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Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation

D3.7 AI and Data-driven Supply Chain Optimisation M12

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Abbreviations

Acronym	Description
SCOPT	Supply Chain OPTimisation
SCDT	Supply Chain Digital Twin
LCA	Life Cycle Assessment
CO_2	Carbon dioxide
Json	JavaScript Object Notation

Executive Summary

The D3.7 *AI and Data-driven Supply Chain Optimisation* provides a description of the first stage of the Supply Chain OPTimisation (SCOPT) component. The first stage of the SCOPT development is mainly focused to the preliminary identification and validation of the performance of the tool in the manufacturing logistics as well as in the supply chain arrangements. This deliverable reports the activities undertaken until M12 under Task 3.4 *AI and Data-driven Supply Chain Optimisation* in order to provide a first complete release of the SCOPT as a Software-as-a-Service (SaaS) running at the servers of Cyprus University of Technology (CUT).

This deliverable presents an overview of the SCOPT with a description of the component and its main use in the CIRCULOOS platform. Furthermore, presents the interaction of the SCOPT component with the other components of the CIRCULOOS platform. Additionally, optimization problems for manufacturing logistics and supply chain have been presented to illustrate the implementation of the component and to validate the performance of the tool.

1 Introduction

1.1 Deliverable Purpose

The scope of the deliverable D3.7 "AI and Data-driven Supply Chain Optimisation" is to report the progress of the first stage in the development of the Supply Chain OPTimisation (SCOPT) component of the CIRCULOOS platform. The deliverable is the outcome of the efforts undertaken within the context of Task 3.4 "AI and Data-driven Supply Chain Optimisation".

The purpose of D3.7 is the presentation and the description of SCOPT component. The deliverable provides an analysis of the functionality and capabilities of the module.

1.2 Positioning within the Project

The deliverable D3.7 is the outcome of the efforts undertaken within the context of Task 3.4 "AI and data-driven supply chain optimisation". The deliverable D3.7 is devoted to describe the first stage in the development of Supply Chain OPTimisation (SCOPT) component at M12, within the second one at M24, deliverable D3.8 AI and Data-driven supply chain, where machine learning techniques will be integrated to enhance the proposed methodology with a predictive analytics module based on the system model and data.

1.3 Deliverable Structure

The deliverable is organized as follows:

i. In section 1, the purpose of the deliverable, the positioning with the CIRCULOOS Project and the related structure is presented.
ii. In section 2, the SCOPT component is defined, the architecture of the tool is presented, the connection of the tool with the components of the CIRCULOOS platform is described and manufacturing logistics and supply chain problems are detailed presented.
iii. Section 3 outlines the activities undertaken in the first stage of the SCOPT development as well as the upcoming activities to proceed with the advanced development of the SCOPT in the second stage.

2 Supply Chain OPTimisation (SCOPT)

2.1 Definition of SCOPT component

The Supply Chain OPTimisation (SCOPT) is a tool for the manufacturing logistics and supply chain optimisation problems developed by Cyprus University of Technology (CUT) based on the SPECTER task planner[1]. Automated task planning is a core technology in Artificial Intelligence and is implemented in this tool by leveraging the SPECTER task planner, to provide global (i.e. between the factories and suppliers) and local (within the factory) supply chain arrangements, with optimality properties when feasible. The component is provided as Software-as-a-Service (SaaS) module which leverages a model-based approach to:

i. analyze the intra-factory manufacturing logistics and resources availability,
ii. determine alternative supply chain arrangements
iii. provide optimisation results of the current processes

To feed the supply chain process orchestration and execution tool (SCPO). The SCOPT builds on the SPECTER task planner, that builds on the BPO component[2,3] which was developed and evolved by the EU Projects L4MS and BETTER FACTORY. SCOPT will increase the reusability and scalability of SPECTER and CIRCULOOS will offer it, through the SCOPT tool, under an SaaS framework.

2.2 Overview of SCOPT component architecture

The Supply Chain OPTimisation is a tool that yields optimal (or optionally sub-optimal) results for intra-factory manufacturing logistics as well as for supply chain arrangements.

From the factory aspect, the SCOPT tool creates an abstraction model of the workflow, using the model of the current manufacturing workflow, to provide optimal results based on the available resources and processes according to sustainability and circularity performance of products and processes in manufacturing considering all stages of the life cycle. The life cycle stages include production, use, and disposal, as well as the energy and materials used at each stage.

