very detailed [383]. There is not much information about the architecture of the engine itself, here called Intalio Server. Its only mentioned that it is based on J2EE architecture [387] and Apache ODE [388].	0
APIs and GUI Replacement	There is a BPEL Management API mentioned in few threads form 2006 [390, 391]. But no information found that is up to date. Probably because the engine itself is based on Apache ODE.	2
License	With the community license you can modify the software, but the license has to be kept [379]. In Enterprise Edition you can make changes without sharing them, distribution is not allowed [392].	2

Table 122. BPMS Enterprise by Intalio – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	Intalio Designer [381], Human Task Service, Business Activity Monitoring, different connectors (e.g. ServiceMix Connector) [327]	4
Availability of IDE Plug-ins	Intalio BPMS Designer is basically a set of Eclispe plug-ins. It provides functionality which allows to check the dependencies, designs and deploy BPMN processes[381].	4
Debugger Support	The debugger is planned for a future release [368].	0
Developer Support	There is training [394] and commercial support [393] for the Enterprise edition. There is documentation in a reasonable amount, but the documentation does not cover all important aspects (e.g. connector description) in a sufficient matter [395, 396, 397]. The community is relative small [398].	2

Table 123. BPMS Enterprise by Intalio – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	Intalio BPMS Console [400] is a Web based GUI with which you can access the engine [399].	4
Proper Logging for Auditing and Tracking Purpose	Good logging capabilities with Intalio's BAM (Business Activity Monitoring) component [401]. Intalio BPMS Console [400] also provides information about what happened while the process was running [403]. There are also logging capabilities for the engine itself, not of the process. This capabilities provide useful information for debugging, but lack in readability [401].	4
Access to Engine Status Information	The information provided in Intalio BPMS Console is good readable and useful [400].	4

Table 124. BPMS Enterprise by Intalio – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	The Enterprise edition of Intalio BPMS provides dynamic clustering [327, 404, 405].	4
Utilization of Flexible Storage Services	N/A	N/A
Available Tools Allowing Cloud Administration	N/A	N/A
Data Transfer and Access Efficiency	N/A	N/A

Table 125. BPMS Enterprise by Intalio – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	Transactions are supported in the enterprise edition [327, 406].	4
Dynamic Service Selection / Service Discovery	There where discussions [408] about the feature in 2007, but no sign that the feature was implemented for Intalio BPMS. Also see Intalio BRE [409] for Intalio BPM.	0
Central Exception Handling	Its shown how to handle exceptions using the business process [410, 411, 412], but no central exception handling.	0
Behavior under Heavy Load	There are statements that indicate good resistance for large workloads. For example: "Largest number of concurrently running process instances: 250,000,000" [367]	4
Persistent Data Storage	The data is stored in the configured database. The reliability of these can be configured. Derby is the default database [327].	4

Table 126. BPMS Enterprise by Intalio – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	The log-in step is mentioned in every tutorial [413]. But there is no description in Intalio's documentation. Since the engine is based on Apache ODE, probably Apache's authentication solution is used. [see Apache ODE evaluation, Chapter 3.3.3	2
Role Based Access	Basic role assignment with access limitations is provided [414, 415].	4
Encrypted Data Transmission	Nothing mentioned in Intalio's documentation. See Apache ODE evaluation, Chapter 3.3.3	4

Table 127. BPMS Enterprise by Intalio – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for	Intalio claims that the engine has a "Multi-Tenant Architecture", which means: "Support the needs of multiple organizations from	N/A

	different Tenants	the same process infrastructure." [368] But no information found about customized configurations for different users from Intalio's documentation. In addition, most of the results of the search about multi-tenancy were about other Intalio's products, for example the Intalio Cloud and it's CRM component [416]. The engine is based on Apache ODE, which also does not support multi-tenancy (See Chapter 3.3.3).	
Data Isolation	N/A	N/A
Performance Isolation	N/A	N/A
Tenancy based Identity and Access Management	N/A	N/A
Management Portal for Tenants	N/A	N/A

Table 128. BPMS Enterprise by Intalio – Evaluation of Category Multi-Tenancy

3.3.9. Windows Workflow Foundation (.NET) by Microsoft (not evaluated)

Windows Workflow Foundation does not support BPEL any more, it was only temporary supported in a community technology preview [46]. Therefore it is not evaluated.

3.3.10. BPM Suite 11g by Oracle

Functionality

Capability	Evaluation	Pts.
Workflow Languages	Oracle BPM supports BPMN 2.0 and BPEL from modeling and implementation to run time and monitoring [330].	4
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows.	4
Advanced Functionality	It enables business user to test and simulate, generate process documentation, has a collaborative development life-cycle, richer social BPM, rich process analytics and adaptive case management [332].	4
Supported Workflow Execution Patterns	Supports long-running processes [331].	4

Table 129. BPM Suite 11g by Oracle – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	FTP, SOAP, WSDL, UDDI, IBM MQSeries, EJB, Oracle B2B, JMS, REST [334, 335]	4

Supported Databases	It supports DB2 9.7, Microsoft SQL Server 2008, MySQL 5.5, Sybase 15.5+, Java DB 10.5.3.0 (network) [328]	4
Platforms able to run on	Its certified on IBM WebSphere, BEA WebLogic, and JBoss. It runs on Windows, Solaris, Red Hat Linux and Suse Linux [329]. Apart from Weblogic application server, IBM WebSphere Application Server can be used with SOA suite [328].	4
Interoperability with other Cloud Systems	Setting up the SOA suite involves a lot of steps as it's a business process platform that needs to be set up. Though a lot of platforms are supported, it would require a lot of effort to migrate across different IaaS Clouds [330].	2

Table 130. BPM Suite 11g by Oracle – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	WebLogic Integration supports a plug-in framework that is available for extending BPM functionality. This plug-in framework should only be used for extending the native functionality of the BPM [339].	4
Modular Architecture	It leverages existing investments by being modular, open, extensible and hot-pluggable; this eliminates the need to remove or replace existing systems as well as supporting incremental deployment and ROI [338].	4
GUI Replacement and APIs	APIs are provided as JMX interfaces.Also A Guide to customizing the look and feel of Oracle BPM WorkSpace is given here[431]	4
License	The license is proprietary.	0

Table 131. BPM Suite 11g by Oracle – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	Oracle BPM Studio is primarily used by the Oracle SOA Suite for developing compositions [336]. Eclipse can also be used [337].	4
Availability of IDE Plug-ins	Full-fledged BPM Studio means no requirement for plug-ins, but workload distribution across cloud components is not possible [424].	2
Debugger Support	A new process-level debugger allows developers to introduce breakpoints and debug complete processes running in Studio. When the execution reaches a breakpoint, the engine pauses and Studio's debugging view appears [341].	4
Developer Support	active community, Oracle support, training, good documentation [343]	4

Table 132. BPM Suite 11g by Oracle – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	BPM WorkSpace is the Web-based interface you use to participate in BPM processes [342].	4

Proper Logging for Auditing and Tracking Purpose	Logging can be done on many levels (production or development) and the events can be audited [344].	4
Access to Engine Status Information	A variety of events that occur in the BPM engine can be logged for further investigation [346].	4

Table 133. BPM Suite 11g by Oracle – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	The engine can be deployed on clustering mode [347]. Scale up and scale down of resources as needed based on predefined policies for such metrics as end user and application health, performance and availability monitoring and related business impact SLAs [348].	4
Utilization of Flexible Storage Services	Oracle Secure Backup allows customers to backup Oracle Databases directly to Amazon S3 using the Oracle Recovery Manager [349].	4
Available Tools Allowing Cloud Administration	12g is expected to have Oracle Enterprise Manager Cloud Control support, but no support found in 11g [350].	0
Data Transfer and Access Efficiency	N/A	N/A

Table 134. BPM Suite 11g by Oracle – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	Distributed Transaction Processing (DTP), more commonly known as XA can be configured to satisfy the ACID properties throughout the transaction [352].	4
Dynamic Service Selection / Service Discovery	By changing dynamically the service endpoint address, this can be achieved [264].	4
Central Exception Handling	The active exception handler can perform associated corrective actions when the process engine throws or catches an exception [234].	4
Behavior under heavy Load	It leverages the underlying application server capabilities for load balancing and high availability [345]	4
Persistent Data Storage	A default persistent data store can be configured for transaction recovery as mentioned in [354].	4

Table 135. BPM Suite 11g by Oracle – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	Windows native authentication, SSO configuration with Microsoft clients, Java Platform Security, J2EE basic authentication (HTTP) [372, 369]	4

Role Based Access	Different groups are formed and role-based access is implemented [370].	4
Encrypted Data Transmission	The following transport security and authentication methods are available: SSL (HTTP/S), WS-Security-compliant services, Axis services, J2EE basic authentication (HTTP) and Java and Enterprise Java Bean (EJB) binding.[372]	4

Table 136. BPM Suite 11g by Oracle – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	Not supported in 11g.	0
Data Isolation	Not supported in 11g.	0
Performance Isolation	Not supported in 11g.	0
Tenancy based Identity and Access Management	Not supported in 11g.	0
Management-Portal for Tenants	Not supported in 11g..	0

Table 137. BPM Suite 11g by Oracle – Evaluation of Category Multi-Tenancy

3.3.11. NetWeaver BPM Process Server by SAP (not evaluated)

The workflow engines from both Oracle and SAP share the same vision in their offering.They are business process platform providers more than a stand-alone Business Process Management System provider. Further they dint provide native multi-tenancy support. Due to their similarities and for reasons explained in 4.1, we have decided not to further evaluate this engine.

3.3.12. webMethods BPMS by Software AG

Functionality

Capability	Evaluation	Pts.
Workflow Languages	support for BPEL 2.0, XPDL 2.1 and BPMN 2.0 [172], import of ARIS, BPEL and XPDL, mapping of XPDL to BPMN and vice versa [189]	4
Workflow Management Functionality	"design, simulate, test and deploy processes — then in real-time monitor those processes" [42]	4
Advanced Functionality	Ad-hoc workflows, dynamic workflows, human-workflow management and a metadata library [42]	4
Suitability for Long-Term Workflows	yes [171, p. 35]	4

Table 138. Software AG webMethods BPMS – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	via Integration Server component; transport standards: HTTP, HTTPS, FTP, FTPS, SMTP; message formats: MIME, S/MIME; data standards: XML and XML Schema, custom flat file formats with delimited fixed- or variable-length records; protocols: SOAP, XML RPC, JMS; specifications: Web service Description Language (WSDL); integration patterns: REST, Web services, event-driven, request-reply [176, p.51], no information on JBI support for Process Engine found	2
Supported Databases	Oracle 11g, IBM DB2 9.7, Microsoft SQL Server 2005 und 2008 [175]	2
Platforms able to run on	OS: Windows, Linux, Solaris, AIX, HP UX; JDK: Oracle, HP, IBM [175]	4
Interoperability with other Cloud Systems	N/A	N/A

Table 139. Software AG webMethods BPMS – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	N/A	N/A
Modular Architecture	Process Engine itself uses a database, but there is no information on further modules. The webMethods suite has components for e.g. monitoring and designing processes [178].	0
APIs and GUI Replacement	APIs available as Java services through the Integration Server component, which allow pausing and resuming process instances, altering process states, modifying process instance correlations	2

	and other tasks mainly needed for maintenance purposes [179]	
License	commercial [427]	4

Table 140. Software AG webMethods BPMS – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	The webMethods acts as a whole with tools like Designer, Monitor, Deployer, etc. [426]	4
Availability of IDE Plug-ins	Eclipse Plugin for modelling [173]	4
Debugger Support	yes with tracing, breakpoints and data pipeline views using the suite's Designer component [172, 180]	4
Developer Support	small community and low forum activity [181], average documentation (not very detailed) [178], commercial training and consulting/support available [182]	1

