**C**loud-based **R**apid **E**lastic **MA**nufacturing


# WP5 – Cloud Manufacturing Process and Optimisation Framework

# D5.8 – T5.4 – CREMA Design Time Optimisation – Prototype II

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Contributing Partners: DFKI, IKER, TCO

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This deliverable provides a description of the second prototype implementation of task T5.4 Design Time Optimisation. As stated in the Description of Action (DoA), this deliverable is a prototype (software) deliverable. As such, this document is reduced in length and its only purpose is to briefly describe the prototype functionality as well as to give installation instructions and usage clarifications. This document is delivered with instructions to obtain the software itself.

| Document Status | |
|---|---|
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## Note

*The type of the official deliverable is OTHER, as it is a software deliverable. This document mainly describes how to obtain the software and how to run it.*

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# Executive Summary

This deliverable provides the requirements, installation, and execution details of the second prototype of the Design Time and Runtime Optimisation (ODERU) component with focus on its functionality for design time optimisation (ODE). The ODE part of ODERU is responsible for functional and non-functional optimisation of service-based process models in annotated BPMN at their design time.

The second prototype of ODERU extends the functionality of the first prototype (see deliverable D5.7) by means of the (a) integrated functional and non-functional process optimisation of process service plans at design time, and (b) the integration of the CREMA security concept into the workflow of ODERU.

The CREMA use case specific constraint optimisation problems (COP) to be solved by ODERU for a non-functional optimisation of the given process service plan have been re-checked with and approved by the user partners for both use cases.

The software of the first prototype is available at https://go.abelssoft.de/oderu_prototype2 (password: crema_reviewers_1234).

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## Figures



## Tables

# 1 Introduction

CREMA – Cloud-based Rapid Elastic MAnufacturing – is a project funded by the Horizon 2020 Programme of the European Commission under Grant Agreement No. 637066.

Within this deliverable, the process of installation and execution of the software prototype is described to support administrators and users.

## 1.1 CREMA Project Overview

CREMA aims at simplifying the establishment, management, adaptation, and monitoring of dynamic, cross-organisational manufacturing processes following Cloud manufacturing principles. CREMA will also provide the means to integrate data from distributed locations as if the complete manufacturing was carried out on the same shop floor, by integrating extra- and inter-plant manufacturing assets and making them “mobile”.

CREMA will be built upon concepts and methods from the fields of Virtual Factories, Service-oriented Computing, Ubiquitous Computing, Cyber-Physical Systems, the Internet of Things and the Internet of Services, and naturally and most importantly Cloud computing. To achieve its goals, the project will define tools and approaches in these areas:

- Manufacturing Virtualisation & Interoperability
- Cloud Manufacturing Process and Optimisation Framework
- Cloud Manufacturing Collaboration, Knowledge and Stakeholder Interaction Framework

Thus, to achieve its goals, CREMA conducts original research and applies technologies from the fields of full end-to-end integration of Cloud manufacturing, integration of manufacturing assets and corresponding data sources, the design and execution of manufacturing processes, to the end user support via collaboration and interaction tools. For more information, please refer to the project Website[1].

## 1.2 Deliverable Purpose, Scope and Context

The purpose of this deliverable is to accompany the second prototype implementation of the CREMA component ODERU for design time optimisation (ODE) in T5.4. As such, its main purpose is to briefly clarify the scope of the relevant part of the ODERU prototype, and to show the download, installation instructions and the use of the API of the ODERU software. The document is limited in length as the main focus of the task is the software itself rather than its accompanying document.

## 1.3 Document Status and Target Audience

This document is listed in the Description of Action (DoA) as ‘public’, which means ‘Restricted to other programme participants (including the Commission Services)’, primarily since the audience of the document is largely internal. It is true, of course, that the largest audience for dissemination itself is external, but this document covers only the planning around this and not the outputs of doing this and hence its non-public nature.

[1] http://www.crema-project.eu/

## 1.4 Abbreviations and Glossary

A glossary of common terms and roles related to the realisation of CREMA as well as a list of abbreviations is provided as an online glossary[2] / abbreviations list[3].

## 1.5 Document Structure

This deliverable is broken down into the following sections:

- Section 1 (Introduction): Provides an introduction for this deliverable, including a general overview of the project, and outlines the purpose, scope, context, status, and target audience of this deliverable.
- Section 2 (Scope and Relationship): Clarifies the context and scope of the second software prototype deliverable for design time optimisation, and its relationship with other CREMA components for this purpose.
- Section 3 (Requirements and Preparations): Describes the requirements of and preparations for installing the software component ODERU.
- Section 4 (Deployment): Describes the deployment of the component for its execution and usage.
- Section 5 (Execution and Usage): Describes the execution and usage of the deployed component ODERU.
- Section 6 (Feature Status): Provides an overview of the implemented features of the ODE part of ODERU matching its final technical and functional requirements.
- Section 7 (Annex): Provides the grammatical specification of the CREMA use case specific optimisation problems in the ODERU-COP I/O grammar and the respective encoding of the result in the process service plans produced by ODERU.

[2] http://crema-project.eu/glossary
[3] http://crema-project.eu/abbreviations

# 2 Scope and Relationship

The ODERU component implements the complete set of functionalities for process optimisation at design time and runtime as specified in the functional and technical architecture (see deliverables D3.3 and D3.4). This section summarizes the ODERU part for the optimisation at design time of process models (ODE) with focus on functionalities that have been added to the first prototype (see deliverable D5.7).