From the supply chain aspect, the SCOPT tool creates an abstraction model of the supply chain arrangements, including individuals and factories that are involved in creating or recycling a product, so as to provide optimal results considering the availability of the suppliers, resources, products as well as the life cycle stages.

Apart from optimisation results, the SCOPT can be utilized to determine data driven abstractions of the factory or the supply chain in order to produce optimal arrangement (at both the factory and the supply chain levels) recommendations. This provides the capability to the production manager of the factory to test different scenarios utilizing the SCDT tool before any change is made in the factory arrangement. This is part of the second state of development of the SCOPT tool.

[1] A. A. Tziola and S. G. Loizou, "Autonomous task planning for heterogeneous multi-agent systems," in 2023 IEEE International Conference on Robotics and Automation (ICRA), pp. 3490–3496, 2023.
[2] https://betterfactory.eu/apps/bpo/
[3] https://opil-documentation.readthedocs.io/en/latest/BPO/Getting_started.html

2.3 Connection with CIRCULOOS platform

The SCOPT will interact with Supply Chain Digital Twin (SCDT) and GREen TArgets (GRETA) tools in order to retrieve data for the factory and supply chain models as well as the Life Cycle Assessment (LCA) indicators of product, processes, production lines or factories. The interaction of the SCOPT with the components of the CIRCULOOS platform is illustrated in the Figure 1.

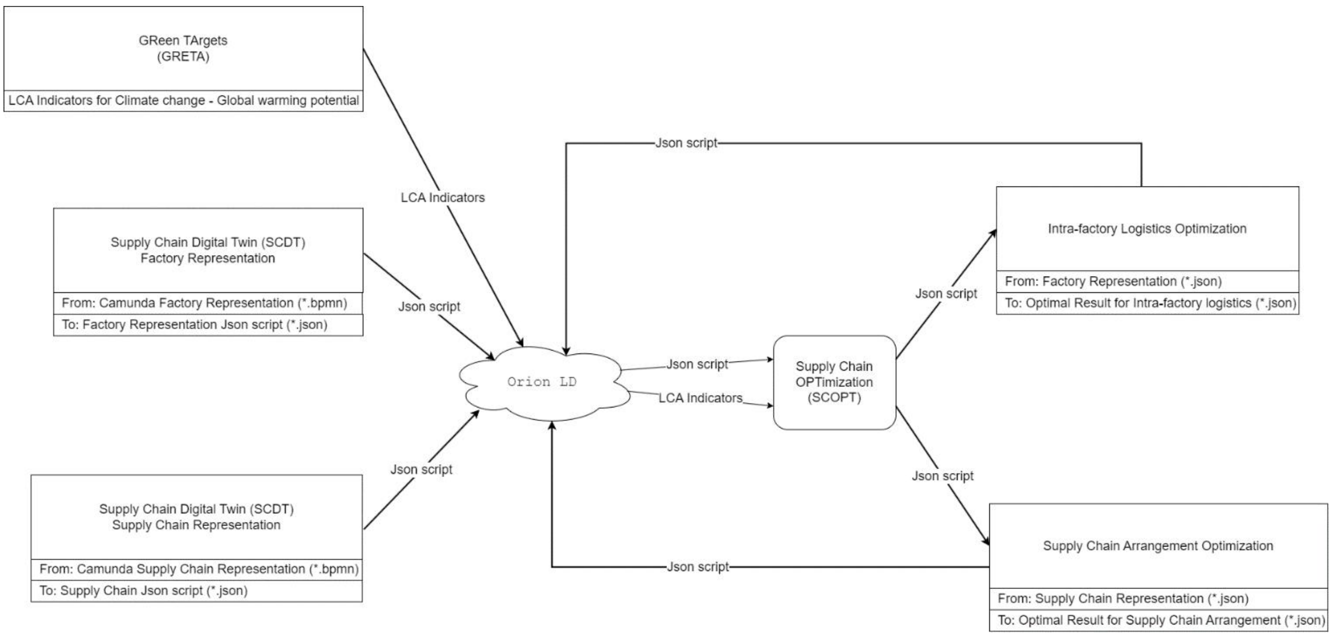

Figure 1: Data Feed Connection with SCOPT.