Table 141. Software AG webMethods BPMS – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	yes, via Integration Server, functionality seems limited [179]	4
Proper Logging for Auditing and Tracking Purpose	Via Monitor, Integration Server Administrator and Audit Log database components; logging of basic process status, documents, services, security, tasks, guaranteed delivery, sessions, errors, custom process log messages, etc.; advanced search and sorting [179, 183, 184]	4
Access to Engine Status Information	status information on each subsystem's state (running, not configured, not running or not configured) with message in case of problems [179]	4

Table 142. Software AG webMethods BPMS – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	yes, Process Engines are installed packages within the Integration Server, which can be clustered by configuring a Broker, support for failover, but load balancing is done via 3rd party tools [179, 185]	2
Utilization of Flexible Storage Services	although FTP is in the list of supported protocols in the Integration Server component, the Process Engine documentation has no reference to it	0
Available Tools Allowing Cloud Administration	webMethods suite can be run in the Cloud (AWS and VMware), but no Cloud features like elasticity, load balancing etc. are supported out of the box [186]	0
Data Transfer and Access Efficiency	Optimizations for local data transfer, Express Pipeline (reduced data set) and Volatile Transition Documents are available options [428].	4

Table 143. Software AG webMethods BPMS – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	reliable messaging (JMS transactions) in non-clustered environments [179], no statements on support of database transactions	4
Dynamic Service Selection / Service Discovery	Integration Server retries failed Web service calls, but does not seem to use different bindings or UDDI[187]	0
Central Exception Handling	yes, Integration Server takes care of Web service exception handling (logging and compensation) [187]	4
Behavior under Heavy Load	Process Engine can be configured to perform faster by parallel execution (threads), using a cluster with shared memory, holding data only in RAM and minimize logging, but no statements of behaviour in attack scenarios [179].	0
Persistent Data Storage	Process data can be stored in databases, which can be configured to be reliable [179].	4

Table 144. Software AG webMethods BPMS – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	No statements on authentication in the Process Engine itself [179]. Integration Server component takes care of client and server authentication and offers Basic Auth, client certificate, SSO, and Windows Authentication [188].	4
Role Based Access	No multi-tenancy support, but configurable groups and rights (ACL and LDAP support) [188].	4
Encrypted Data Transmission	Connections via HTTPS and FTPS are possible, also WS-Security is supported [188].	4

Table 145. Software AG webMethods BPMS – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	N/A	0
Data Isolation	N/A	0
Performance Isolation	N/A	0
Tenancy based Identity and Access Management	N/A	0
Management Portal for Tenants	N/A	0

Table 146. Software AG webMethods BPMS – Evaluation of Category Multi-Tenancy

3.3.13. Business Operations Platform (BOP) Suite by Cordys

Functionality

Capability	Evaluation	Pts.
Workflow Languages	BPMN 1.1 (partial), XPDL 2.0, BPEL [34]	4
Workflow Management Functionality	extensive support for the stages "Qualify and Analyze", "Design and Model", "Develop and Deploy" and "Run and Monitor" [133]	4
Advanced Functionality	KPI creation from business model [134]	2
Suitability for Long-Term Workflows	yes, trackable in Process Instance Manager (PIM) [122]	4

Table 147. Cordys Business Operations Platform – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	WSDL, XSD, XML, SOAP, WS-I Basic Profile 1.0, XPDL 2.0, WS-Security 1.1, etc. [33], BPEL [34], no information on REST found	2
Supported Databases	Oracle (10g and 11g), Microsoft (SQL Server 2005 Service Pack 3, SQL Server 2008, SQL Server 2008 R2) and MySQL (5.1 and MySQL 5.5) [135]	2
Platforms able to run on	OS: Windows, Linux, AIX, Solaris; Web Server: IIS and Apache [135, 140]	4
Interoperability with other Cloud Systems	found only general information on ability to run in a Cloud [122], but no detailed information	4

Table 148. Cordys Business Operations Platform – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	N/A	0
Modular Architecture	no architectural information on the BPM engine of BOP found, other BOP components have a modular architecture [122]	0
APIs and GUI Replacement	there are APIs but non for the BPM engine found [109]	N/A
License	commercial	0

Table 149. Cordys Business Operations Platform – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	integrated Web-based graphical modeling tool, which allows deployment [114], ESB, Case Management, Master Data Management, Rules Management, BAM, Mashup Maker (Cordys Process Factory) [122]	4
Availability of IDE Plug-ins	Eclipse Plug-ins are available to develop in teams and help with Java integration [114]	2
Debugger Support	yes, with Web-based debugger called Process Debugger [113]	4
Developer Support	up to date extensive documentation, online video training, learning material with exercises and VMWare image for training [109], active forum [110], 382.000 Google hits on "Business Operations Platform", professional training [111] and consulting [112], not 4CaaSt member	4

Table 150. Cordys Business Operations Platform – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	fully Web-based application [117]	4
Proper Logging for Auditing and Tracking Purpose	JMX based logging for things like memory usage [115], Log4j logging output for "certain critical activities during runtime" [116], log analyzing tool [114], special auditing settings and tools down to the database [116], audit options are "Method-based, Database activity, Loading of Independent Software Vendor (ISV) packages, BPM models and rules, A generic framework for custom auditing" [120]	4
Access to Engine Status Information	monitoring available on process, instance and activity leven [118]	4

Table 151. Cordys Business Operations Platform – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	clustering and load balancing possible, no information on dynamic node instantiation [122, 138]	2
Utilization of Flexible Storage Services	N/A	0
Available Tools Allowing Cloud Administration	N/A	0
Data Transfer and Access Efficiency	N/A	0

Table 152. Cordys Business Operations Platform – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	yes, for short lived processes in databases and messaging middleware [122]	4
Dynamic Service Selection / Service Discovery	seems possible due to full SOA orientation including UDDI [122]	4
Central Exception Handling	N/A, maybe with BAM	N/A
Behavior under Heavy Load	high performance configuration settings are provided [139], "High availability: Mission critical applications must be available always to ensure high availability. The BOP platform can be deployed on a network of systems, ensuring there is no single point of failure.", allows thousands of short lived business processes per second, [122] no information on behaviour under attacks like (D)DOS found	0
Persistent Data Storage	data is stored in database, which has to take care of persistence properties [135]	4

Table 153. Cordys Business Operations Platform – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	SSO, LDAP, SAML 1.1 and 2.0, HTTP (Basic, Digest, Domain Authentication (NTLM) and Certificate-based authentication) [122]	4
Role Based Access	yes [122]	4
Encrypted Data Transmission	SSL encryption for database communication [135], XML Encryption [140]	4

Table 154. Cordys Business Operations Platform – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	the engine configuration seems to be the same for all tenants, only users can be configured	0
Data Isolation	yes [121], 122]	4
Performance Isolation	N/A	N/A
Tenancy based Identity and Access Management	yes [122]	4
Management Portal for Tenants	yes, via tool called SDF [119]	4

Table 155. Cordys Business Operations Platform – Evaluation of Category Multi-Tenancy

3.3.14. Business Suite by Polymita (not evaluated)

Polymita did not answer on our requests to provide us access to the product or documentation. The publicly available documentation is not sufficient to do an evaluation, therefore Polymita's Business Suite is not evaluated.

3.3.15. Interstage BPM / Cloud BPM by Fujitsu

Functionality

Capability	Evaluation	Pts.
Workflow Languages	Interstage Business Process Manager supports leading standards, including XPDL, Wf-XML, ASAP, BPEL and BPMN, ensuring that companies never get locked into any particular solution [306].	4
Workflow Management Functionality	The engine provides all necessary functionalities for running and managing workflows. Interstage BPM Studio is a standalone tool that can be used independently of Interstage BPM Server. Process definitions can be exported from Interstage BPM Studio and imported into an Interstage BPM Server [324].	4
Advanced Functionality	dynamic tasking capabilities [307], Web services and SOA asset management platform holding all of an enterprise's metadata and offering reports on usage [318], automated business process discovery	4
Supported Workflow Execution Patterns	ASAP provides a standardized "plug" that allows one long-running service to be easily plugged into another long-running service using SOAP calls – without any programming – making the functionality both simple and cost-effective to implement [308].	4

Table 156. Fujitsu Interstage BPM – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	SMTP, FTP, CORBA, Rosettanet, ebXML, SOAP, WSDL, UDDI, REST [309, 310]	4
Supported Databases	Oracle, DB2 and Microsoft SQL Server [324]	2
Platforms able to run on	The server engine is J2EE-compliant and runs on popular application servers that support this standard [318]. Its certified on IBM WebSphere, BEA WebLogic and JBoss. Interstage BPM runs on Windows, Solaris, AIX, HP-UX, Red Hat Linux and Suse Linux [324].	4
Interoperability with other Cloud Systems	The Interstage BPM server can be deployed across different IaaS clouds with minor tweaks.	4

Table 157. Fujitsu Interstage BPM – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	The engine offers an API called the "Model API". The engine can be extended with Java classes to access the same capabilities outside of the system using Model API [318].	4
Modular Architecture	Modular architecture of the Interstage offerings makes it easy for partners to embed the components that best fit their needs [311].	4
GUI Replacement and APIs	Forms Designer, which is part of the engine can be extended. Each layout created within the designer has a corresponding Java adapter class, which can be extended by the developers to include custom business logic. The server also offers an API called the "Model API" and a Web services interface to access all the functionality delivered through the server [318].	4
License	commercial	0

Table 158. Fujitsu Interstage BPM – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	Process Designer is a graphical tool to facilitate the creation of sequential, parallel and conditional tasks in a workflow. WYSIWYG Forms Designer to create rich browser-based forms. Decision Tables provides users with a business rules modeling and editing environment so that they can create simple process-centric rules in a tabular form [318].	4
Availability of IDE Plug-ins	BPM Studio provides different views for developers and process experts. For Eclipse users, a similar plug-in is provided. In BPM	4

	Studio, the Deployment Wizard allows users to upload and download applications built within Studio to and from BPM Server [318].	
Debugger Support	Users can simulate "what if" scenarios within this environment. BPM studio comes with options to test and debug compositions [318].	4
Developer Support	on-going developer-level support, experienced consulting teams, Web access to partner support tool, customized training programs, small community [382]	4

Table 159. Fujitsu Interstage BPM – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	The server provides a 100% Web-based console for process and task management [318].	4
Proper Logging for Auditing and Tracking Purpose	Interstage BPM maintains a history of every event that occurs during the execution of a process and the user responsible for the event. All events are recorded in the process history (also known as audit data). Users can view this process history from the administration interface [318].	4
Access to Engine Status Information	Process enactment events are encapsulated in JMS messages that the message-driven beans (MDBs) process. The MDBs realize the flow of information between the server components by means of asynchronous messages [318]. Interstage BPM provides powerful graphical run time monitoring capabilities to change live processes on the fly. Every step in the process can be configured to trap error events and auto-compensate the exceptions raised by the system. Using the Web-based graphical process instance editor, users can rollback, suspend, resume, abort, activate/deactivate nodes and add/modify nodes to enable rule-based as well as ad-hoc process changes [324]	4

Table 160. Fujitsu Interstage BPM – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	The Interstage BPM engine can run in a clustered environment with full fail-over capabilities, which means that if one server goes down, the users will be switched over to the other servers without interruption to their work [318].	2
Utilization of Flexible Storage Services	The Document Management System (DMS) Adapter is used to connect the Interstage BPM system to a document management system. No information on usage of flexible storage services like Amazon S3 has been found.[318]	0
Available Tools	N/A	N/A

Capability	Evaluation	
Allowing Cloud Administration		
Data Transfer and Access Efficiency	N/A	N/A