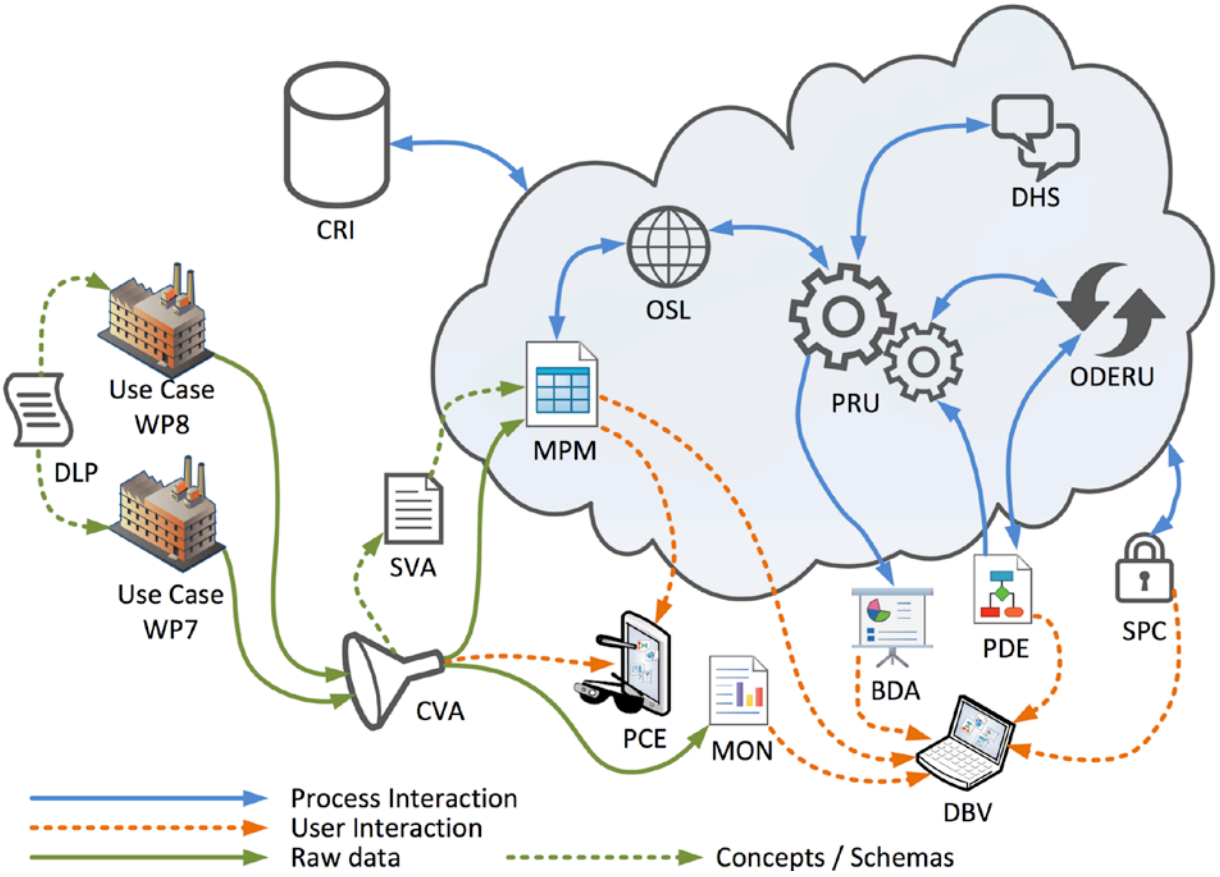


Figure 1: ODERU position in the CREMA platform architecture

The main improvements of the ODE part of the second prototype of ODERU compared to its first prototype are as follows:

(a) The COP solving software modules (for non-functional optimisation) are fully integrated with the internal component workflow of ODERU. The optimisation result in terms of optimal service parameter values and bindings required for the optimal execution of the produced process service plan (PSP) are embedded into the plan which is returned to the PDE.

(b) The CREMA Security and Privacy component (SPC) was integrated into the internal workflow of ODERU. Since the aspect of authentication of inter-component requests required a major revision of previously implemented interaction of ODERU with MPM and CRI, a significant amount of efforts from the final implementation phase of ODERU was put into enabling this integration. This integration was concerned with addressing user-specific access/visibility constraints in the internal computation of optimal process service plans.

The implemented modules of the ODE part of ODERU and its interactions with CREMA components for process optimisation at design time are shown in Figures 2 and 3[4].

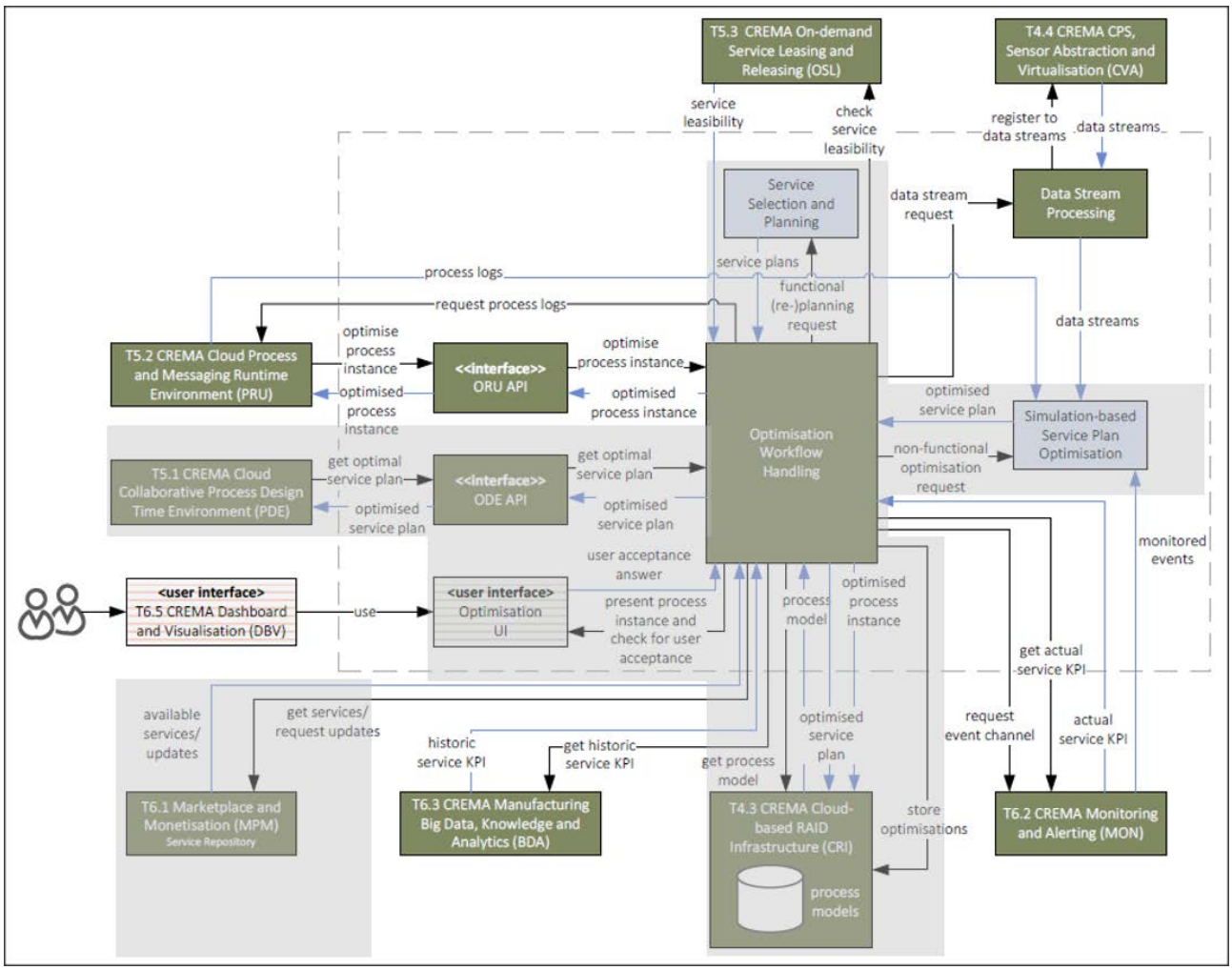


Figure 2: Modules of ODERU Prototype II for optimisation at design time

[4] An asterisk (*) before a named entity denotes the link to this entity stored in the CRI.

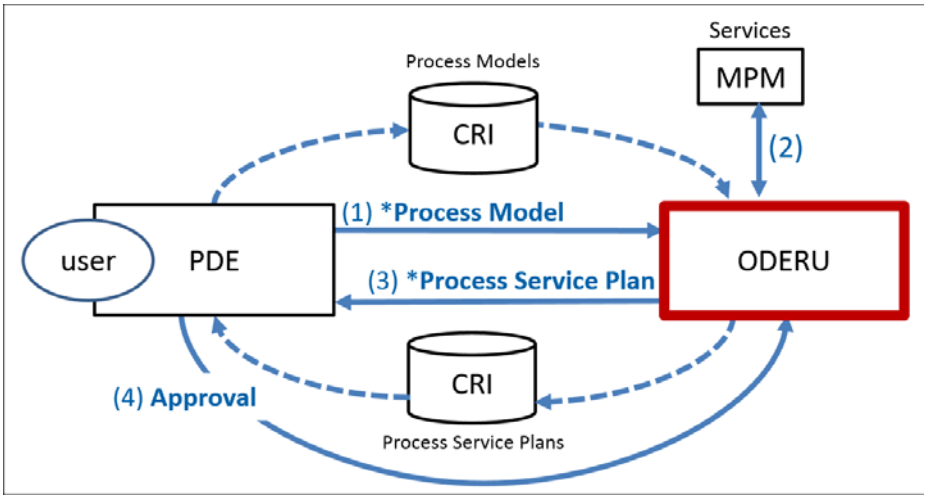


Figure 3: CREMA component interactions with ODERU for optimisation at design time

The interactions of ODERU with CREMA components for process optimisation in both CREMA use cases at runtime are described in the deliverable D5.10.