The SCDT provides a simulation of a factory workflow and a collection of factories as well as the interaction among them. The GRETA tool provides the LCA indicators of products, processes and factories. The SCOPT requires a model of the factory workflow or the model of the supply chain in order to provide optimisation results using the LCA costs.

The SCDT component provides the representation of the factories in the format of a Json script. The GRETA component provides the LCA metrics for climate change and global warming potential of products/processes/factories. The SCOPT calculates the optimal sequence of factory processes or the optimal supply chain arrangement to produce a product using the LCA indicators.

2.4 Manufacturing Logistics Optimisation

Manufacturing logistics optimisation ensures the improvement and effectiveness of overall business performance and the cost reduction through manufacturing operations. The SCOPT component formulates the manufacturing logistics optimisation problems as mathematical models to maximize or minimize specified objectives. This section presents the description of the SCOPT procedure to yield optimisation results using a non-trivial part of a manufacturing workflow of a plastic manufacturing industry as shown in Figure 2.

In this case, the processes of the manufacturing workflow of a hypothetical Factory X[4] are depicted in pink blocks. Each process could be associated with energy cost and/or CO_2 emissions. The materials/products in red blocks indicate the non-recycled products which are obtained from another supplier. The materials/products in green blocks indicate the material/products produced by other factories from recycling scrap, such as pellet produced by Factory A with recycled grains. Each process has ingoing and outgoing arrows indicating the input and output materials/products, respectively. The outgoing green arrows indicate the scrap produced from each process, while the outgoing black arrows indicate the produced material/product of each process.

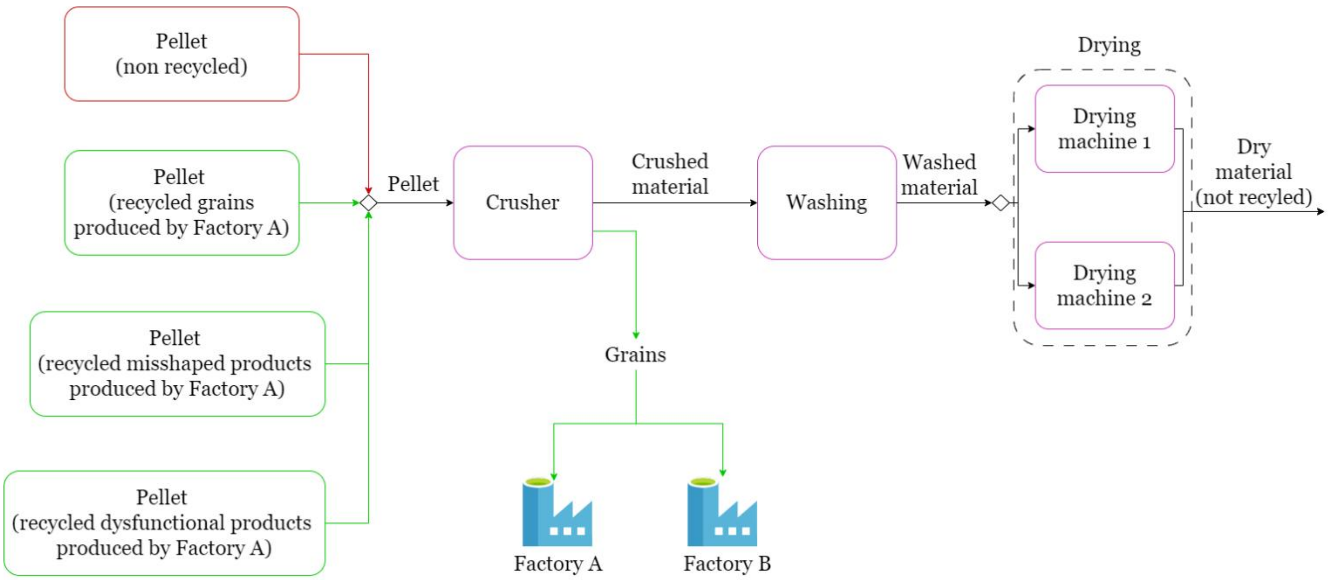

Figure 2: A part of a manufacturing workflow of a plastic manufacturing industry (Factory X).

Through the SCDT, the factory representation is developed. The data representation is converted to a Json script that is uploaded to the Orion LD server as shown in Figure 3. Using the factory presentation provided by SCDT, the abstraction of the factory workflow is constructed as follows.