Table 161. Fujitsu Interstage BPM – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	Container-based transactions ensure a consistent state of the server [318].	4
Dynamic Service Selection / Service Discovery	Interstage Business Process Manager incorporates advanced support for sub-processes from different providers, which allows dynamic binding at runtime [324].	4
Central Exception Handling	Every Java action can have one or more error actions or compensation actions. Error actions provide the mechanism to handle exceptions that arise from a particular integration call. Compensation actions can be defined to take care of a regular Java action – e.g., for cleaning up the system and ensuring a consistent state of external systems involved in a transaction [318].	4
Behavior under heavy Load	Interstage BPM can run on multiple application servers thereby leveraging the underlying load balancing and fail-over capabilities for non-stop operation with 100% reliability [318].	4
Persistent Data Storage	The server communicates with the database adapter to maintain process state data, process instance and activity-related data and process history information. Included with the base system is an adapter that persists the structures in a relational database using JDBC and stored procedures [318].	4

Table 162. Fujitsu Interstage BPM – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	Http basic[425],LDAP, Single Sign-On, Custom authentication required by applications can be supported by developing custom authentication adapters. Authentication can be disabled as well [318] .	4
Role Based Access	Interstage BPM Analytics has integrated role management capabilities, which enable users to access the system based on the roles that individuals have in the organization, such as administrator, designer, and analyst [385].	4
Encrypted Data Transmission	N/A	N/A

Table 163. Fujitsu Interstage BPM – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	Multi-tenant administrator can be considered as super-admin and he can customize differently for different tenants in the Cloud [384].	4
Data Isolation	All of the applications and all of the data for a particular partition(=tenant) can be accessed only in that one partition and you cannot access any data from any other partition. Thus, each tenant is completely isolated from each other [382].	4
Performance Isolation	All the tenants share the same memory space on the server, no tenant specific memory allocation [382].	0
Tenancy based Identity and Access Management	The server is designed with internal logical partitions, each of which can be assigned to a tenant. When you log in, you access only one partition [382].	4
Management-Portal for Tenants	Each tenant has a set of users and can define users which are distinct from all other tenants. They have their own management portal [382].	4

Table 164. Fujitsu Interstage BPM – Evaluation of Category Multi-Tenancy

3.3.16. BPM by Intalio (not evaluated)

After contacting Intalio, see Appendix D, we found out that the SaaS solution is not yet publicly available. A beta release is planned at the end of January 2012. Since there is no public release of Intalio BPM yet and only a beta version will be released during the limited time scope of this student report, this workflow service will not be evaluated.

3.3.17. RunMyProcess (not evaluated)

After spending more time evaluation RunMyProcess we found that it does not fit our KO criteria. The supported BPMN 2.0 standards seems to only be related to the modeling part where only a subset of BPMN 2.0 notations are supported [167, 168]. Also when looking at the user interface, there is no way to import or export process definitions. The integration of the SOAP protocol is very limited since SOAP requests have to be defined by creating text templates sent to a server [169]. WSDL is not supported [169]. With respect to all theses facts it made no sense for us to further evaluate the service since it is proprietary and does not support open standards as we desired. Also the service seems not to be enterprise ready.

3.3.18. BPMN Process Engine by JBoss

Functionality

Capability	Evaluation	Pts.
Workflow Languages	BPMN 2.0 [224]	2

Workflow Management Functionality	Basic necessary functions are provided[225]	4
Advanced Functionality	Web-based and Eclipse-based graphical editor, WS-HumanTask, "Pluggable persistence and transactions based on JPA / JTA"[225], History logging, Process repository.[225]	4
Suitability for Long-Term Workflows	N/A	N/A

Table 165. BPMN Process Engine by JBoss – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	WS-HumanTask, REST, FTP [228, under jBPM 5.2], Its possible to implement own asynchronous task handlers with the communication standard you use, mentioned are Web services and JMS [227, Chapter 5.8.7.1],	4
Supported Databases	Default H2 Database [229]. No information about further database support.	0
Platforms able to run on	The engine is running on Java run-time. So it can be used on the most popular operating systems. [230]	4
Interoperability with other Cloud Systems	It is mentioned that the core engine can be deployed on a Cloud [231]. Also the fact that the engine runs in a java run-time is good for a potential cloud deployment. For other arguments see [232].	2

Table 166. BPMN Process Engine by JBoss – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	N/A	N/A
Modular Architecture	The architecture is presented, but its not likely to split it [237].	2
APIs and GUI Replacement	A respective set of APIs is provided, there are suited for custom components [238, 239].	4
License	jBPM Engine is under Apache Software License 2.0, (previous versions were LGPL), jBPM Eclipse Designer is under Eclipse Public License, jBPM Modeller is under the MIT license [240]. The BPM console is GNU LGPL licensed [243].	4

Table 167. BPMN Process Engine by JBoss – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	There are two designers for workflows for this engine. One is a plug-in for Eclipse, the other one is Web-based. There is also a Web console for managing your processes [241].	4
Availability of IDE Plug-ins	The JBPM Eclipse Editor is a Eclipse plug-in which also provide unit testing and debugging [241, 242].	4
Debugger Support	Unit testing and debugging of the process models is provided [244].	4
Developer Support	There is a good community [246], training is provided [245], and there is good documentation [247].	4

Table 168. BPMN Process Engine by JBoss – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	An Web-based designer and management console provided [241].	4
Proper Logging for Auditing and Tracking Purpose	Logging by using the Eclipse BIRT(Business Intelligence Reporting Tool) [248, 249].	4
Access to Engine Status Information	A reasonable set of usable information is provided [250].	4

Table 169. BPMN Process Engine by JBoss – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	There are some attempts for working jBPM in a cluster,but there weren't successful and the function is not provided from the developer [251,252, 253].	0
Utilization of Flexible Storage Services	N/A	N/A
Available Tools Allowing Cloud Administration	N/A	N/A
Data Transfer and Access Efficiency	N/A	N/A

Table 170. BPMN Process Engine by JBoss – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	jBPM supports transactional behavior by the optional use of the Java Transaction API (JTA) [254].	4

Dynamic Service Selection / Service Discovery	N/A	N/A
Central Exception Handling	The exception handling in jBPM in not described. There ale few questions on forum about it, where you can deduce from that there is no central error handling [255, 256, 257].	0
Behavior under Heavy Load	N/A	N/A
Persistent Data Storage	Depends on the used H2 Database [229] and if the Java Persistence API (JPA) is used [258].	4

Table 171. BPMN Process Engine by JBoss – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	The Web console supports user authentication with JAAS(Java Authentication and Authorization Service) [259].	2
Role Based Access	Role based access in the Web console for the human tasks is provided [259].	4
Encrypted Data Transmission	N/A	N/A

Table 172. BPMN Process Engine by JBoss – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	The engine don't support multi-tenancy [260].	0
Data Isolation	N/A	N/A
Performance Isolation	N/A	N/A
Tenancy based Identity and Access Management	N/A	N/A
Management Portal for Tenants	N/A	N/A

Table 173. BPMN Process Engine by JBoss – Evaluation of Category Multi-Tenancy

3.3.19. Activiti

Functionality

Capability	Evaluation	Pts.
Workflow Languages	BPMN 2.0 [266], also planned jPDL [267]	2
Workflow Management	All necessary basic functionality is provided [268, 269].	4

Functionality		
Advanced Functionality	Versioning of process definitions [271], forms [272], JPA [273], experimental customer data integration (CDI) [275], Activiti Explorer [276], Activiti Designer [277]	4
Suitability for Long-Term Workflows	The developers considered the long-term nature of workflows, proven by the following quote: "A BPMN business process is typically a long-running interaction, comprised of both user and system tasks." [278]	4

Table 174. Activiti – Evaluation of Category Functionality

Integration and Communication Standards

Capability	Evaluation	Pts.
Communication Protocols	REST [274], WSDL [279], JMS [280]	2
Supported Databases	H2, MySQL, Oracle, Postgres, DB2, MSSQL [265]	4
Platforms able to run on	Since the engine is running on Java run-time, it can be used on most of the popular platforms [281].	4
Interoperability with other Cloud Systems	Its mentioned that the engine can be deployed on the Cloud and that its build for it [267, 282]. Also the fact that the engine runs in a java run-time speaks for a potential cloud deployment. Some attempts were taken but not by the developer company.	2

Table 175. Activiti – Evaluation of Category Integration and Communication Standards

Extensibility

Capability	Evaluation	Pts.
Plug-in Interface	"The Process Virtual Machine is the architectural base layer of the Activiti Engine. It allows for easy pluggability of activity types, features and complete process languages." [267] It possible to extend the Activiti modeler since its based on Oryx [284]. The Activiti Designer is also extensible [285].	2
Modular Architecture	There is not much shown about the architecture of the engine. Only in the perspective of the tooling [267]. It seems unlikely that the engine itself can be split.	2
APIs and GUI Replacement	A good set of APIs is provided [269]. JPA [273]. REST API, which is powerful enough to be a base for a potential GUI component[274]. There is also an API for the process virtual machine provided, which can be used for education and for building new process languages [270].	4
License	"Activiti is distributed under the Apache V2 license." [286]	4

Table 176. Activiti – Evaluation of Category Extensibility

Tools and Development

Capability	Evaluation	Pts.
Tools Availability	There is a Web-application called Activiti Explorer [276], where users can manage their processes. Also an Eclipse plug-in for process designing named Activiti Designer [277]. Oryx based	4

	Aktiviti Modeller [267], engine administration tool Activiti Probe [267], Actviti Cycle [267].	
Availability of IDE Plug-ins	Activiti Designer is a Eclipse plug-in for process designing, testing and deploying [277].	4
Debugger Support	Unit testing [294] and debugging unit tests [295] are provided.	2
Developer Support	The community is small and active [296]. The documentation is good [267, 297]. Training course is provided [298].	3

Table 177. Activiti – Evaluation of Category Tools and Development

Management and Operation

Capability	Evaluation	Pts.
Web-based GUI	"Activiti Explorer is a Web application that provides access to the Activiti Engine runtime for all users of the system." [267]	4
Proper Logging for Auditing and Tracking Purpose	There are different logging capabilities for the engine. The gathered information is stored in the database and can be viewed in the Activiti Explorer. The information is useful and well readable [299]. There is also a history for auditing purposes [300].	4
Access to Engine Status Information	With Activiti Probe you can "show if the Activiti Engine is up and running or if there is a problem somewhere" [267]	2

Table 178. Activiti – Evaluation of Category Management and Operation

Scalability & Elasticity

Capability	Evaluation	Pts.
Clustering	"Activity is cluster friendly." [301] Activity can be run on a clustered environment [302].	2
Utilization of Flexible Storage Services	N/A	N/A
Available Tools Allowing Cloud Administration	N/A	N/A
Data Transfer and Access Efficiency	N/A	N/A

Table 179. Activiti – Evaluation of Category Scalability & Elasticity

Reliability

Capability	Evaluation	Pts.
Transactional Behavior	"Activiti executes processes in a transactional way which can be configured to suite your needs" [303]. Transactions are based on JPATransactionManager [304]. "Runs on any Java environment like Spring, JTA, standalone with any form of transaction demarcation." [267]	4
Dynamic Service Selection / Service Discovery	Its mentioned that a service task is re-tried few times and that its possible to manually reassign resources for a task when the process is running. But automatic service reassignment was not mentioned. [312, 313]	0
Central Exception	Engine exceptions are handled in the source code, for this	0

74

	purpose a special API is used[314]. But this approach is not necessary central, since you can catch the error anywhere.	
Behavior under Heavy Load	The are few attempts to make Aktiviti more suitable for high workloads [315, 316, 317]. But not one of them where implemented by the Aktiviti developers.	0
Persistent Data Storage	Depends on the used database and how it is configured [321] and if JPA [273] is used.	4

Table 180. Activiti – Evaluation of Category Reliability

Security

Capability	Evaluation	Pts.
User Authentication	Good authentication functionality is provided, for example REST API [323] and Activiti Explorer [276], but no information what protocols are used.	2
Role Based Access	Role based access is provided [325].	4
Encrypted Data Transmission	N/A	N/A

Table 181. Activiti – Evaluation of Category Security

Multi-Tenancy

Capability	Evaluation	Pts.
Customize Configuration for different Tenants	Multi-Tenancy is not supported [326].	0
Data Isolation	N/A	N/A
Performance Isolation	N/A	N/A
Tenancy based Identity and Access Management	N/A	N/A
Management Portal for Tenants	N/A	N/A

Table 182. Activiti – Evaluation of Category Multi-Tenancy

3.4. Sample Deployments

The evaluation of the workflow engines and workflow services shouldn't only be based on their documentation. It's very likely that the user experience will differ from the one promised in the documentation of the products. This effects mostly ease of use, e.g. while deploying or importing custom processes or other integration issues. To complete the evaluation with practical experience, the "WatchMe" sample process from Chapter 1.4 will be deployed and run on a set of the evaluated workflow engines and services. Due to the limited resources of the student report, only a limited set of services and engines can be evaluated. The focus lies on workflow services where the authors have access to, which are WSO2 Stratos' SaaS version called WSO2 StratosLive and RunMyProcess. Also Cordys BOP engine will be

practically tested, due the fact, that Cordy is providing a virtual machine image, where the engine is already deployed. Because there is no installation and configuration effort, the engine can be tested without outrunning the scope of this student paper.