# 3 Requirements and Preparations

There are no major changes of requirements and preparations to be done for installing ODERU prototype II compared to its first prototype (see D5.7 Sect. 3.1).

Note on licensing[5]: The code of the ODERU is Open Source under the Apache 2.0 license[6]. The state of the code at the end of the project CREMA represents/constitutes the final state of this component. Please note that ODERU makes use of the Java constraint programming solver JaCoP which code is released under GNU Affero General Public License v3[7] by the core developers who are the JaCoP code copyright holders. If ODERU is used for commercial purposes the embedded JaCoP code can be released by the copyright holders under different license schemes[8].

The ODERU component provides process optimisation at design time (ODE, see deliverable D5.7) and runtime (ORU, see deliverables D5.9 and D5.10). This section provides requirements for running the second prototype of ODERU, its installation and instructions to make the component available for interconnected components at design time of process models, and describes the process how to execute the installed instance of this CREMA component.

Since there is no graphical user interface (GUI) the component can only be used via the ODERU REST API, which is documented at http://docs.crema-project.eu/#oderu. The complete software of the second prototype of ODERU is available at https://go.abelssoft.de/oderu_prototype2 (password: crema_reviewers_1234).

A few preparations to install and run the ODERU component and the COP solving software in the second prototype software package have to be made. It is recommended to use a Linux-based operating system (e.g., Ubuntu 16.04) to host the Docker[9] VM (virtual machine). The Docker version used for the testing is 17.03.1-ce-win12 (build number 12058). The installation of Java JDK version 8 and respective setting of the PATH environment variable is required.

[5] https://choosealicense.com/licenses/
[6] http://www.apache.org/licenses/LICENSE-2.0.html
[7] http://www.gnu.org/licenses/agpl-3.0.de.html
[8] https://osolpro.atlassian.net/wiki/display/JACOP/JaCoP+Licence
[9] https://www.docker.com/

# 4 Deployment

There are no changes of actions required to be performed for deploying ODERU prototype II compared to its first prototype (see D5.7 Sect. 3.2).

The complete software of the first prototype of ODERU is available in the file ODERU_Prototype2.zip which is available at https://go.abelssoft.de/oderu_prototype2. The ODERU is delivered in a self-contained form as a Docker image and can be obtained from https://go.abelssoft.de/oderu_prototype2. The Docker image is in the file oderu.zip which is part of the complete software of the first prototype of ODERU in the downloaded file ODERU_Prototype2.zip.

Once deployed in the local Docker virtual machine every required component for ODERU is in place and no external dependencies exists with the host OS. To install the software, the Docker image has to be downloaded, expanded, and built. Following these steps, the ODERU software is launched:

```
zip –x oderu.zip .

cd oderu/oderu-app

docker build -f Dockerfile -t oderu .

docker run -p 8080:80 -t oderu
```

For more information, please refer to the *README.md* file text in the main directory of the release. The ODERU answers to the external port 8080. The basic configuration is already present in the deployed Docker image. For a final release, some configurations will be available, for example to customise the locations of the MPM and CRI components.

Note: The software module for solving the flexible job-shop scheduling COP is also included in ODERU_Prototype2.zip as separate zip file shopST.zip. The default COP solver JaCoP is fully integrated in the ODERU prototype II. The code for the second COP solver of ODERU, that is the shopST for approximated optimal flexible job-shop scheduling, is in the file shopST.zip. This file should be extracted and saved in an individual base directory named shopST; the executable solver in this directory is compiled as shopST.jar.

# 5 Execution and Usage

There are no changes of actions required for executing and using ODERU prototype II compared to its first prototype (see D5.7 Sect. 3.3). The only difference is, that the COP solver JaCoP is now fully integrated in ODERU. Therefore, no stand-alone application of JaCoP is provided anymore.

Once the ODERU component (Docker image) is deployed and launched, the ODERU REST API is exposed automatically through the port 8080, waiting for incoming connections/requests.

The installed COP solver shopST in the directory shopST can be executed for approximated optimal job-shop scheduling with, for example, the Hurink benchmark as follows:

```
java –jar shopST.jar -b benchmarks\Hurink_Data\vdata\la40.fjs -r 10 -si 500 -tl 60 -disp
RNDRND -c TOPC -ml 5 -gui true
```

with parameters (see explanation in params_definition.pdf)

-b path to test data file, otherwise a random scenario is generated

-r number of simulated trading rounds

-si number of iterations per simulated trading round

-tl maximal execution time in minutes

-seed basis of random number generation

-disp disposition rule for initial planning, e.g.:

RND: random, FASFS: first at shop first served, SPT: shortest processing time

-c cost function, e.g.:

TOPC: total operation completion date, TOPL: total operation lateness,

TOPT: total operation tardiness, TOPSL: total operation slack time

-ml maximal number of trading levels

-gui shows GUI (true, false)

# 6 Feature Status

The status of the implemented functionality of the ODE part of the CREMA ODERU Prototype II matching the respective requirements is shown in Table 1 (marked **Design Time** in the column for comments). The functions and requirements indicated in the table are extracted from the deliverables D3.2 Functional Specification and D3.3 Technical Specification (Sect. 5.4), and the deliverables D5.7 and D5.9 for the first prototype. In summary, the required functionality ODE part of ODERU has been fully implemented.

Table 1: Status of the ODERU Prototype II

| Requirement of ODERU Prototype II | ID/Source | Priority | Status | Comments |
|---|---|---|---|---|
| Functionally optimal composition of process service plan for given process model in BPMN | ODERU_F 010 | Must | done | **Design Time** REST method PUT |
| Non-functional optimisation of process model by solving of associated constraint optimisation problem COP | ODERU_F 020 | Must | Done | **Design Time** REST method PUT |
| Realise (functionally compose and non-functionally optimise) a process service plan for given process model | ODERU_H 510 | Must | Done | **Design Time** REST method PUT |
| Functionally optimal composition of service plan for process *instance* | ODERU_F 050 | Must | Done | Runtime REST method PUT |
| Non-functional optimisation of process *instance* | ODERU_F 040 | Must | Done | Runtime REST method PUT |
| Realise (functionally compose and non-functionally optimise) a process service plan for a process instance. | ODERU_H 520 | Must | Done | Runtime REST method PUT |
| Approve a newly computed process service plan | ODERU_F 030 | Must | Done | **Design Time**, Runtime REST method PUT |
| Return ordered list of services implementing a given process task (service selection) | ODERU_F 060 | Must | Done | **Design Time**, Runtime REST method GET |
| Retrieve previously computed process service plan for a given process model | ODERU_F 070 | Must | Done | **Design Time** REST method GET |
| Retrieve previously computed process service plan for a given process instance | ODERU_F 080 | Must | Done | Runtime REST method GET |
| Notify about new/updated service in MPM component (push approach) | ODERU_F 100 | Must | Done | **Design Time**, Runtime REST method PUT |
| Remove an existing service from MPM component (push approach) | ODERU_F 110 | Must | Done | **Design Time**, Runtime REST method DELETE |