[4] The process is partly motivated by the example of Thermolympics plastic factory but appropriately extended to demonstrate the capabilities of the tool.

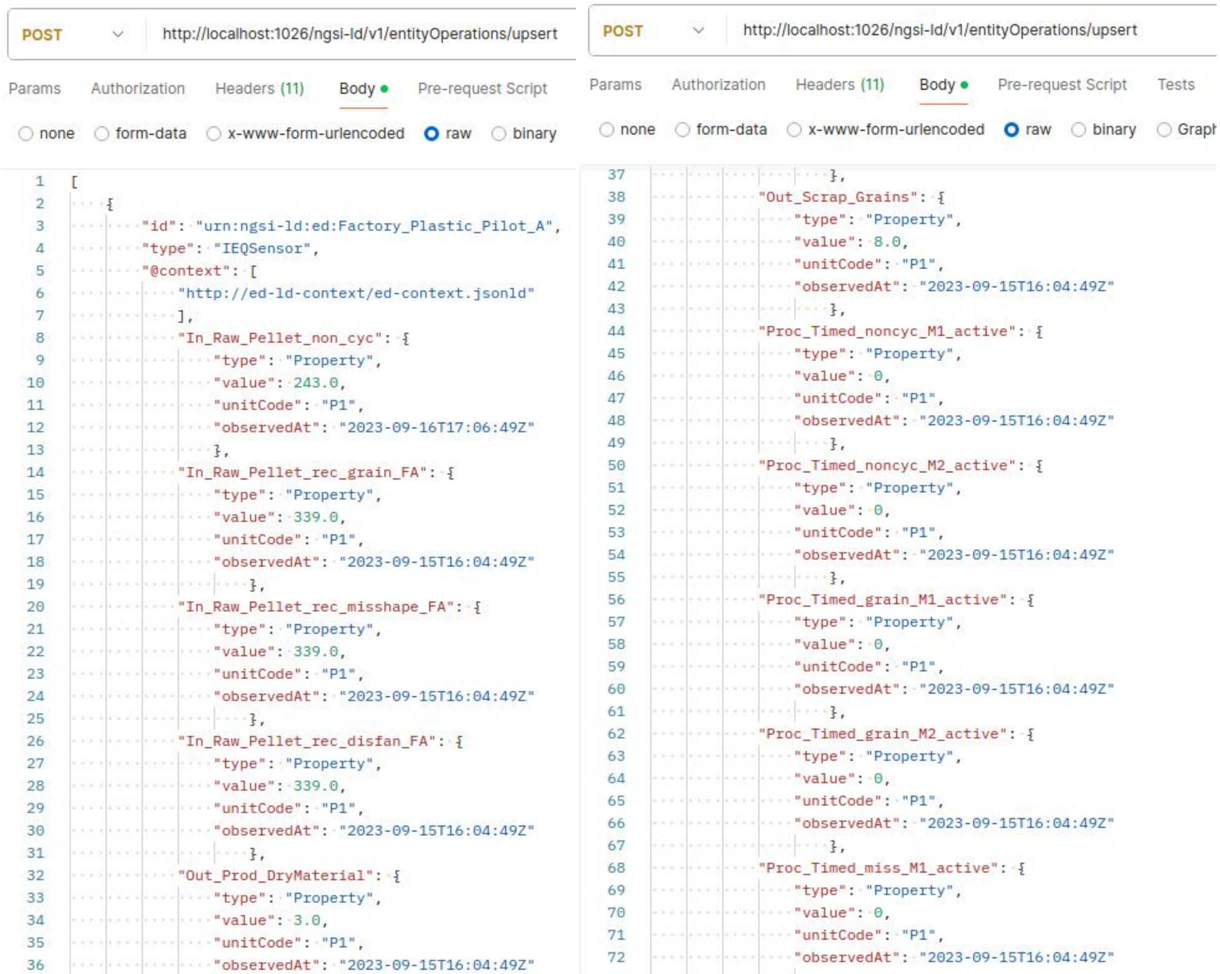

Figure 3: Factory representation in json script uploaded to the Orion LD.

2.4.1 Abstraction model of the manufacturing workflow

To be able to model the process an appropriate abstraction needs to be determined (for more on the implementation/theoretical aspects see here[5,6]. For the needs of CIRCULOOS and of the current deliverable, also based on the interaction with D3.3, a generic abstraction is implemented where a factory is abstracted by its inputs, processes and outputs (and their interconnections).