The practical evaluation will include the following steps:
1. import the "WatchMe" process in the workflow service or workflow engine,
2. deploy all Web services that are used in the "WatchMe" process,
3. adjust the Web service endpoint references to their new location,
3. activate or launch the process in the workflow service or workflow engine and
4. validate the process execution using either the tools provided by the vendor or other available tools.

All gathered positive and negative impressions, and occurred problems, while working with the workflow systems, will be documented and summarized to provide a practical aspect on the workflow engine and workflow service evaluation.

3.4.1. WSO2 StratosLive

WSO2 StratosLive provides a nice Web interface to upload the BPEL processes and the services [440]. It also provides an easy way to install a sample application called "GlobalShoppingSample" to get accustomed with the console.
The steps followed and the issues faced were described below:

1. The latest Eclipse JavaEE Helios and Carbon Studio v1.0.14 was downloaded to deploy the processes. We faced issues with the plug-in to remotely deploy missing applications. The support on the forum was very minimal as well [438].
2. Deploying the BPEL process and the services directly via the console was tried later. For that, a carbon application package was built with the BPEL process and the required Web archives (WAR) following the available instructions in Watch-Me process "read-me.txt". However, the uploaded Carbon application did not get listed despite multiple attempts [439].
3. The services and the BPEL process were independently deployed without packaging inside a Carbon application. When the business process was tried using the "try-it" tool, chrome browser snapped with no exception message.
4. With the limited documentation, limited support, product experience and the limited time constraint, the deployment couldn't be finished.

3.4.2. Cordys BOP

For the practical test of Cordys workflow product, we use Cordys BOP-4 Self Study Training Environment [435]. "The VMware contains a fully installed Cordys environment on CentOS with MySQL..." [435]. The setup of the virtual environment was straight forward and was complete without further problems. In the study environment were some sample user accounts configured, so we could start with the work almost right away. There was some configuration necessary to be able to deploy or model some processes. For example: creating a workspace [437]. Cordys Web-based GUI is user-friendly and provides a good view over the available functionality.

1. When we tried to import the "WatchMe" process we found out, that the training environment provides no possibility to import BPEL processes. There is only a plug-in that allows XPDL import [436]. Also further research showed that the user guide contains no description of BPEL import. This can be considered as a discrepancy in Cordys description, since in this white paper [34] it is said that there is BPEL support.

Since is not possible to import the "WatchMe" process, the deployment could not be continued.

3.4.3. RunMyProcess

When we tried to import the sample "WatchMe" process definition we realized that there is no import functionality. Even with the built-in designer we were not able to copy the process definition because the designer was very buggy and did not allow us to join two branches that were split before. We tried this with different browsers, which all are on the list of supported browsers [62].

At this stage we stopped the deployment of the "WatchMe" process for this workflow service because it could not be mapped to it.

4. Results and Discussion

In this chapter, we begin by introducing the products that were eliminated from the initial candidates list(Section 4.1) with reasoning. Then, we also discuss the eliminated features from the initial criteria(section 4.2) and the logic behind it.Then the results of the evaluations are presented (section 4.3). Then in Section 4.4 the shortcomings of the engines from our viewpoints with respect to cloud usage are discussed in detail.

4.1. Eliminated Products from Evaluation

When further researching and testing our selection of 19 workflow engines and workflow services we discovered that some did not qualify our KO criteria (BPEL or BPMN support), some providers did not offer us documentation or access to trials and that due to our limited time in the "Fachstudie" we could not evaluate all remaining workflow engines and workflow services.

Therefore the following workflow engines and workflow services were not evaluated: Intalio BPM, Windows Workflow Foundation (.Net), Business Suite by Polymita, RunMyProcess and Netweaver BPM Process Server by SAP.

The workflow offerings of SAP and Oracle are very similar with the vision of both the providers as well as the capabilities. With little native Cloud support, it was decided that only one of them will be evaluated. For this purpose, we studied the functionalities of both SAP and Oracle peripherally. In the end it was decided to ignore SAP Netweaver 7.3 because of the following reasons:

1. SAP's BPM strategy can be summarized as standardize, integrate and innovate. SAP uses SAP Business Suite for standardization, Netweaver Process Integration for integration (which provides a BPEL process engine) and innovate is done using Netweaver Composition environment.

CCBPM (Cross component BPM) is a part of Netweaver Process Integration, which provides BPEL support. However CCBPM [287] is designed to model system-system processes alone.

On the other hand SAP Netweaver BPM (in short referred as BPM) is intended to implement business process management starting from a visual modeling tool. The issue is BPM supported BPEL till version 7.1. From 7.3 its not supported [288].

SAP Netweaver BPM and SAP NetWeaver Business Rules Management are the latest offerings from SAP that are designed for BPM [289, slide no.19] and they don't support for BPEL Modelling. They only support BPMN [293].

2. Also some of Netweaver BPM's features are weak compared to Oracle, such as group interaction pattern support, business and IT role collaboration, automated UI generation and content integration beyond attachments as mentioned in this evaluation [291, p. 19].

3. The Oracle BPM Engine provides a run-time environment for running business processes. It provides native support for both BPMN and BPEL processes while Netweaver only support BPMN natively [292].

4.2. Eliminated Evaluation Capabilities

After looking at seven workflow engines and workflow services (ActiveVOS Data Center Edition by ActiveEndpoints, Composition Engine by Ericsson, Apache ODE, WSO2 Stratos / Business Process Server, IBM Business Process Manager, webMethods BPMS by Software AG, and Business Operations Platform Suite by Cordys) we had an advisor meeting and looked at the information we found for each workflow engine and workflow service and their capability and decided to not further evaluate the following categories: Theoretical Foundation and Quality of Service. For both categories we were not able to find enough information for most of the so far evaluated engines to do a meaningful and comparable points assignment.

For the category "**Theoretical Foundation**" we almost found no information at all and for the "**Quality of Service**" category we did find some information, but they were not relevant for our capabilities, which focused on QoS enforcement and Cloud-awareness (billing and metrics).

Further under the category "**Scalability and Elasticity**" we did not find sufficient information for the capabilities "Component Architecture Allows to Distribute Usage" and "Transparent Scalability" and therefore decided to not further examine it. Same applies to the the capability "Data Encryption" and "Compliance with Data-Access Rules from a Region" in the "**Security**" category.

BOP by Cordys and WSO2 Stratos would have benefited with a higher score if we left in the "Quality of Service" category. IBM Business Process Manager would have benefited if we left in the "Scalability and Elasticity" category. Bonita Open Solution and Apache ODE would have benefited if we left in the "Formal Model" category and Oracle BPM Suite 11g would have benefited if we left in the "Data Encryption" capability.

Appendix B shows the findings of the seven workflow engines and workflow services of the further ignored capabilities.

4.3. Results

The following Table 183 shows, the points assignment for each capability and for all workflow engines and workflow services.
The weighing methodology is explained in detail in Chapter 1.3. For some of the features for which no relevant information was found, it was marked as N/A and assigned lowest possible value.

Capability	ActiveVOS DCE	Ericsson	Apache ODE	OW2 Orchestra	WSO2 Stratos	BonitaSoft	IBM Business Process Mgr.	BPMS Intalio	BPM Suite 11g Oracle	webMethods BPMS Software AG	BOP Cordys	Interstage BPM Fujitsu	JBoss	Activiti
Functionality	20	4	20	20	20	24	28	28	32	32	28	32	20	28
Workflow Languages **	2	0	2	2	2	4	2	2	4	4	4	4	2	2
Workflow Management Functionality **	4	N/A	4	4	4	4	4	4	4	4	4	4	4	4
Advanced Functionality **	N/A	2	N/A	4	N/A	4	4	4	4	4	2	4	4	4
Suitability for Long-Term Workflows **	4	N/A	4	4	4	N/A	4	4	4	4	4	4	N/A	4
Integration and Comm. Standards	28	4	28	24	28	22	14	12	22	10	22	26	18	18
Communication Protocols **	4	2	4	2	4	4	4	2	4	2	2	4	4	2
Supported Databases *	4	0	4	4	4	4	2	4	4	2	2	2	0	4
Platforms Able to Run on *	4	N/A	4	4	4	4	4	4	4	4	4	4	4	4
Interoperability with other Cloud Systems ***	4	N/A	4	4	4	2	N/A	N/A	2	N/A	4	4	2	2
Extensibility	8	8	28	28	32	20	12	8	24	12	0	28	20	24
Plug-in Interface **	0	2	4	4	4	4	2	N/A	4	N/A	0	4	N/A	2
Modular Architecture **	2	N/A	4	4.	4	N/A	2	0	4	0	0	4	2	2
APIs and GUI-Replacement **	2	2	2	2	4	2	2	2	4	2	N/A	4	4	4
License **	0	0	4	4	4	4	0	2	0	4	0	0	4	4
Tools and Development	12	4	8	8	12	10	14	10	14	13	14	16	16	13
Tools Availability *	2	0	2	2	4	4	4	4	4	4	4	4	4	4
Availability of IDE Plugins for Modelling and Managing Workflows *	4	2	2	2	4	N/A	2	4	2	4	2	4	4	4
Debugger Support *	2	2	2	2	2	2	4	0	4	4	4	4	4	2
Developer Support *	4	0	2	2	2	4	4	2	4	1	4	4	4	3
Management and Operation	24	12	20	24	24	24	24	24	24	24	24	24	24	20
Web-based GUI **	4	0	2	4	4	4	4	4	4	4	4	4	4	4
Proper Logging for Auditing and Tracking Purpose **	4	2	4	4	4	4	4	4	4	4	4	4	4	4
Access to Engine Status Information **	4	4	4	4	4	4	4	4	4	4	4	4	4	2
Scalability and Elasticity	12	6	30	6	18	12	24	12	24	18	6	6	0	6
Clustering ***	4	2	0	2	0	2	4	4	4	2	2	2	0	2
Utilization of Flexible Storage Services ***	0	N/A	4	N/A	4	2	N/A	N/A	4	0	0	0	N/A	N/A
Available Tools Allowing Cloud Administration ***	0	N/A	2	0	2	N/A	0	N/A	0	0	0	N/A	N/A	N/A
Data Transfer and Access Efficiency ***	0	N/A	4	0	0	N/A	4	N/A	N/A	4	0	N/A	N/A	N/A
Reliability	32	8	32	32	32	20	28	24	40	24	24	40	16	16
Transactional Behavior **	4	N/A	4	2	4	4	4	4	4	4	4	4	4	4
Dynamic Service Selection / Service Discovery **	0	4	4	2	4	N/A	2	0	4	0	4	4	N/A	0
Central Exception Handling **	4	N/A	4	4	N/A.	4	0	0	4	4	N/A	4	0	0
Behavior under Heavy Load **	4	0	0	4	4	N/A	4	4	4	0	0	4	N/A	0
Persistent Data Storage **	4	N/A	4	4	4	2	4	4	4	4	4	4	4	4
Security	28	0	16	12	28	16	28	24	28	28	28	16	12	12
User Authentication **	4	N/A	2	N/A	4	4	4	2	4	4	4	4	2	2
Role Based Access **	4	N/A	0	0	4	4	4	4	4	4	4	4	4	4
Encrypted Data Transmission ***	4	N/A	4	4	4	0	4	4	4	4	4	N/A	N/A	N/A
Multi- Tenancy	60	12	0	0	54	48	0	0	0	0	36	48	0	0
Customize Configuration for different	4	0	0	0	4	4	0	0	0	0	0	4	0	0

Tenants ***														
Data Isolation ***	4	4	0	0	4	4	0	N/A	0	0	4	4	N/A	N/A
Performance Isolation ***	4	0	0	0	2	0	N/A	N/A	0	0	N/A	0	N/A	N/A
Tenancy based Identity and Access Management ***	4	N/A	0	0	4	4	N/A	N/A	0	0	4	4	N/A	N/A
Management Portal for Tenants ***	4	N/A	0	0	4	4	N/A	N/A	0	0	4	4	N/A	N/A
Total	224	58	182	154	248	196	172	143	208	161	182	236	126	137

Table 183. Summary of the Points Assignment for Each Evaluated Product and Service, and Capability

As Table 183 shows, the three most suitable workflow engines according to our criteria and weightings are WSO2 Stratos, Interstage BPM by Fujitsu and ActiveVOS Datacenter Edition. All three are also most suitable for Cloud usage.