| Requirement of ODERU Prototype II | ID/Source | Priority | Status | Comments |
|---|---|---|---|---|
| Notify about new data bucket from an external “buffered stream” | ODERU_F 120 | Must | Done | **Design Time**, Runtime<br>REST method PUT, part of module RSP |
| Implement module RSP “Data Stream Processing” (RDF stream reasoning/processing) | D3.2, Sect. 5.4.1 | Must | Done | Runtime |
| Interaction with PRU:<br>Get optimisation request via process log; Return re-optimised *process service plan for continued execution | D3.2, Sect. 5.4.1<br>D5.9, Sect. 2 | Must | Done | Runtime |
| Interaction with MPM:<br>Retrieve/remove service descriptions | D3.2, Sect. 5.4.1<br>D5.9, D5.7, Sect. 2 | Must | Done | **Design Time**, Runtime |
| Interaction with CRI:<br>Get/Store process models and process service plans | D3.2, Sect. 5.4.1<br>D5.9, D5.7, Sect. 2 | Must | Done | **Design Time**, Runtime |
| Interaction with OSL:<br>Check for service leasability | D3.2, Sect. 5.4.1<br>D5.9, Sect. 2 | Must | Done | Runtime |
| Interaction with PDE:<br>Get optimisation request; Return optimal process service plan | D3.2, Sect. 5.4.1<br>D5.7, Sect. 2 | Must | Done | **Design Time** |
| Support of dynamic and flexible job-shop scheduling in smart factories | D3.2, Sect. 5.4.1<br>D5.7, Sect. 2 | Should | Done | Runtime, **Design Time**<br>Anytime FJSS solver system<br>In addition to CREMA use cases |

Note on component testing: The integration (interaction) of the ODERU component with other components has been manually performed according to the component workflows for process optimisation in the CREMA use cases. Regarding the ODE part of ODERU (see Sect. 2, Figure 3) its REST-based interactions with PDE, MPM and CRI were successfully tested and used in the demonstrations of the CREMA use cases at the second project review. In addition, the user partners approved the returned results of process optimisation by ODERU in the considered use cases. Final integration testing will be performed during the validation phase of the final CREMA use case demonstrators.

# 7 Annex

The CREMA use case specific process optimisation problems are technically specified in the developed ODERU-COP grammar and embedded into the associated process model in annotated BPMN. This annotated process model is passed to ODERU as an optimisation request, and the results are embedded into the returned process service plans. The following sections provide the technical specification of the optimisation requests and results that were produced in the CREMA use case demonstrators in the past reporting period.

## 7.1 UC1-COP Specification in Process Model

The UC1-COP is a linear multi-objective constrained optimisation problem. The actual problem to solve for given input data and output format is described as an instance of the general class with relevant bindings to concrete service parameters. The UC1-COP has been comprehensively described in the deliverable D5.7, Sect. 5.1.

```
TYPE linear multi END TYPE
SOLVER both END SOLVER
CLASS
VARIABLES
   T[]
   SP[]
END VARIABLES
CONSTANTS
   C
   F
   Wmin
   Cmax
   Tmax
   CtravelT[]
   CmaintenanceT[]
   TmaintenanceT[]
   TtravelT[]
   CpartSP[]
   CdeliverySP[]
   TdeliverySP[]
   WSP[]
END CONSTANTS
FUNCTIONS
CostMaintenance(T) = SUM(i,1,T.length, T[i] * CmaintenanceT[i] + T[i] * CtravelT[i])
CostSparePart(SP) = SUM(i,1,SP.length, SP[i] * CpartSP[i] + SP[i] * CdeliverySP[i])
```

```
TimeMaintenance(T) = SUM(i,1,T.length, T[i] * TmaintenanceT[i])
TimeStoppageBeforeMaintenance(T,SP) = MAX{SUM(i,1,T.length, T[i] * TtravelT[i]), SUM(i,1,SP.length, SP[i] * TdeliverySP[i])}
CostStoppage(T,SP) = (F * TimeStoppageBeforeMaintenance(T,SP) + TimeMaintenance(T)) * C
TotalCost(T,SP) = CostMaintenance(T) + CostSparePart(SP) + CostStoppage(T,SP)
TotalTime(T,SP) = TimeStoppageBeforeMaintenance(T,SP) + TimeMaintenance(T)
END FUNCTIONS

CONSTRAINTS
      SUM(i,1,T.length, T[i]) = 1
      SUM(i,1,SP.length, SP[i]) = 1
      TotalCost(T,SP) <= Cmax
      TotalTime(T,SP) <= Tmax
END CONSTRAINTS

minimize TotalCost(T,SP) -> http://localhost/ontology/fake.owl#Cost
minimize TotalTime(T,SP) -> http://localhost/ontology/fake.owl#Time
END CLASS

INSTANCE

DOMAINS
   T[] {0,1}
   SP[] {0,1}
END DOMAINS

VALUES
   C = 1.5
   F = 0
   Wmin = 3
   Cmax = 8000
   Tmax = 15

INPUT
CtravelT <- (ServiceTask_1wsl4ob, http://localhost/ontology/fake.owl#travelCost)
CmaintenanceT <- (ServiceTask_1wsl4ob, http://localhost/ontology/fake.owl#maintenanceCost)
TmaintenanceT <- (ServiceTask_1wsl4ob, http://localhost/ontology/fake.owl#maintenanceTime)
```

```
TtravelT <- (ServiceTask_1wsl4ob, http://localhost/ontology/fake.owl#travelTime)
CpartSP <- (ServiceTask_1yjnl8n, http://localhost/ontology/fake.owl#partCost)
CdeliverySP <- (ServiceTask_1yjnl8n, http://localhost/ontology/fake.owl#deliveryCost)
TdeliverySP <- (ServiceTask_1yjnl8n, http://localhost/ontology/fake.owl#deliveryTime)
WSP <- (ServiceTask_1yjnl8n, http://localhost/ontology/fake.owl#guarantee)
END INPUT
END VALUES
END INSTANCE

OUTPUT
   T[] :: ServiceTask_1wsl4ob
   SP[] :: ServiceTask_1yjnl8n
END OUTPUT
END PROBLEM
```

## 7.2 UC1-COP Solution in Process Service Plan

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?><bpmn:definitions
xmlns:bpmn="http://www.omg.org/spec/BPMN/20100524/MODEL"
xmlns:bpmndi="http://www.omg.org/spec/BPMN/20100524/DI"
xmlns:camunda="http://camunda.org/schema/1.0/bpmn"
xmlns:crema="http://crema.project.eu" xmlns:dc="http://www.omg.org/spec/DD/20100524/DC"
xmlns:di="http://www.omg.org/spec/DD/20100524/DI"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" id="Definitions_1"
targetNamespace="http://bpmn.io/schema/bpmn">
<bpmn:process id="Process_1" isExecutable="true">
<bpmn:extensionElements>
<crema:metadata>
<crema:optimization>
<crema:formulation>
PROBLEM
TYPE linear multi END TYPE
SOLVER both END SOLVER
CLASS
   VARIABLES
      T[]
      SP[]
   END VARIABLES
   CONSTANTS
      C
```