Using the factory representation json script provided by SCDT through the Orion LD, the SCOPT creates the abstraction of the manufacturing workflow as shown in Table 1. The abstraction model of the workflow, called "Environment model", is provided in a json file with 7 entities: "Areas of interest", "Agents", "Capabilities", "Constraints", "Inter-Agent Capabilities", "Inter-Agent Constraints", "Current Positions", "Goal Positions".

[5] Anatoli A. Tziola, S. G. L., 2024. Discrete Abstractions for Manufacturing Logistics Optimization for the Food Service Industry. Valletta, MALTA.
[6] Anatoli A. Tziola, S. G. L., 2024. Manufacturing Logistics Optimization using the SPECTER Task Planner: A Shoe Manufacturing Logistics Case Study. Rimini, ITALY.

The “Areas of interest” entity defines the processes, the buffer zones, the factories or any other possible area that a product could be. The “Agents” entity defines the materials, products, scrap and any other entity that is used and produced in the factory or exchanged in the supply chain. The “Capabilities” entity defines the individual capabilities of each agent. The “Constraints” entity defines the individual constraints of each agent. The “Inter-Agent Capabilities” defines the capabilities that emerge when multiple agents are present, i.e. moving an item, cooperation of machines to produce a product, multiple materials used by a machine to produce another product. The “Inter-Agent Constraints” entity defines the constraints that emerge when multiple agents are present, i.e. multiple materials are not allowed to be transported in a specific location at the same time, multiple machines are not allowed to operate simultaneously. The “Current Positions” entity defines the starting position of each agent at the time when the scenario is running. The “Goal Positions" defines the objective stating the goal position of the agents. If there is a change in the workflow, then the abstraction model should be modified accordingly. Otherwise, the “Current position” and the “Goal position” are changed based on the objective of each scenario, while the rest of the entities remain unchanged.

The cost is related to the CO_2 emissions per 1 unit of a specific product. For these case studies, the costs have been set approximately to present the capabilities of the SCOPT tool and validate its performance. In the second stage of the SCOPT development, these costs will be obtained from the GRETA tool through the Orion LD. The individual and inter-agent capabilities and constraints are defined based on the capabilities and constraints of the workflow.


```
{
 "Environment": {
  "Areas of interest": {
   "Name": [ "Crusher", "Washing", "Drying_machine_1", "Drying_machine_2" ],
   "Number": [ 1,          2,          3,                  4  ]
  },
  "Agents": {
   "pellet_nr": [ 0, 1 ],
   "pellet_bygrains": [ 0, 1 ],
   "pellet_byshapedpr": [ 0, 1 ],
   "pellet_bydysfpr": [ 0, 1 ],
   "crushed_material": [ 0, 1, 2 ],
   "grains": [ 0, 1 ],
   "washed_material": [ 0, 2, 3, 4 ],
   "dry_material_nr": [ 0, 3, 4 ]
  }
 },
 "Capabilities": {
  "pellet_nr": {
   "0": { "1":30 },
   "1": { "0":1 }
  },
  "pellet_bygrains": {
   "0": { "1":12 },
   "1": { "0":1 }
  },
  "pellet_byshapedpr": {
   "0": { "1":11 },
```

```
    "1": { "0":1 }
   },
   "pellet_bydysfpr":     {
    "0": { "1":13 },
    "1": { "0":1 }
   },
   "grains": {
    "1": { "0":1 }
   },
   "crushed_material": {
    "2": { "0":1 }
   },
   "washed_material": {
    "3": { "0":1 },
    "4": { "0":1 }
   },
  "Constraints": {
   "crushed_material": {
    "2":  [ 1 ]
   },
   "washed_material": {
    "3":  [ 2 ],
    "4":  [ 2 ]
   }
  },
  "Inter-Agent Capabilities": {
   "1": {
    "cost":[21],
    "pellet_nr": [ 1, 1 ],
    "crushed_material": [ 0, 1 ],
    "grains": [ 0, 1 ]
   },
   "2": {
    "cost":[12],
    "pellet_bygrains": [ 1, 1 ],
    "crushed_material": [ 0, 1 ],
    "grains": [ 0, 1 ]
   },
   "3": {
    "cost":[11],
    "pellet_byshapedpr": [ 1, 1 ],
    "crushed_material": [ 0, 1 ],
    "grains": [ 0, 1 ]
   },
   "4": {
    "cost":[13],
    "pellet_bydysfpr": [ 1, 1 ],
    "crushed_material": [ 0, 1 ],
    "grains": [ 0, 1 ]
   },
   "5": {
```

```
    "cost":[10],
    "crushed_material": [ 1, 2 ],
    "washed_material": [ 0, 2 ]
   },
   "6": {
    "cost":[12],
    "washed_material": [ 2, 3 ],
    "dry_material_nr": [ 0, 3 ]
   },
   "7": {
    "cost":[14],
    "washed_material": [ 2, 4 ],
    "dry_material_nr": [ 0, 4 ]
   }
  },
  "Inter-Agent Constraints": {
   "1": {
    " pellet_nr":  [ 1, 1 ],
    " pellet_bygrains":  [ 1, 1 ],
    " pellet_byshapedpr": [ 1, 1 ],
    " pellet_bydysfpr": [ 1, 1 ]
   }
 },
  "Current positions": {
    "pellet_nr": [ 0 ],
    "pellet_bygrains": [ 0 ],
    "pellet_byshapedpr": [ 0 ],
    "pellet_bydysfpr": [ 0 ],
    "crushed_material": [ 0 ],
    "grains": [ 0 ],
    "washed_material": [ 0 ],
    "dry_material_nr": [ 0 ]
  },
  "Goal positions": {
    "pellet_nr": [ 0 ],
    "pellet_bygrains": [ 0 ],
    "pellet_byshapedpr": [ 0 ],
    "pellet_bydysfpr": [ 0 ],
    "crushed_material": [ 0 ],
    "grains": [ 0 ],
    "washed_material": [ 0 ],
    "dry_material_nr": [ 3 ]
  }
}
```