When looking at the SaaS/PaaS offerings the best workflow service is the hosted version of Interstage BPM by Fujitsu. All other SaaS/PaaS offerings are either not available or did not provide us enough information to evaluate them or not enterprise ready.
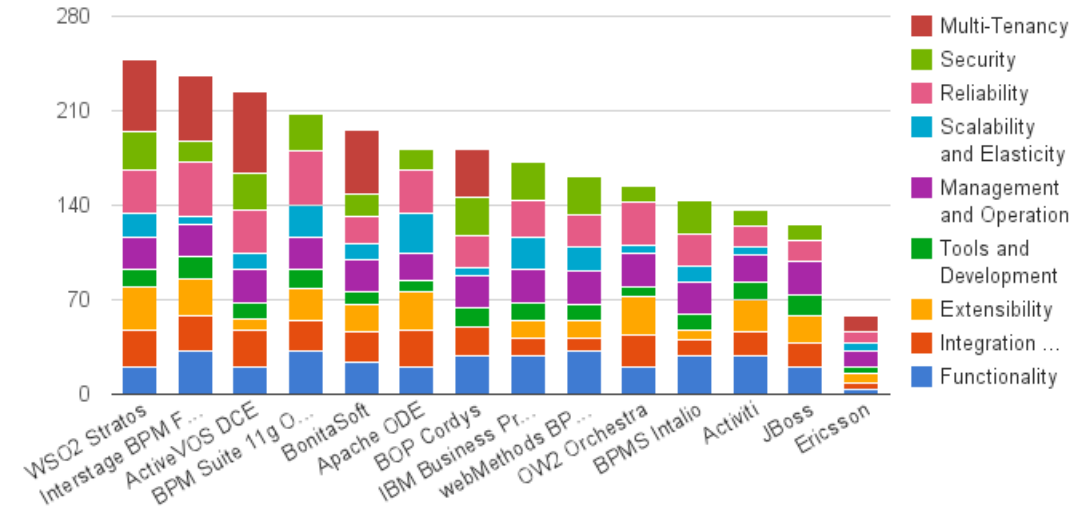
Figure 2. Results of the Evaluation by Product/Service and Evaluation Category

What most engines and services missed is already reflected in Chapter 4.2, which lists the eliminated evaluation capabilities where we did not find any information for the workflow engines or workflow services or the capabilities were explicitly not supported.

As Table 183 shows, most traditional workflow engines perform well in the traditional workflow areas like workflow functionality, integration, communication, extensibility, reliability, security, development support, operation and management support and clustering. But in new areas which this evaluation focused on, like Cloud-awareness, multi-tenancy capabilities and quality of service enforcement, most evaluated traditional workflow engines fail and have therefore significant shortcomings when trying to deploy them "as-is" in the Cloud.

Some providers even claim to be Cloud-aware or have multi-tenancy support, but their products are not yet available (see Intalio BPM [55]) or just have clustering capabilities without Cloud-awareness, which means they don't support Cloud storage, transparent scalability or QoS enforcement [235, 236].

The findings are further emphasized in Figure 2. Out of the 14 evaluated engines, 8 don't support multi-tenancy, though they are major workflow engine providers. It must be noted as

explained in Chapter 1.3, that a weighting methodology was used so that Cloud-related features are given a higher weightage than traditional workflow engine features. The defined criteria and their weightage influenced the final ranking as depicted in Figure 2. For example, the engines that support multi-tenancy benefited a lot in the final rankings as its given a weightage factor of 3. In this way its ensured that Cloud-aware engines are ranked better than otherwise strong traditional workflow engine providers. This can be inferred below in Figure 3.
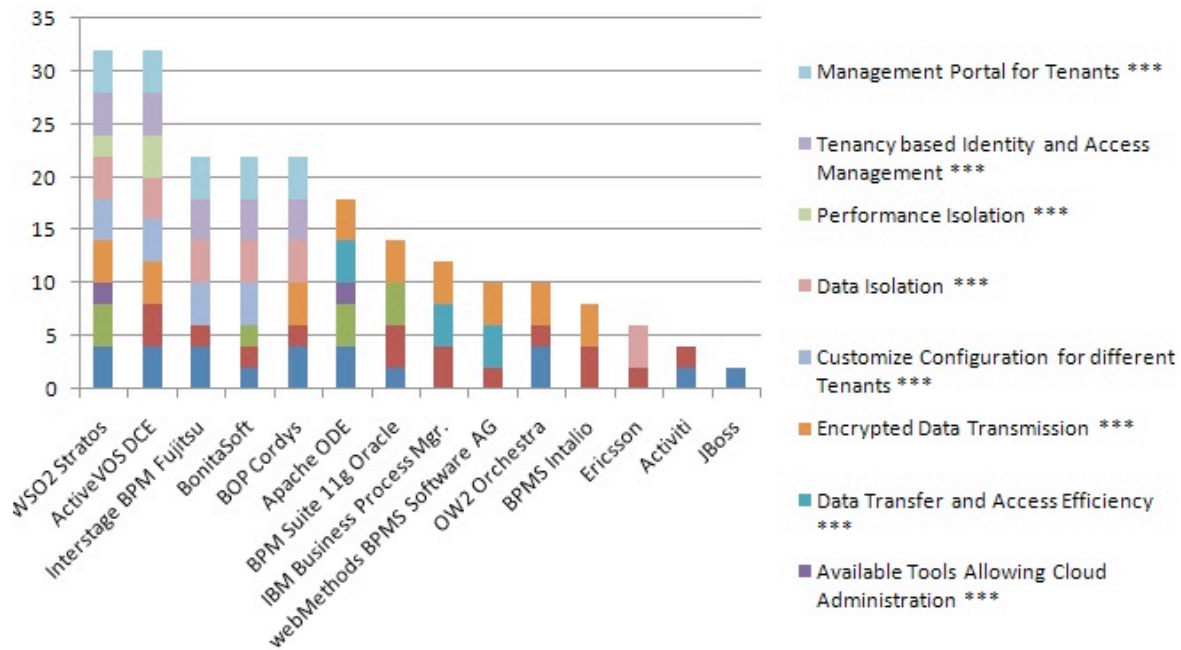
Figure 3. Results of the Evaluation by Product/Service and Cloud Features

The weightage given to Cloud features have affected the outcome of the ranking of the engines as we wanted. From Figure 3 one can also infer how all the engines fared as well when compared with Cloud-features alone. It shows for example that Fujitsu's Interstage BPM here only got the third highest ranking when only looking at Cloud related features. In the overall comparison although it ranked with the second highest score. Same applies to Oracle's BPM Suite 11g which has rank four in the overall ranking and rank seven in the Cloud-only related features ranking.

When neglecting the weightage of all capabilities the result looks very similar to Table 183 and Figure 2, which contain our weightings. The result can be seen in Figure 4. There are only minor differences, for example a switch in rank 3 and 4, or in rank 5 and 6.
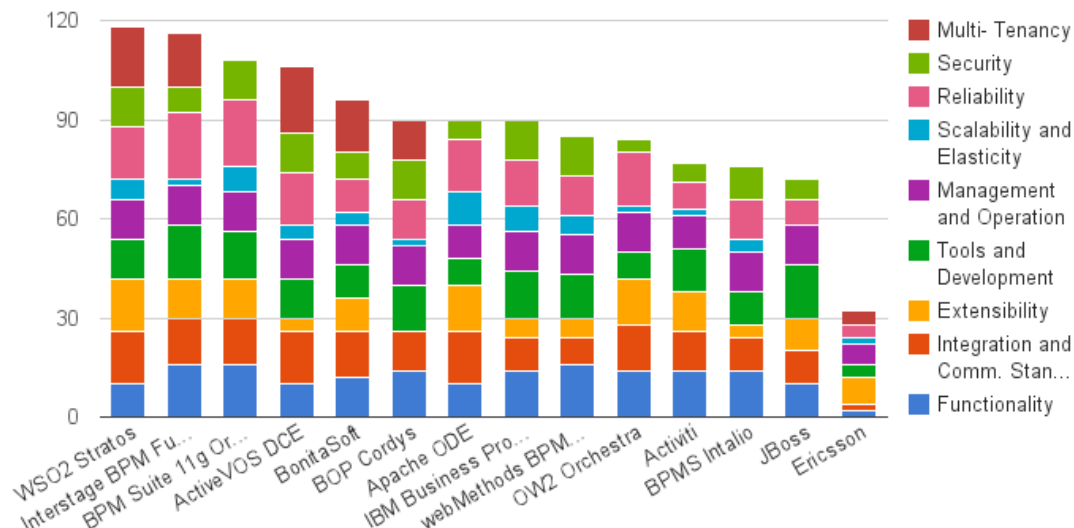
Figure 4. Results of the Evaluation by Product/Service and Evaluation Category Without Any Weightings

4.4. Shortcomings for Cloud Usage

The following paragraphs describe the most common shortcomings we found and prioritizes them. The goal is to take a traditional workflow engine and deploy it on the Cloud with all Cloud features, especially transparent scalability or elasticity. We assume that the workflow engine is already multi-tenant aware and can be run in a cluster, because this is true for many evaluated workflow engines already.

Many Cloud related shortcomings can be found under the category **scalability and elasticity,** which was divided into the capabilities clustering, utilization of flexible storage services, component architecture allows to distribute workflow engine components, available tools allowing Cloud administration, transparent scalability and data transfer and access efficiency.

Clustering is supported by most workflow engines, which is important for Cloud-awareness, but needs to go one step further, to scale transparently in order to be called elastic. Also *distributing the components of a workflow engine* to different machines can help gaining higher resource (e.g. CPU/RAM) utilization.

Flexible storage services are natively supported by only few workflow engines (e.g. WSO2 Stratos). Cloud storage like Amazon Web Service's RDS or S3 offering needs to be supported by more engines in order to provide better scalability in case data is currently stored on local hard drives or a non-Cloud database. Almost all workflow engines use a database to store process data but there are still workflow engines which store data on disk, which is not suitable for a scalable and Cloud-aware workflow engine, whose instances need to be able to be shut down and restarted at any point in time. The *data transfer and access efficiency* adds the requirement to transfer data reliably and fast, which is also only supported by few engines.