```
      F
      Wmin
      Cmax
      Tmax
      CtravelT[]
      CmaintenanceT[]
      TmaintenanceT[]
      TtravelT[]
      CpartSP[]
      CdeliverySP[]
      TdeliverySP[]
      WSP[]
   END CONSTANTS
   FUNCTIONS
      CostMaintenance(T) = SUM(i,1,T.length, T[i] * CmaintenanceT[i] + T[i] *
CtravelT[i])
      CostSparePart(SP) = SUM(i,1,SP.length, SP[i] * CpartSP[i] + SP[i] * CdeliverySP[i])
      TimeMaintenance(T) = SUM(i,1,T.length, T[i] * TmaintenanceT[i])
      TimeStoppageBeforeMaintenance(T,SP)=MAX{SUM(i,1,T.length, T[i] * TtravelT[i]),
SUM(i,1,SP.length, SP[i] * TdeliverySP[i])}
      CostStoppage(T,SP) = (F * TimeStoppageBeforeMaintenance(T,SP) +
TimeMaintenance(T)) * C
      TotalCost(T,SP) = CostMaintenance(T) + CostSparePart(SP) + CostStoppage(T,SP)
      TotalTime(T,SP) = TimeStoppageBeforeMaintenance(T,SP) + TimeMaintenance(T)
   END FUNCTIONS

   CONSTRAINTS
      SUM(i,1,T.length, T[i]) = 1
      SUM(i,1,SP.length, SP[i]) = 1
      TotalCost(T,SP) &lt;= Cmax
      TotalTime(T,SP) &lt;= Tmax
   END CONSTRAINTS
      minimize TotalCost(T,SP) -&gt; http://localhost/ontology/fake.owl#Cost
       minimize TotalTime(T,SP) -&gt; http://localhost/ontology/fake.owl#Time
END CLASS

INSTANCE
   DOMAINS
      T[] {0,1}
```

```
      SP[] {0,1}
   END DOMAINS
   VALUES
      C = 1.5
      F = 0
      Wmin = 3
      Cmax = 8000
      Tmax = 15

INPUT
         CtravelT                      &lt;-                      (ServiceTask_1wsl4ob,
http://localhost/ontology/fake.owl#travelCost)
         CmaintenanceT                   &lt;-                   (ServiceTask_1wsl4ob,
http://localhost/ontology/fake.owl#maintenanceCost)
         TmaintenanceT                   &lt;-                   (ServiceTask_1wsl4ob,
http://localhost/ontology/fake.owl#maintenanceTime)
         TtravelT                      &lt;-                      (ServiceTask_1wsl4ob,
http://localhost/ontology/fake.owl#travelTime)

         CpartSP                      &lt;-                       (ServiceTask_1yjnl8n,
http://localhost/ontology/fake.owl#partCost)
         CdeliverySP                   &lt;-                      (ServiceTask_1yjnl8n,
http://localhost/ontology/fake.owl#deliveryCost)
         TdeliverySP                   &lt;-                      (ServiceTask_1yjnl8n,
http://localhost/ontology/fake.owl#deliveryTime)
         WSP &lt;- (ServiceTask_1yjnl8n, http://localhost/ontology/fake.owl#guarantee)
      END INPUT
   END VALUES
END INSTANCE

OUTPUT
      T[] :: ServiceTask_1wsl4ob
      SP[] :: ServiceTask_1yjnl8n
END OUTPUT
END PROBLEM
</crema:formulation>

<crema:results>
<crema:log>COPSE2 meta -&gt; COPSE2 transformation done.
The following services have been excluded due to missing QoS entries:
6e0940f0-289f-45ee-b514-efd533ae9be0
```

96e7d49d-e380-49e9-9842-22946ccdb662

6e0940f0-289f-45ee-b514-efd533ae9be0

96e7d49d-e380-49e9-9842-22946ccdb662

6e0940f0-289f-45ee-b514-efd533ae9be0

96e7d49d-e380-49e9-9842-22946ccdb662

6e0940f0-289f-45ee-b514-efd533ae9be0

96e7d49d-e380-49e9-9842-22946ccdb662

**JaCoP optimizer**

precision = 1.0E-5

timeout occurred = false

**T_0 = 1.0**

**T_2 = 5.551115123125784E-17**

**SP_2 = 5.551115123125784E-17**

**T_1 = 0.0**

**SP_0 = 1.0**

**SP_1 = 0.0**

</crema:log>

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http://www.crema-project.eu/DLP/UC1.owl#MechanicalSkill)</crema:element>
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  <bpmndi:BPMNDiagram id="BPMNDiagram_1">
    <bpmndi:BPMNPlane bpmnElement="Process_1" id="BPMNPlane_1">
      <bpmndi:BPMNShape bpmnElement="StartEvent_1" id="_BPMNShape_StartEvent_2">
        <dc:Bounds height="36" width="36" x="173" y="113"/>
        <bpmndi:BPMNLabel>
```

```
          <dc:Bounds height="0" width="0" x="191" y="149"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="ServiceTask_0m71o4m" id="ServiceTask_0m71o4m_di">
        <dc:Bounds height="80" width="100" x="407" y="91"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1f758os" id="SequenceFlow_1f758os_di">
        <di:waypoint x="507" xsi:type="dc:Point" y="131"/>
        <di:waypoint x="572" xsi:type="dc:Point" y="131"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="540" y="116"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNShape                              bpmnElement="ExclusiveGateway_0nuu4me"
id="ParallelGateway_0rtrn62_di">
        <dc:Bounds height="50" width="50" x="572" y="106"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="597" y="156"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="ServiceTask_1wsl4ob" id="ServiceTask_1wsl4ob_di">
        <dc:Bounds height="80" width="100" x="714" y="4"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="ServiceTask_1yjnl8n" id="ServiceTask_1yjnl8n_di">
        <dc:Bounds height="80" width="100" x="714" y="186"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_0ct27vn" id="SequenceFlow_0ct27vn_di">
        <di:waypoint x="597" xsi:type="dc:Point" y="106"/>
        <di:waypoint x="597" xsi:type="dc:Point" y="44"/>
        <di:waypoint x="714" xsi:type="dc:Point" y="44"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="612" y="65"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1lsa1oc" id="SequenceFlow_1lsa1oc_di">
        <di:waypoint x="597" xsi:type="dc:Point" y="156"/>
        <di:waypoint x="597" xsi:type="dc:Point" y="226"/>
        <di:waypoint x="714" xsi:type="dc:Point" y="226"/>
        <bpmndi:BPMNLabel>
```

```
          <dc:Bounds height="0" width="0" x="612" y="191"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1pykuax" id="SequenceFlow_1pykuax_di">
        <di:waypoint x="814" xsi:type="dc:Point" y="44"/>
        <di:waypoint x="922" xsi:type="dc:Point" y="44"/>
        <di:waypoint x="922" xsi:type="dc:Point" y="106"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="868" y="29"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1epspvu" id="SequenceFlow_1epspvu_di">
        <di:waypoint x="814" xsi:type="dc:Point" y="226"/>
        <di:waypoint x="922" xsi:type="dc:Point" y="226"/>
        <di:waypoint x="922" xsi:type="dc:Point" y="156"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="869" y="211"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNShape                          bpmnElement="ExclusiveGateway_0x9zr10"
id="ParallelGateway_16l8dg6_di">
        <dc:Bounds height="50" width="50" x="897" y="106"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="922" y="156"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="ServiceTask_0gihpia" id="ServiceTask_0gihpia_di">
        <dc:Bounds height="80" width="100" x="996" y="91"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1pj7f7l" id="SequenceFlow_1pj7f7l_di">
        <di:waypoint x="947" xsi:type="dc:Point" y="131"/>
        <di:waypoint x="996" xsi:type="dc:Point" y="131"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="972" y="116"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNShape bpmnElement="EndEvent_018gkww" id="EndEvent_018gkww_di">
        <dc:Bounds height="36" width="36" x="1494" y="113"/>
        <bpmndi:BPMNLabel>
```

```
        <dc:Bounds height="0" width="0" x="1512" y="149"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNShape>
    <bpmndi:BPMNEdge bpmnElement="SequenceFlow_0k75tbo" id="SequenceFlow_0k75tbo_di">
      <di:waypoint x="1096" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="1179" xsi:type="dc:Point" y="131"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="0" width="0" x="1138" y="116"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
    <bpmndi:BPMNEdge bpmnElement="SequenceFlow_17oban5" id="SequenceFlow_17oban5_di">
      <di:waypoint x="209" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="308" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="308" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="407" xsi:type="dc:Point" y="131"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="0" width="0" x="324" y="131"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
    <bpmndi:BPMNShape bpmnElement="ServiceTask_0psqf1k" id="ServiceTask_0psqf1k_di">
      <dc:Bounds height="80" width="100" x="1179" y="91"/>
    </bpmndi:BPMNShape>
    <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1x12p5g" id="SequenceFlow_1x12p5g_di">
      <di:waypoint x="1279" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="1347" xsi:type="dc:Point" y="131"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="0" width="0" x="1313" y="116"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
    <bpmndi:BPMNShape bpmnElement="ServiceTask_1kmvdwv" id="ServiceTask_1kmvdwv_di">
      <dc:Bounds height="80" width="100" x="1347" y="91"/>
    </bpmndi:BPMNShape>
    <bpmndi:BPMNEdge bpmnElement="SequenceFlow_1di101i" id="SequenceFlow_1di101i_di">
      <di:waypoint x="1447" xsi:type="dc:Point" y="131"/>
      <di:waypoint x="1494" xsi:type="dc:Point" y="131"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="0" width="0" x="1471" y="116"/>
      </bpmndi:BPMNLabel>
```

```
      </bpmndi:BPMNEdge>
    </bpmndi:BPMNPlane>
  </bpmndi:BPMNDiagram>
</bpmn:definitions>
```