Table 1: Abstraction model of the manufacturing workflow.

The break-down explanation of the abstraction model of Factory X of Table 1 follows.

The “Areas of interest” shown in Table 2 presents the possible positions that a material or a product could be. The processes of the factory are considered as areas of interest in this scenario and they are associated with a unique number. For example, the “Crusher” process is indicated with the number “1”.

```
"Areas of interest": {
    "Name": [ "Crusher", "Washing", "Drying_machine_1", "Drying_machine_2" ],
    "Number": [ 1,             2,             3,             4  ]
},
```

Table 2: Areas of interest of Factory X.

All materials and products utilized and produced in the factory are considered as agents. Using the numbering of the areas of interest, the possible positions of each agent are defined representing the state space of each agent. The agents considered, shown in Table 3, are the "pellet_nr" represents the pellet produced by non-recycled products, the "pellet_bygrains" represents the pellet produced by recycled grains, the "pellet_byshapedpr" represents the pellet produced by recycled misshaped products, the "pellet_bydysfpr" represents the pellet produced by recycled dysfunctional products, the "crushed material" represents the output product of crusher process, the "grains" represents the scrap of the crusher process, the "washed_material" represents the output of the washing process, the "dry_material_nr" represents the final product produced by drying process using either drying machine 1 or drying machine 2. The position "0" denotes that there is not any available unit of an agent or the product is not produced yet. An example of an agent's state space is that the "crushed_material" could be transported/utilized to/in the crusher machine or to/in the washing machine or it could not be available (i.e. resources fully consumed).

```
  "Agents": {
    "pellet_nr": [ 0, 1 ],
    "pellet_bygrains": [ 0, 1 ],
    "pellet_byshapedpr": [ 0, 1 ],
    "pellet_bydysfpr": [ 0, 1 ],
    "crushed_material": [ 0, 1, 2 ],
    "grains": [ 0, 1 ],
    "washed_material": [ 0, 2, 3, 4 ],
    "dry_material_nr": [ 0, 3, 4 ]
  },
```

Table 3: Agents of Factory X and agents' state space.

The "Capabilities" entity defines the individual possible transitions of agents derived from the agents' state space. A part of agents' capabilities is shown in Table 4. For example, the Factory X is able to purchase units of "pellet_nr" producing 30kg of CO_2 emissions per unit of "pellet_nr". The "crushed_material" is utilized producing 1kg of CO_2 emissions per unit of "crushed_material".

```
 "Capabilities": {
  "pellet_nr": {
   "0": { "1":30 },
   "1": { "0":1 }
  },
<...>
  "crushed_material": {
   "2": {"0":1 }
  },
<...>
},
```

Table 4: A part of agents' capabilities of Factory X.