Since most evaluated workflow engines are not Cloud-aware, they also don't provide *tools for Cloud administration*. These tools are necessary to further enable transparent scalability, billing and optimization for Green IT (see capability description).

Taking the Scalability and Elasticity category, we think that Transparent Scalability and Flexible Storage Services are the two most important shortcomings to run a workflow engine in the Cloud, because those two features are necessary to leverage the Cloud abilities, as defined in Chapter 1.5 "on-demand network access to a shared pool of configurable computing resources [...] that can be rapidly provisioned and released with minimal management effort or service provider interaction". When considering the Cloud's "Essential Characteristics: On-demand self-service, Broad network access, Resource pooling, Rapid elasticity, Measured Service" we also need the tools for Cloud administration to make a workflow engine fully Cloud enabled.

The category **multi-tenancy** was divided into the capabilities *customize configuration for different tenants*, *data isolation*, *performance isolation*, *tenancy based identity and access management* and *management portal for tenants*. The engines which have multi-tenancy support usually hold each tenant's data isolated but almost no engine supplier stated that their engine supports performance isolation. This is a significant part of multi-tenancy support to guarantee a stable performance to all tenants on the system (priority one). All other multi-tenancy capabilities were supported in some engines.

The category **quality of service** was divided into the capabilities *QoS enforcement*, *metrics and billing system* and *Cloud-aware QoS enforcement*. No evaluated engine satisfied all of our desired QoS capabilities. This is a major problem and goes hand in hand with scalability and elasticity because the metrics here should determine the load on a workflow engine instance. In case of a higher than allowed load, a QoS system or load balancer should trigger a new instance to be launched, which is essentially *Cloud-aware QoS enforcement* .

A *metrics and billing system* is needed once elasticity and scalability is in place to charge the tenants based on their usage.

When ranking the QoS capabilities, we think a metrics system is most important (priority one) because it is a basis for QoS enforcement (priority two) by delivering input data for the QoS system. Once a QoS enforcement is in place it can be adapted for the Cloud and a billing system can be used to charge tenants (both priority three).

The category **Security** was divided into User Authentication, Role Based Access, Data Encryption, Encrypted Data Transmission and Compliance with Data-Access Rules from a Region. Here, most of the engines do not provide the capabilities Compliance with Data-Access Rules from a Region and Data Encryption. When ranking these capabilities, Data Encryption is given top priority above compliance. The reason behind the prioritization is that Data Encryption is a vital issue in a Cloud scenario with or without multiple tenants, as privacy is a top priority for all organizations independent of size. Data loss is a reality and the possibility of 100% privacy during those cases are very important as most often the data is very sensitive. All engines except the offering from Oracle don't provide any information regarding this feature. Compliance with Data-Access Rules from a Region is also important but it is not relevant for all Cloud migration scenarios and hence given a lower priority.

Category / Priority	Scalability and Elasticity	Multi-Tenancy	Quality of Service	Security
Priority 1	transparent scalability and utilization of flexible storage services	performance isolation	metrics system	data encryption
Priority 2	tools for Cloud administration		QoS enforcement	compliance with data-access rules from a region
Priority 3	component architecture which allows to distribute workflow engine components		billing system and Cloud-aware QoS enforcement	

Table 184. Prioritization of Mostly Missing Capabilities for Each Category

When looking at the prioritized shortcomings overview in Table 184, the four capabilities transparent scalability, QoS enforcement, metrics and billing system and Cloud-aware QoS enforcement are very tightly connected to each other. Transparent scalability is the higher goal, which can be reached by installing a metrics and billing system to monitor the performance and utilization of running instances, a QoS enforcement systems takes actions like sending alerts to system administrators when a SLA is close to be breached. Finally putting this in a Cloud environment, the Cloud-aware QoS uses the 'unlimited' compute power, storage and bandwidth to adapt the system to its degree of utilization. These connections are also shown in Figure 3. It shows one possible schematic representation of running traditional application clusters in the Cloud. The QoS enforcement system takes care of transparent scalability after it receives the system load from the metrics system. It also communicates with the billing system to take cost into account during QoS enforcement. Figure 5 also includes a flexible storage service, which we see as a self-contained system that scales itself based on its utilization. The figure also shows that the Cloud further provides administration tools to launch or shutdown instances of the application depending on the usage criteria.
Also, requiring a component architecture, which allows to distribute workflow engine components is probably too advanced for the current state of workflow engines and near future ones.

The only other missing capability in Figure 5 from Table 184 is Performance Isolation. This is due to the many areas where performance isolation can be managed, e.g. in each workflow engine's instance, at virtual machine level or by a load-balancer, all depending on the multi-tenant architecture.
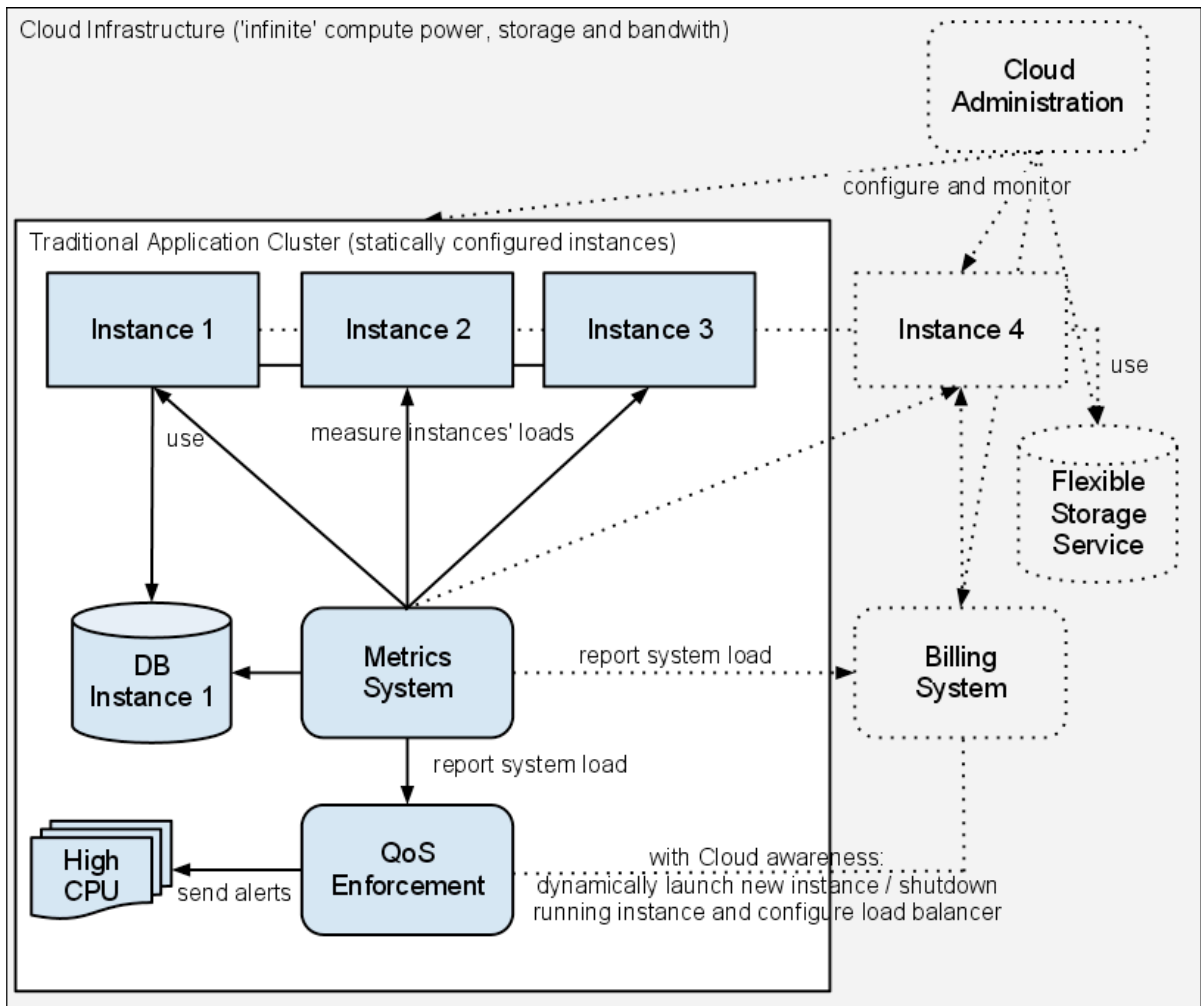
Figure 5. Simplified Comparison of a Traditional Application Cluster and a Cloud Infrastructure - or How To Run Traditional Application Clusters in the Cloud

After considering all capabilities with shortcomings and how they are connected to each other, we came up with the following ranking (1 representing the topmost priority) of shortcomings:

1. data encryption
2. metrics system (measure CPU utilization and latency) and performance isolation
3. Cloud-aware QoS enforcement (launch new / terminate existing instances, configure load balancer)
4. usage of flexible storage services (database as a service, scalable file storage)
5. tools for Cloud administration (configure and monitor all components)
6. billing system
7. component architecture which allows to distribute workflow engine components
8. compliance with data access rules from a region

Note that the previous mentioned transparent scalability capability can be seen as a result of the combination of a metrics system and connected Cloud-aware QoS enforcement.

Since performance isolation for us is equally important than the whole transparent scalability issue we decided to rank it as priority one as well. We believe these are the challenges that need to be addressed by Cloud enabled workflow engines.

5. Summary and Outlook

5.1. Summary

The workflow engine WSO2 Stratos is best suited for Cloud deployment and it has an open source license so it can be adapted to everyone's needs. It lacks support for "Data Transfer and Access Efficiency", "Central Exception Handling" and "Clustering", where clustering support is currently experimental and already supported in WSO2 Carbon, see 4CaaSt D7.1.1 [12, p. 93].

The best commercial workflow engine is Interstage BPM by Fujitsu, although it lacks "Utilization of Flexible Storage Services", "Available Tools Allowing Cloud Administration", "Data Transfer and Access Efficiency", "Encrypted Data Transmission" and "Performance Isolation".

From the initial set of 19 workflow engines five could not be evaluated due to different reasons, being not enough available information, non-matching KO criteria, and not enough time of the authors.

The most important shortcomings with respect to Cloud deployment were missing metrics systems, no performance isolation, no Cloud-aware QoS enforcement, no support for flexible (Cloud) storage services, no tools for Cloud administration, and no billing systems.

Within the workflow services we were not able to find a candidate where we could sign up for a trial and test the service with our sample scenario. RunMyProcess did not support to import or export BPMN or BPEL processes and their service was limited with respect to WSDL/SOAP service invocations, we skipped the further evaluation. The request for trying out Fujitsu's Interstage BPM SaaS stayed unresponded and WSO2 StratosLive allowed us to import our sample process but we could not manage to run it due to thrown exceptions where we had no time to look further into it. For Cordy's BOP we got a virtual machine image with a pre-installed version, but although the documentation states support for BPEL we were not able to import the sample BPEL process and had to skip this practical evaluation as well.

5.2. Outlook

In the future we expect more traditional workflow engine providers to offer PaaS and SaaS offerings, which some already announced. Also we expect that moving a process from one provider to another will become easier.

Services like RunMyProcess could probably evolve to be ready for enterprise usage and new services from SaaS startups will try to gain a slice of the BPM market.

With respect to features we assume that BPMN 2.0 will play a major role and REST services will become more and more supported in the future.

For many companies that currently use workflow technology, the public Cloud as a workflow runtime environment will not be an option due to data privacy issues and regulations. For them private Clouds and therefor PaaS products will play a major role. Companies that use workflow technology even out of the company's boundary to coordinate processes with partners, like suppliers, probably could use a public Cloud workflow runtime environment as a neutral instance, once data privacy issues are resolved and regulations are allowing public Cloud solutions even for critical data.