## 7.3 UC2-COP Specification in Process Model

The UC2-COP is a non-linear, single-objective (transformed from its multi-objective form) constrained optimisation problem. As mentioned above, the actual problem to solve for given input data and output format is described as an instance of the general class with relevant bindings to concrete service parameters. The UC2-COP has been comprehensively described in the deliverable D5.9, Sect. 5.2.

```
PROBLEM
TYPE nonlinear single END TYPE
SOLVER both END SOLVER

CLASS

VARIABLES
   R[]
   I
   F
   S
END VARIABLES

CONSTANTS
   A0[]
   A1[]
   A2[]
   A3[]

   B0[]
   B1[]
   B2[]
   B3[]

   C0[]
   C1[]
```

```
C2[]
C3[]

D0[]
D1[]
D2[]
D3[]

Cref
HDref

E0[]
E1[]
E2[]
E3[]
F0[]
F1[]
F2[]
F3[]
G0[]
G1[]
G2[]
G3[]
H0[]
H1[]
H2[]
H3[]
L0[]
L1[]
L2[]
L3[]
M0[]
M1[]
M2[]
M3[]
PERFepsilon
QUALepsilon
Tprod
```

```
END CONSTANTS


FUNCTIONS


MTBFws(I)  = SUM(i,1,R.length, R[i]*A0[i] + R[i]*A1[i] * I + R[i]*A2[i] * I^2 + R[i]*A3[i]
* I^3)

MTBFmt(I)  = SUM(i,1,R.length, R[i]*B0[i] + R[i]*B1[i] * I + R[i]*B2[i] * I^2 + R[i]*B3[i]
* I^3)

MTBFts(I)  = SUM(i,1,R.length, R[i]*C0[i] + R[i]*C1[i] * I + R[i]*C2[i] * I^2 + R[i]*C3[i]
* I^3)

MTBFtos(I) = SUM(i,1,R.length, R[i]*D0[i] + R[i]*D1[i] * I + R[i]*D2[i] * I^2 + R[i]*D3[i]
* I^3)

MTBF(I) = MAX{ MTBFws(I) , MTBFmt(I) , MTBFts(I) , MTBFtos(I) }

PERF(S) = Cref / S

hd(I,S) = HDref * I^2 / S


Fu1(I) = SUM(i,1,R.length, R[i]*E0[i] + R[i]*E1[i] * I + R[i]*E2[i] * I^2 + R[i]*E3[i] *
I^3)

Fu2(I,S) = SUM(i,1,R.length, R[i]*F0[i] + R[i]*F1[i] * hd(I,S) + R[i]*F2[i] * hd(I,S)^2
+ R[i]*F3[i] * hd(I,S)^3)

Fu3(I) = SUM(i,1,R.length, R[i]*G0[i] + R[i]*G1[i] * I + R[i]*G2[i] * I^2 + R[i]*G3[i] *
I^3)

Fu4(I,S) = SUM(i,1,R.length, R[i]*H0[i] + R[i]*H1[i] * hd(I,S) + R[i]*H2[i] * hd(I,S)^2
+ R[i]*H3[i] * hd(I,S)^3)

Fu1and3(I,S) = IF I <= 200 * hd(I,S) THEN Fu1(I) ELSE Fu3(I) END IF

Fu2and4(I,S) = IF 200 * hd(I,S) <= 100 THEN Fu2(I,S) ELSE Fu4(I,S) END IF

DPMwp(I,S) = Fu1and3(I,S) + Fu2and4(I,S)

Fu5(I) = SUM(i,1,R.length, R[i]*L0[i] + R[i]*L1[i] * I + R[i]*L2[i] * I^2 + R[i]*L3[i] *
I^3)

Fu6(I,S) = SUM(i,1,R.length, R[i]*M0[i] + R[i]*M1[i] * hd(I,S) + R[i]*M2[i] * hd(I,S)^2
+ R[i]*M3[i] * hd(I,S)^3)

DPMs(I,S) = Fu5(I) + Fu6(I,S)

DPM(I,S) = DPMwp(I,S) + DPMs(I,S)

QUAL(I,S) = 1 - DPM(I,S)/1000000

OEE(I,S) = MTBF(I) * PERF(S)

END FUNCTIONS


CONSTRAINTS

       PERF(S) >= (1 - PERFepsilon)

       PERF(S) <= (1 + PERFepsilon)

       MTBF(I) >= Tprod

END CONSTRAINTS
```

```
maximize OEE(I,S) -> http://www.crema-project.eu/ontology/wp8/tenneco.owl#OEE
END CLASS

INSTANCE

DOMAINS
    R[] {0,1}
   I [120.0,250.0]
   F [6.0,10.0]
   S [1.2,2.3]
END DOMAINS

VALUES
   Cref = 1.5
   HDref = 0.0003401
   PERFepsilon = 0.05
   QUALepsilon = 0.0075
   Tprod = 7.55

INPUT
A0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A0)
A1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A1)
A2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A2)
A3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A3)
B0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B0)
B1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B1)
B2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B2)
B3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B3)
C0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C0)
C1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C1)
C2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C2)
C3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C3)
D0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D0)
D1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D1)
D2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D2)
D3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D3)
E0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E0)
```

```
E1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E1)
E2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E2)
E3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E3)
F0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F0)
F1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F1)
F2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F2)
F3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F3)
G0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G0)
G1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G1)
G2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G2)
G3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G3)
H0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H0)
H1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H1)
H2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H2)
H3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H3)
L0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L0)
L1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L1)
L2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L2)
L3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L3)
M0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M0)
M1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M1)
M2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M2)
M3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M3)
END INPUT
END VALUES
END INSTANCE


OUTPUT
R[] :: ServiceTask_0ngkfqo
I            ->                        (ServiceTask_0ngkfqo,           http://www.crema-
project.eu/ontology/wp8/tenneco.owl#electricity)
F            ->                        (ServiceTask_0ngkfqo,           http://www.crema-
project.eu/ontology/wp8/tenneco.owl#wirespeed)
S            ->                        (ServiceTask_0ngkfqo,           http://www.crema-
project.eu/ontology/wp8/tenneco.owl#feedrate)
END OUTPUT


END PROBLEM
```