The "Constraints" entity, shown in Table 5, defines the individual prohibited transitions of agents that are not allowed to be implemented in the factory. For example, the "crushed_material" is not allowed to be transported at the crusher machine; and the "washed_material" is not allowed to be used as input product of washing process, since it is already washed.

```
  "Constraints": {
    "crushed_material": {
      "2":  [ 1 ]
    },
    "washed_material": {
      "3":  [ 2 ],
      "4":  [ 2 ]
    }
},
```

Table 5: Agents' constraints of Factory X.

The "Inter-Agent Capabilities" enable transitions conditioned on multiple agents, at a time instant with a specific cost per each transition. As shown in Table 6, for example, in the inter-agent capability "1", the "pellet_nr" can be used as input in the crusher machine to produce the output "crushed_material" producing 21kg of CO_2 per unit of crushed material. Also, this process produces the "grains" scrap. In the inter-agent capability "6", the "washed_material" is used as input of drying machine 1 to produce the final product, the "dry_material_nr". This process produces 12kg of CO_2 per unit of "dry_material_nr". In the inter-agent capability "7", the "washed_material" is used as input of drying machine 2 to produce the "dry_material_nr". This process produces 14kg of CO_2 per unit of "dry_material_nr".

```
  "Inter-Agent Capabilities": {
    "1": {
      "cost":[21],
      "pellet_nr": [ 1, 1 ],
      "crushed_material": [ 0, 1 ],
      "grains": [ 0, 1 ]
    },
<...>
    "6": {
      "cost":[12],
      "washed_material": [ 2, 3 ],
      "dry_material_nr": [ 0, 3 ]
    },
    "7": {
      "cost":[14],
      "washed_material": [ 2, 4 ],
      "dry_material_nr": [ 0, 4 ]
    }
},
```

Table 6: A part of inter-agent capabilities of Factory X.

The "Inter-Agent Constraints" disable transitions of multiple agents simultaneously at a time instant. As shown in Table 7, for example, the inter-agent constraint "1" determines that the "pellet_nr", "pellet_bygrains", "pellet_byshapedpr", "pellet_bydysfpr" can not be used simultaneously as input in the crusher machine.

```
 "Inter-Agent Constraints": {
  "1": {
   " pellet_nr":  [ 1, 1 ],
   " pellet_bygrains":  [ 1, 1 ],
   " pellet_byshapedpr": [ 1, 1 ],
   " pellet_bydysfpr": [ 1, 1 ]
  }
},
```

Table 7: A part of inter-agent constrains of Factory X.

The current positions of the agents are considered as shown in Table 8. More specifically, the position of all agents is "0" since it is considered that none of them has been already produced or purchased.

```
 "Current positions": {
   "pellet_nr": [ 0 ],
   "pellet_bygrains": [ 0 ],
   "pellet_byshapedpr": [ 0 ],
   "pellet_bydysfpr": [ 0 ],
   "crushed_material": [ 0 ],
   "grains": [ 0 ],
   "washed_material": [ 0 ],
   "dry_material_nr": [ 0 ]
 },
```

Table 8: Current positions of agents in Factory X.

The objective of the presented use-case is to produce 1 unit of the final product, the "dry_material_nr" utilizing non-recycled pellet or recycled pellet. The objective, shown in Table 9, states that produce "dry_material_nr". The positions of the rest of the agents are set to "0" in order to define that these agents is not mandatory to be defined.

```
 "Goal positions": {
   "pellet_nr": [ 0 ],
   "pellet_bygrains": [ 0 ],
   "pellet_byshapedpr": [ 0 ],
   "pellet_bydysfpr": [ 0 ],
   "crushed_material": [ 0 ],
   "grains": [ 0 ],
   "washed_material": [ 0 ],
   "dry_material_nr": [ 3 ]
 }
```

Table 9: Goal position of agents to produce the final product in Factory X.