Appendix A

List of Engines and Services:

Product	Company	License	BPEL capable	BPMN capable
ActiveVOS Data Center Edition	ActiveEndpoints	commercial	Yes [3] [1]	Yes [4] [1]
LiveCycle Enterprise Suite 2	Adobe	commercial	?	Yes
BPMS	AgilePoint formerly Ascentn	commercial	?	Yes [5]
Appian Enterprise / BPM Suite	Appian	commercial	?	Yes
ProcessManager	axway	commercial	?	Yes [4]
BPM Suite	Bizagi	commercial	?	Yes [4], [5]
inubit	Bosch Group	commercial	?	Yes
Documentum xCelerated Composition Platform	EMC	commercial	?	Yes
Composition Engine	Ericsson	commercial	- [1]	- [1]
BizFlow Plus / BPM Suite	HandySoft	commercial	?	Yes [4]
BPWS4J (experimentell)	IBM	commercial	Yes [3]	?
IBM Business Process Manager (formerly: WebSphere Process Manager / WebSpehre Dynamic Process Edition)	IBM	commercial	Yes [3]	Yes
FileNet Business Process Manager	IBM (FileNet)	commercial	?	Yes
WebSphere Lombardi Edition / Teamworks / Blueprint	IBM (Lombardi)	commercial	?	Yes

Process Engine	inbuit	commercial	?	Yes [4]
BPMS Enterprise	Intalio	commercial	Yes [3]	Yes
Papyrus Platform	ISIS	commercial	?	Yes [4]
BPMN Process Engine	Joinwork	commercial	?	Yes [4]
ActiveFlow .Net Workflow Engine	KAISHA TEC	commercial	?	Yes [4]
BizTalk Server	Microsoft	commercial	Yes [3]	?
Windows Workflow Foundation (.NET)	Microsoft	commercial	Yes [3], only .NET 3 as CTP	?
OmniFlow	Newgen Software Technologies	commercial	Yes	Yes
Metastorm BPM	OpenText former Metastorm	commercial	?	Yes [4]
viewPoint / Process Management	OpenText formerly Global360	commercial	?	Yes [4]
BPEL Process Manager (Oracle SOA Suite)	Oracle	commercial	Yes [3]	?
BPM Suite 11g	Oracle	commercial	?	Yes [5]
Business Process Manager	Oracle	commercial	?	Yes [4]
BPMone Control	Pallas Athena	commercial	?	Yes [4]
Work Management	Pega	commercial	?	Yes [4]
Sequence BPM Suite	PNMsoft	commercial	Yes	Yes
ProcessMaker Enterprise Subscriptions	ProcessMaker	commercial	?	Yes [4]
Seagull LegaSuite Workflow	Rocket	commercial	?	Yes [4]
XIP BPM Platform	santeon	commercial	?	Yes [4]
Exchange Infrastructure	SAP	commercial	Yes [3]	?
NetWeaver BPM Process server	SAP	commercial	?	Yes [4]

BPM Server	Savvion	commercial	?	Yes [4]
BusinessManager	Savvion/Progress	commercial	?	?
Business Integration Server	SEEBURGER	commercial	Yes [3]	?
Business Mashups Server	Serena	commercial	Yes [3]	?
TotalAgility	Singularity	commercial	?	?
Skelta BPM.NET	Skelta	commercial	?	Yes [4]
webMethods BPMS	Software AG	commercial	?	Yes [4]
ActiveMatrix BPM	Tibco	commercial	?	Yes [4]
iProcess	Tibco	commercial	Yes [5]	Yes [5]
Rendezvous	Tibco	commercial	?	?
M3O Business Process Management Server	Vitria	commercial	?	Yes
Living Systems Process	Whitestein Technologies	commercial	?	Yes [4]
ELMA		commercial	?	Yes [4]
Workflow Management	IYOPRO	commercial/free	?	Yes [4]
Bonita Open Solution	BonitaSoft	open source	- [1]	Yes [1]
BPMN Process Engine	JBoss	open source	Correction. For BPEL there is an onther engine called riftsaw [6]	Yes [4]
BPEL SE (Bestandteil von OpenESB)	Sun Microsystems	open source	Yes [3]	?
Activiti		open source	?	Yes [4]
Apache ODE		open source	Yes [3] [1]	- [1]
Enhydra Shark		open source	?	Yes
OW2 Orchestra		open source	Yes [1]	Yes [1]

Business Operations Platform	Cordys	PaaS / SaaS (CAF)	Yes	Yes [4]
Business Suite	Polymita	PaaS	?	Yes [5]
Cloud BPM	Appian	SaaS	?	Yes [2], [4]
Barium Live!	Barium	SaaS	?	Yes [4]
Interstage BPM / Cloud BPM	Fujitsu	SaaS	?	Yes [4]
BPM	Intalio	SaaS	Yes [5]	Yes [5], [4]
Business Process Cloud	Pega	SaaS	?	Yes [4]
ProcessMaker Cloud	ProcessMaker	SaaS	?	Yes [4]
LiveAgility	Singularity	SaaS	?	?
BPM in the Cloud	Tibco	SaaS	?	Yes [4]
RunMyProcess		SaaS	?	Yes
WSO2 Stratos / Business Process Server		SaaS (open source)	Yes [1]	- [1]

Notes from the Engine Research:

ActiveVOS Data Center Edition by ActiveEndpoints
- version 10
- workflow engine name: BPM Engine [30]
- Standards: BPMN 2.0 modeling, BPEL 2.0 execution, BPEL4People & WS HumanTask, WS *, including WS Policy, REST, JMS, EJB and others [30]
- features: "modeling, simulation, testing, debugging, monitoring, reports, instance repair console" [30]
- Multi tenant Support [30]
- new in the market, small niche player, competes with Intalio BPMS Enterprise [29]
- JEE product, comes more from IT side (SOA, integration) than business side, low-cost as entry point for BPM technology [29]
- "ActiveVOS has a good Eclipse-based SOA service development environment that is well-respected in the Java development community.", "ActiveVOS includes a good Web services directory.", "Active Endpoints has invested heavily in providing a new, more business-friendly human workflow environment.", [30]

Composition Engine by Ericsson (commercial)
- GUI based [35]
- for service providers, e.g. teleco operators [35], specially for all-IP networks [36]

94

- example scenerio: sms (communication) to all online (available, via Internet) friends in the neighborhood (GPS) [35]
- uses "industry-standard technology", telephony protocols and Web 2.0 services like Facebook and last.fm [36]
- JEE product [36]
- kind of multi-tenancy, partners of a telco operator can use the engine as well
- standards for service invocation: "SIP services, CAP/INAP-based IN servic- es, SOAP/Web services, and JSON RESTful services" [37]
- no BPEL or BPMN support [no source]
- Ericsson is member of the 4CasST project

Activiti
- Version: Activiti 5.8, Apache License, workflow engine name: ProcessEngine [54]
- Standards: BPMN 2.0, JPA [54]
- Eclipse integration to inspect database and BPMN files [54]
- 6 supported databases [54]
- Spring integration optional [54]
- manageable through Java API and REST API [54]
- supports: Web Service calls, human tasks, script tasks, Java tasks, Emails etc. [54]

IBM Business Process Manager
- formerly: WebSpehre Dynamic Process Edition
- version: WebSphere Process Manager Advanced V. 7.5
- standards: BPEL, BPMN 2.0 [38]
- compatible to WebSphere Lombardi Edition and WebSphere Process Server [38]
- "Many IBM customers view WDPE is a "natural" option, since they have already invested in WebSphere Application Server, WebSphere Portal and other products of the family." [29]
- also made for business people, not only IT staff [38]
- "Manage processes directly from Microsoft® Office - Enables end users to launch and perform process tasks directly from the popular Microsoft products..." [136]
- It's possible to have different kinds of deployment environment configurations, so the user can choose to set up more or less Process Servers.[88, p. 34]

BPMS Enterprise by Intalio
- competes with ActiveEndpoints [29]
- version: Intalio|BPMS Server 6.2.4
- cheap, since usage of open source components [29]
- also has cloud delivery model (paas) [29]
- "strong advocate for open standards and open source" [29]
- standards: "BPEL, BPEL4People, BPMN (1.2 in Enterprise Edition and 2.0 natively in Intalio/BPM) and the WS-Human Task life cycle" [29]
- JEE application which works on almost all Java application servers [29]
  - "Enterprise Edition 6.0 has such dependencies (including Ajax General Interface, Eclipse BIRT, Alfresco, JBoss Community Drools, MuleSoft, Apache ServiceMix and WSO2)", products might get replaced over time [29]
- multi-tenant, user management, role-based access control, audit trail, … [39]

BPM Suite 11g by Oracle
- version: 11g, workflow engine: Oracle BPEL Process Manager Runtime [40]
- native BPEL engine [40]
- standards: XML, WSDL and Web Services, XSLT, XPATH, JMS, and JCA [40], BPMN-2.0 [29]

- "The Oracle BPEL Process Manager executes standard BPEL processes and provides a "dehydration" capability so that the state of long-running flows is automatically maintained in a database, enabling clustering for both fail-over and scalability" [40]
- human workflow support, monitoring, auditing, advanced exception management, side-by-side versioning, high performance, scalable [40]
- also available as SaaS in Oracle BPM Suite 11g [29]

NetWeaver BPM Process Server by SAP
- version: NetWeaver BPM Process Server, part of SAP NetWeaver Business Process Management, part of SAP NetWeaver Composition Environment (CE) 7.2.
- standards: BPMN [41, 29]
- "JEE-based runtime execution engine", "SAP's process server is BPMN-native" [41]
- BPEL support via SAP NetWeaver Process Integration [41]
- good for SAP ERP integration [29]

webMethods BPMS by Software AG
- version: 8.2 [42]
- standards: SOAP, WSDL, UDDI, Web services, XML and HTTP, EDI [42], BPEL [43], BPMN 2.0 [44]
- supports Ad-hoc, dynamic workflows and Human-workflow management, metadata library [42]
- "In a collaborative environment, business and IT can work together to design, simulate, test and deploy processes—then in real-time monitor those processes. They can optimize processes by integrating whatever resource is required across your enterprise—people, systems and documents." [42]
- Eclipse based design, collaboration of IT and business possible, rich simulations, integrated business rules management [42]
- enterprise suited: support for complex processes, "high-volume performance and scalability" [42]

Business Operations Platform (BOP) by Cordys
- version 4.1 [31]
- workflow engine name: unknown, but part of Business Process Management Suite (BPMS)
- "Cordys' best innovations recently are in its cloud offerings and partnerships for process content." [29]
- available as PaaS (BOP) and SaaS (Cordys Process Factory) [32, 29]
- partners host SaaS solutions [29]
- "BOP is one of the few natively cloud-enabled, full multitenant cloud platforms. (It is available as a cloud-based PaaS from Cloud Harbor and Capgemini.)" [29]
- only average ease of use / UI is not pretty (as of version 4.0) [29]
- standards: BPMN 1.1 (partial) WSDL, XSD, XML, SOAP, WS-I Basic Profile 1.0, XPDL 2.0, WS-Security 1.1, etc. [33], BPEL [34]

Business Suite by Polymita
- version Polymita 6
- "BPMN, Web-based modeler, a cloud-based platform-as-a-service (PaaS) package, and a new tool (FreeFlow) to manage unstructured processes and to discover process patterns" [29]
- "Polymita features model-driven development with a strong emphasis on MDM to create a single view of data and processes. This approach enables business users to make changes to processes and master data on running processes." [29]
- "supports unstructured and structured processes interactively in a natural way, leveraging self-adjusting processes based on personalization and behavioral patterns." [29]
- "one of the strongest approaches to case management as a BPMS usage scenario" [29]

- "Some customers have reported that they need to do more custom coding than they expected" [29]
- Java offering [29]
- "100% on-line, from a web browser" [48]
- focuses on model driven development [49]
- "combination of SOA, Web 2.0, Cloud Computing, Data Management and Model-Driven Development" [49]
- "Polymita 6 is 100% cloud-based, and totally independent of the customer infrastructure environment. It allows the online composition, configuration, execution and management of process-based enterprise solutions and end-to-end business processes." [49]
- standards: BPMN, XPDL, XSLT, WSDL, XML, SOAP, Webservice, JDBC, JMS, FTP, POP3, IMAP, SMTP [50]
- runs on many DBs, Application Servers, OSs, Firefox & IE [50]
- hosted solution or SaaS [51]

Interstage BPM / Cloud BPM by Fujitsu
- version Interstage BPM 11
- available as SaaS and on-premise solution [52]
- "define, refine, automate, analyze and optimize processes", "process discovery
and visualization through to modeling and simulation, automation, analysis and process optimization" [52]
- "InterstageBPM.com can help automate processes that span multiple applications and organizations." [52]
- multi-tenancy optional: "Each client gets its own instance and can run multiple applications within each instance.", "solution providers" get a multi tenancy edition [52], "Fujitsu Interstage BPM is a multitenant SaaS platform that can be used for private cloud services, or as a platform for external SaaS or cloud offerings." [29]
- good discovery and optimization facilities [29]
- standards: BPMN, XPDL, BPEL, WebDAV, Wf-XML 2.0, UDDI, Web Services [53]
- Java based, supports multiple JEE application servers [53]
- ARIS & Visio import [53]
- 100% browser based [53]

Bonita Open Solution
- For long-term workflows found only examples that given duration[194]
- There is an training called "Advancet Integration[203]" where its possible to learn the architecture of Bonita Open Solution.