## 7.4 UC2-COP Solution in Process Service Plan

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?><bpmn:definitions
xmlns:bpmn="http://www.omg.org/spec/BPMN/20100524/MODEL"
xmlns:bpmndi="http://www.omg.org/spec/BPMN/20100524/DI"
xmlns:camunda="http://camunda.org/schema/1.0/bpmn"
xmlns:crema="http://crema.project.eu" xmlns:dc="http://www.omg.org/spec/DD/20100524/DC"
xmlns:di="http://www.omg.org/spec/DD/20100524/DI"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" id="Definitions_1"
targetNamespace="http://bpmn.io/schema/bpmn">
<bpmn:process id="Process_1" isExecutable="true">
<bpmn:extensionElements>
<crema:metadata>
<crema:optimization>
<crema:formulation>
PROBLEM
TYPE nonlinear single END TYPE
SOLVER both END SOLVER
CLASS
   VARIABLES
      R[]
      I
      F
      S
   END VARIABLES
   CONSTANTS
      A0[]
      A1[]
      A2[]
      A3[]
      B0[]
      B1[]
      B2[]
      B3[]
      C0[]
      C1[]
      C2[]
      C3[]
      D0[]
      D1[]
      D2[]
```

```
      D3[]
      Cref
      HDref
      E0[]
      E1[]
      E2[]
      E3[]
      F0[]
      F1[]
      F2[]
      F3[]
      G0[]
      G1[]
      G2[]
      G3[]
      H0[]
      H1[]
      H2[]
      H3[]
      L0[]
      L1[]
      L2[]
      L3[]
      M0[]
      M1[]
      M2[]
      M3[]
      PERFepsilon
      QUALepsilon
      Tprod
   END CONSTANTS


   FUNCTIONS
      MTBFws(I)  = SUM(i,1,R.length, R[i]*A0[i] + R[i]*A1[i] * I + R[i]*A2[i] * I^2 +
R[i]*A3[i] * I^3)
       MTBFmt(I)  = SUM(i,1,R.length, R[i]*B0[i] + R[i]*B1[i] * I + R[i]*B2[i] * I^2 +
R[i]*B3[i] * I^3)
       MTBFts(I)  = SUM(i,1,R.length, R[i]*C0[i] + R[i]*C1[i] * I + R[i]*C2[i] * I^2 +
R[i]*C3[i] * I^3)
```

```
       MTBFtos(I) = SUM(i,1,R.length, R[i]*D0[i] + R[i]*D1[i] * I + R[i]*D2[i] * I^2 +
R[i]*D3[i] * I^3)

      MTBF(I) = MAX{ MTBFws(I) , MTBFmt(I) , MTBFts(I) , MTBFtos(I) }

      PERF(S) = Cref / S

      hd(I,S) = HDref * I^2 / S

      Fu1(I) = SUM(i,1,R.length, R[i]*E0[i] + R[i]*E1[i] * I + R[i]*E2[i] * I^2 +
R[i]*E3[i] * I^3)

      Fu2(I,S) = SUM(i,1,R.length, R[i]*F0[i] + R[i]*F1[i] * hd(I,S) + R[i]*F2[i] *
hd(I,S)^2 + R[i]*F3[i] * hd(I,S)^3)

      Fu3(I) = SUM(i,1,R.length, R[i]*G0[i] + R[i]*G1[i] * I + R[i]*G2[i] * I^2 +
R[i]*G3[i] * I^3)

      Fu4(I,S) = SUM(i,1,R.length, R[i]*H0[i] + R[i]*H1[i] * hd(I,S) + R[i]*H2[i] *
hd(I,S)^2 + R[i]*H3[i] * hd(I,S)^3)

      Fu1and3(I,S) = IF I <= 200 * hd(I,S) THEN Fu1(I) ELSE Fu3(I) END IF

      Fu2and4(I,S) = IF 200 * hd(I,S) <= 100 THEN Fu2(I,S) ELSE Fu4(I,S) END IF

      DPMwp(I,S) = Fu1and3(I,S) + Fu2and4(I,S)

      Fu5(I) = SUM(i,1,R.length, R[i]*L0[i] + R[i]*L1[i] * I + R[i]*L2[i] * I^2 +
R[i]*L3[i] * I^3)

      Fu6(I,S) = SUM(i,1,R.length, R[i]*M0[i] + R[i]*M1[i] * hd(I,S) + R[i]*M2[i] *
hd(I,S)^2 + R[i]*M3[i] * hd(I,S)^3)

      DPMs(I,S) = Fu5(I) + Fu6(I,S)

      DPM(I,S) = DPMwp(I,S) + DPMs(I,S)

      QUAL(I,S) = 1 - DPM(I,S)/1000000


      OEE(I,S) = MTBF(I) * PERF(S)


   END FUNCTIONS


   CONSTRAINTS


      PERF(S) >= (1 - PERFepsilon)

      PERF(S) <= (1 + PERFepsilon)

      MTBF(I) >= Tprod


   END CONSTRAINTS

      maximize OEE(I,S) -> http://www.crema-project.eu/ontology/wp8/tenneco.owl#OEE


END CLASS


INSTANCE

   DOMAINS
```

```
      R[] {0,1}
      I [120.0,250.0]
      F [6.0,10.0]
      S [1.2,2.3]
   END DOMAINS
   VALUES
      Cref = 1.5
      HDref = 0.0003401
      PERFepsilon = 0.05
      QUALepsilon = 0.0075
      Tprod = 7.55

      INPUT
         A0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A0)
         A1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A1)
         A2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A2)
         A3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#A3)
         B0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B0)
         B1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B1)
         B2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B2)
         B3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#B3)
         C0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C0)
         C1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C1)
         C2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C2)
         C3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#C3)
         D0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D0)
         D1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D1)
         D2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D2)
         D3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#D3)
         E0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E0)
         E1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E1)
         E2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E2)
         E3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#E3)
         F0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F0)
         F1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F1)
         F2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F2)
         F3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#F3)
         G0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G0)
```

```
          G1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G1)
          G2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G2)
          G3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#G3)
          H0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H0)
          H1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H1)
          H2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H2)
          H3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#H3)
          L0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L0)
          L1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L1)
          L2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L2)
          L3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#L3)
          M0 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M0)
          M1 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M1)
          M2 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M2)
          M3 <- (ServiceTask_0ngkfqo, http://localhost/ontology/fake.owl#M3)


       END INPUT
   END VALUES
END INSTANCE


OUTPUT
   R[] :: ServiceTask_0ngkfqo
   I          ->                    (ServiceTask_0ngkfqo,          http://www.crema-
project.eu/ontology/wp8/tenneco.owl#electricity)
   F          ->                    (ServiceTask_0ngkfqo,          http://www.crema-
project.eu/ontology/wp8/tenneco.owl#wirespeed)
   S          ->                    (ServiceTask_0ngkfqo,          http://www.crema-
project.eu/ontology/wp8/tenneco.owl#feedrate)
END OUTPUT
END PROBLEM
</crema:formulation>


<crema:results><crema:log>COPSE2 meta -> COPSE2 transformation done.
JaCoP optimizer
precision = 1.0E-5
timeout occurred = false
I = 186.92
F = 10.0
S = 1.2
```

```
R = 1.0
</crema:log>
<crema:objective name="objective_1"><crema:value> 2.51 </crema:value></crema:objective>
<crema:dimension name="F"><crema:value> 10.0 </crema:value></crema:dimension>
<crema:dimension name="I"><crema:value> 186.92 </crema:value></crema:dimension>
<crema:dimension name="S"><crema:value> 1.2 </crema:value></crema:dimension>
</crema:results>
</crema:optimization>

<crema:implementation>
<crema:service implements="ServiceTask_0ngkfqo" seq="1">
<crema:abstractService>
<crema:marketplaceServiceID>91a5edb9-222d-4426-82c1-
27f8babda59e</crema:marketplaceServiceID>
</crema:abstractService>
<crema:concreteService origin="optimisation"><crema:marketplaceServiceID>9599b1d5-8f17-
4905-870c-
cdb09d59bf1c</crema:marketplaceServiceID><crema:owlsDescription>http://127.0.0.1:80/ode
ru/Service/9599b1d5-8f17-4905-870c-
cdb09d59bf1c.owl</crema:owlsDescription><crema:assignments/><crema:bindings><crema:bind
ing><crema:origin><crema:env/></crema:origin><crema:target><crema:variable name="Brs"
service="9599b1d5-8f17-4905-870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="Mt1" service="9599b1d5-8f17-4905-
870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="Pc1" service="9599b1d5-8f17-4905-
870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="Fr" service="9599b1d5-8f17-4905-870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="P1" service="9599b1d5-8f17-4905-870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="Ws" service="9599b1d5-8f17-4905-870c-
cdb09d59bf1c"/></crema:target></crema:binding><crema:binding><crema:origin><crema:env/>
</crema:origin><crema:target><crema:variable name="El" service="9599b1d5-8f17-4905-870c-
cdb09d59bf1c"/></crema:target></crema:binding></crema:bindings></crema:concreteService>
</crema:service></crema:implementation>
      </crema:metadata>
    </bpmn:extensionElements>
    <bpmn:startEvent id="StartEvent_1">
      <bpmn:outgoing>SequenceFlow_0ec9iz0</bpmn:outgoing>
    </bpmn:startEvent>
    <bpmn:serviceTask camunda:topic="CremaServiceExecution" camunda:type="external"
id="ServiceTask_0ngkfqo" name="EXECUTE an EXHAUST Process Welding">
      <bpmn:extensionElements>
```

```
        <crema:annotations>
          <crema:inputs>
            <crema:input>
              <crema:element                                    name=":Pc1">http://www.crema-
project.eu/DLP/UC2.owl#Production_Cell</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                     name=":P1">http://www.crema-
project.eu/DLP/UC2.owl#Parts</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                    name=":Mt1">http://www.crema-
project.eu/DLP/UC2.owl#Machine_Tools</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                    name=":Brs">http://www.crema-
project.eu/DLP/UC2.owl#batch_run_size</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                     name=":Ws">http://www.crema-
project.eu/DLP/UC2.owl#wirespeed</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                     name=":El">http://www.crema-
project.eu/DLP/UC2.owl#electricity</crema:element>
            </crema:input>
            <crema:input>
              <crema:element                                     name=":Fr">http://www.crema-
project.eu/DLP/UC2.owl#feedrate</crema:element>
            </crema:input>
          </crema:inputs>
          <crema:outputs>
            <crema:output>
              <crema:element                                    name=":Ex1">http://www.crema-
project.eu/DLP/UC2.owl#Exhaust</crema:element>
            </crema:output>
          </crema:outputs>
          <crema:preconditions>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#Welding_Robot
Wr)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#equips           Wr
Pc1)</crema:element>
```

```
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#Location
Lo)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#hasLocation      wr
Lo)</crema:element>
            <crema:element>(http://www.w3.org/2002/07/owl#sameAs  Lo1  http://www.crema-
project.eu/DLP/UC2.owl#UK)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#available
P1)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#loaded           Wr
P1)</crema:element>
          </crema:preconditions>
          <crema:effects>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#readyForTesting
Ex1)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#free
Wr)</crema:element>
            <crema:element>(http://www.crema-project.eu/DLP/UC2.owl#notAvailable
P1)</crema:element>
          </crema:effects>
        </crema:annotations>
      </bpmn:extensionElements>
      <bpmn:incoming>SequenceFlow_0ec9iz0</bpmn:incoming>
      <bpmn:outgoing>SequenceFlow_0ottifi</bpmn:outgoing>
    </bpmn:serviceTask>
    <bpmn:sequenceFlow        id="SequenceFlow_0ec9iz0"        sourceRef="StartEvent_1"
targetRef="ServiceTask_0ngkfqo"/>
    <bpmn:endEvent id="EndEvent_095l0ya">
      <bpmn:incoming>SequenceFlow_0ottifi</bpmn:incoming>
    </bpmn:endEvent>
    <bpmn:sequenceFlow     id="SequenceFlow_0ottifi"     sourceRef="ServiceTask_0ngkfqo"
targetRef="EndEvent_095l0ya"/>
  </bpmn:process>
  <bpmndi:BPMNDiagram id="BPMNDiagram_1">
    <bpmndi:BPMNPlane bpmnElement="Process_1" id="BPMNPlane_1">
      <bpmndi:BPMNShape bpmnElement="StartEvent_1" id="_BPMNShape_StartEvent_2">
        <dc:Bounds height="36" width="36" x="173" y="102"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="ServiceTask_0ngkfqo" id="ServiceTask_0ngkfqo_di">
        <dc:Bounds height="80" width="100" x="324" y="80"/>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_0ec9iz0" id="SequenceFlow_0ec9iz0_di">
        <di:waypoint x="209" xsi:type="dc:Point" y="120"/>
```

```
        <di:waypoint x="324" xsi:type="dc:Point" y="120"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="267" y="105"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
      <bpmndi:BPMNShape bpmnElement="EndEvent_095l0ya" id="EndEvent_095l0ya_di">
        <dc:Bounds height="36" width="36" x="505" y="102"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="523" y="138"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNEdge bpmnElement="SequenceFlow_0ottifi" id="SequenceFlow_0ottifi_di">
        <di:waypoint x="424" xsi:type="dc:Point" y="120"/>
        <di:waypoint x="505" xsi:type="dc:Point" y="120"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="0" width="0" x="465" y="95"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNEdge>
    </bpmndi:BPMNPlane>
  </bpmndi:BPMNDiagram>
</bpmn:definitions>
```