BPMN Process Engine by JBoss
- When the student report started, the current version was 5.1.
- We evaluation the new version 5.2.
- its possible to use JPA/JTA to achive long term persistance of runtime states, but there are no information if it relateds to the ability of runing long term workflows. Seems more related with data persistance.[226]

Appendix B

Findings of further ignored capabilities

3.3.1 ActiveVOS Data Center Edition by ActiveEndpoints
Theoretical Foundation

Capability	Evaluation	Pts.
Formal Model	**N/A, although one source makes it look like it's a graph [73]**	**-**
Syntax Checking	**N/A**	**N/A**
Verification Options	**no information for server part found, designer can generate unit tests and test suites for scenario testing [71]**	**N/A**

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	**no, only server and database can be deployed on separate machines**	**0**
Transparent Scalability	**N/A, seems it is not Cloud-aware**	**0**

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	**N/A**	**N/A**

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	**N/A**	**N/A**
Metrics and Billing System	**N/A**	**N/A**
Cloud-aware QoS Enforcement	**N/A**	**N/A**

3.3.2 Composition Engine by Ericsson
Theoretical Foundation

Capability	Evaluation	Pts.

Formal Model	data and event driven state machine [105]	-
Syntax Checking	N/A	N/A
Verification Options	N/A	N/A

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	N/A	N/A
Transparent Scalability	N/A	N/A

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	N/A	N/A

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	N/A	N/A
Metrics and Billing System	N/A	N/A
Cloud-aware QoS Enforcement	N/A	N/A

3.3.3 Apache ODE

Formal Model

Capability	Evaluation	Pts.
Representation Model	N/A	N/A
Syntax Checking	See [99]	4
Verification Options		

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	Not possible	0
Transparent Scalability	N/A	0

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	N/A	N/A

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	N/A	N/A
Metrics and Billing System	N/A	N/A
Cloud-aware QoS Enforcement	N/A	N/A

3.3.5 WSO2 Stratos / Business Process Server
Formal Model

Capability	Evaluation	Pts.
Representation Model	No information found	N/A
Syntax Checking	N/A	N/A
Verification Options	Try-It wizard for testing new processes before they are deployed.[152]	N/A

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	Not possible	0
Transparent Scalability	Wso2 automatically scales up or down depending on the load. When new resources are needed, WSO2 Stratos transparently adds services and when load goes down, WSO2 Stratos automatically brings services down"[147]	0

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	no information found	N/A

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	**no information found**	**N/A**
Metrics and Billing System	**Tenants' logs are isolated and each tenant admin can download logs related to its tenant from the Manager service[192]. No information whether energy consumption details can be obtained[192]**	**2**
Cloud-aware QoS Enforcement	**It uses throttling to ensure the users only consume resources which are allowed to them according to the usage plan they subscribe to [195]**	**2**

3.3.7 IBM Business Process Manager
Formal Model

Capability	Evaluation	Pts.
Representation Model	**BPEL, BPMN [81,p. 4]**	**N/A**
Syntax Checking	**N/A**	**N/A**
Verification Options	**N/A**	**N/A**

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	**The IBM BPM is composed of a Process Center and one or more Process Servers.[126,p. 1] It's possible to have different kinds of deployment environment configurations.[88, p. 34] And the servers can have different profiles so that they have different functionalities.[88,p. 33-41]**	**4**
Transparent Scalability	**Scalable. But no information if transparent and only by adding servers.[88;126;]**	**0**

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	**N/A**	**N/A**

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	**N/A**	**N/A**
Metrics and Billing System	**N/A**	**N/A**

Cloud-aware QoS Enforcement	N/A	N/A

3.3.12 webMethods BPMS by Software AG
Formal Model

Capability	Evaluation	Pts.
Representation Model	N/A	-
Syntax Checking	N/A	N/A
Verification Options	N/A	N/A

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	only for database [179]	0
Transparent Scalability	N/A	0

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	N/A	0

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	Only static configuration available to tune for performance or robustness [179].	0
Metrics and Billing System	N/A	0
Cloud-aware QoS Enforcement	N/A	0

3.3.13 Business Operations Platform Suite by Cordys
Formal Model

Capability	Evaluation	Pts.
Representation Model	case management is based on state machine [122]	-
Syntax Checking	N/A	N/A

Verification Options	N/A	N/A

Scalability & Elasticity

Capability	Evaluation	Pts.
Component Architecture Allows to Distribute Usage	only information found that database can be run on a different machine [122]	0
Transparent Scalability	N/A	0

Security

Capability	Evaluation	Pts.
Compliance with Data-Access Rules from a Region	N/A	0

Quality of Service

Capability	Evaluation	Pts.
QoS Enforcement	N/A	0
Metrics and Billing System	through SDF, based on custom application transactions that can be reported to the SDF metering service [143], the out of the box metering capabilities are very limited with respect to resource utilization	4
Cloud-aware QoS Enforcement	N/A	0

3.3.19 Bonita Open Solution
Formal Model

Capability	Evaluation	Pts.
Representation Model	BPMN 2.0 based graphical representation	
Syntax Checking	"Error notations and warnings appear when a task is not configured properly or data is missing"[196].	4
Verification Options	N/A	N/A

In the previous version of the "Availability of IDE Plugins […]" capability description was the possibility of cloud interaction mentioned. It contained the following sentence: "Also is it possible to alter the workloads across different Clouds using the plug-ins for the corresponding Cloud?" After the evaluation of the engines, we saw that it's very unlikely for such plug-ins to exist, so we removed it from the criteria description.

When looking at the "Data Encryption" capability later we found out that really only one engine (Oracle) provides reliable information on that capability and decided to ignore it as well. Here are the evaluations we made before we decided to leave out this capability:

3.3.1 ActiveVOS Data Center Edition by ActiveEndpoints
could be realized by the used database, but no information found that assures complete data encryption

3.3.3 Apache ODE
depends on used database or cloud storage provider agreement, no information on complete data encryption found

3.3.4 OW2 Orchestra
depends on used database, no further information found

3.3.6 BonitaSoft Bonita Open Solution
No encryption mentioned, could be realized by the used database, but no statement on complete data encryption found [12, 219, 198].

3.3.7 IBM Business Process Manager
could be realized by used database, but no statement on complete data encryption found [123, 88]

3.3.8 BPMS Enterprise by Intalio
The data encryption could be realized by the used database, but no statement about complete data encryption found [327].

3.3.10 BPM Suite 11g by Oracle
Oracle Internet Directory provides security at every level from data in transit to storage and backups. In addition to LDAP security, it leverages Oracle database security features like Database Vault and Transparent Data Encryption. Database Vault enables separation of duty (SOD) while Transparent Data Encryption secures data in storage and backup [371]. Also to meet additional privacy and regulatory requirements, Oracle Advanced Security and Oracle Label Security can be used [429].

3.3.12 webMethods BPMS by Software AG
Credentials are held in a trust/key store, WS-Security is supported for secure message exchange and process data is held in an external database, which could encrypt it, but no statement on complete data encryption in the documentation [188].

3.3.13 Business Operations Platform (BOP) Suite by Cordys
"The Cordys platform has an advanced set of security measures, including access control lists, auditing, encryption and sandboxing.", XML Encryption [140], data is hold in databases which support encryption, but no statement found that all data that is stored can be completely encrypted.

3.3.18 BPMN Process Engine by JBoss

No encryption mentioned in the documentation, might depend on the H2 database, but no explicit data encryption mentioned in the documentation [229].

3.3.19 Activiti

No encryption mentioned in the documentation, might be possible depending on used database and configuration, but no explicit statement about complete data encryption found [321].

Appendix C

We originally planned to propose possible solutions for the most severe identified shortcomings. Since we had not enough time we skipped that section. Here is what we came up with before we decided to skip the section.

5.3 Metrics System

A metrics system for a workflow engine should deliver basic information that further allows to deploy workloads across the Cloud. This requires the ability to define metrics and measure them accurately. Sample metrics could be resource utilization like CPU load and latency as well as energy consumption with respect to Green IT. We will only focus on a metrics system that is necessary to further distribute workloads and not take power consumption or other non-distribution relevant metrics into consideration, since we think this is the most important part of a metrics system in the context of this "Fachstudie".

Since there are already open-source and commercial monitoring solutions available that can track resource utilization it is probably very easy to install this software on each workflow engine's instance. The information gathered by those monitoring agents can then be pushed into a central monitoring system where the required metrics can be calculated.

Some Cloud providers like Amazon Web Services already have services like Amazon CloudWatch that take care of monitoring and allow to trigger further actions [319]. For other Cloud providers there are also third-party tools like AzureWatch for Window Azure that allow similar tasks [320].

Appendix D

The e-mail conversation with Intalio's staff member Roberto Pasti:

Hi,
I was wondering if Intalio BPM is just a hosted version of Intalio
BPMS Enterprise or if there are other differences.
Thanks,
Thomas Bachmann

Guten Tag Herr Bachmann,
Vielen Dank für Ihre Nachricht.
Beide sind BPM, jedoch die Unterschiede sind groß. Intalio|BPM hat
einen CRM und DMS/ECM mitintegriert.
Ein Beta Release wird Ende Januar rauskommen.
Mit freundlichen Grüßen,
Roberto Pasti

Hallo Herr Pasti,
vielen Dank für Ihre schnelle Antwort.
Gehe ich aber richtig in der Annahme, dass die Workflow Engine
innerhalb von BPMS Enterprise und BPM die gleichen sind? Also keine
entfernte/zusätzliche Funktionalität hat?
Hintergrund: Ich evaluiere verschiedene Workflow Engines (für ein
Universitätsstudie/EU-Projekt) und frage mich ob es Sinn macht beide
Produkte separat zu betrachten.
Vielen Dank!
Thomas Bachmann

Hallo Herr Bachmann,
Ich möchte Ihr Leben so gut es geht zu vereinfachen. Leider macht es
wenig Sinn beide Lösungen als eine zu betrachten, die Unterschiede
sind groß.

Mit freundlichen Grüßen,
Roberto Pasti

Appendix E

1. GridFTP - While workflow engines typically cause data to flow through the machine running the engine, this is highly inefficient for the typically large data movements used in Grids. However, the GridFTP protocol allows this to be avoided via third-party transfer. The role of the workflow engine in handling data is to be able to invoke the GridFTP client with the app. source and destination addresses.

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All links were last checked on 2012-02-14.