Using the environment model of Table 1 that represents the abstraction model of the manufacturing workflow, 2 different scenarios are investigated presented in sections 2.4.2 and 2.4.3. The objective is to find the optimal sequence of actions and the required resources in order to produce the final product, the dry material, utilizing a type of recycled pellet as presented in section 2.4.2 or non-recycled pellet as presented in section 2.4.3.

2.4.2 Use-case I: Produce final product utilizing non-recycled products

In the first scenario, the optimal sequence of actions to produce the final product is investigated utilizing the non-recycled pellet material. Using the abstraction model of Table 1, the optimal solution computed by SCOPT is presented in Table 11. The result contains 3 entities: the "path", the "cost" of each transition, and the "totalcost" to implement the solution.

The solution computed by SCOPT is presented in Table 11, where the "path" entity shows the steps required to fulfil the objective, the total cost specifies the CO_2 emissions produced utilizing the solution and the "cost" entity provides the CO_2 emission cost for each step. More specifically, the objective is fulfilled in 7 steps and the total CO_2 emissions to implement the solution is 47kg CO_2 per 1 unit of produced dry material.

The "path" entity is a list of lists containing the positions of each agent at any time instant until the objective is fulfilled. Each list contains as many elements as there are the agents that have been considered. Each element of the list is a projection of the position of a specific agent. For example, the 1st step "[0, 0, 0, 0, 0, 0, 1, 0]" presents the starting positions of the agents as they are defined in the "Current positions" entity of the abstraction in Table 8. The projection of elements in each list is as shown in Table 10.

crushed_ material	dry_material _nr	grains	pellet_by dysfpr	pellet_by grains	pellet_by shapedpr	pellet_nr	washed_ material
1st element	2nd element	3rd element	4th element	5th element	6th element	7th element	8th element

Table 10: Agents' projection.

Using the agents' projection of Table 10, the result computed by SCOPT is "translated" as follows (see Figure 4 and Figure 5): The objective is fulfilled in 7 steps while the CO_2 emissions to implement the proposed solution are 47kg per unit of dry material. In words, in the 1st step, the non-recycled pellet is utilized as input in the crusher machine. In the 2nd step, the crushed material and scrap grains is produced by crusher machine utilizing non-recycled pellet producing 21kg of CO_2 per unit of crushed material. In the 3rd step, the crushed material is used as input in the washing machine. In the 4th step, the washed material is produced while the crushed material is fully utilized. In the 5th step, the scrap "grains" is transported to another factory for recycling. In the 6th step, there is not any non-recycled pellet left in the factory. In the 7th step, the dry material has been produced by drying machine 3, while in the 8th step shows that the washed material is fully consumed.

{
"costs" :
[21, 10, 1, 1, 1, 12, 1],
"path" :

[
[0, 0, 0, 0, 0, 0, 1, 0],
[1, 0, 1, 0, 0, 0, 1, 0],
[2, 0, 1, 0, 0, 0, 1, 2],
[0, 0, 1, 0, 0, 0, 1, 2],
[0, 0, 0, 0, 0, 0, 1, 2],
[0, 0, 0, 0, 0, 0, 0, 2],
[0, 3, 0, 0, 0, 0, 0, 3],
[0, 3, 0, 0, 0, 0, 0, 0]
],
"totalcost" : 47
}

Table 11: SCOPT result utilizing pellet produced non-recycled materials.

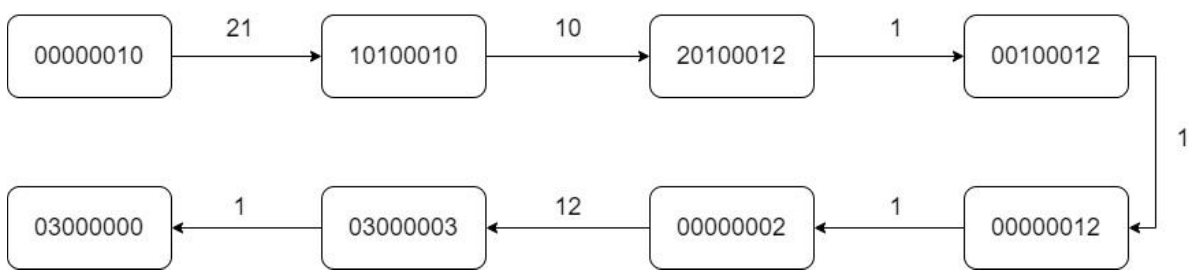

Figure 4: Solution of use-case I.

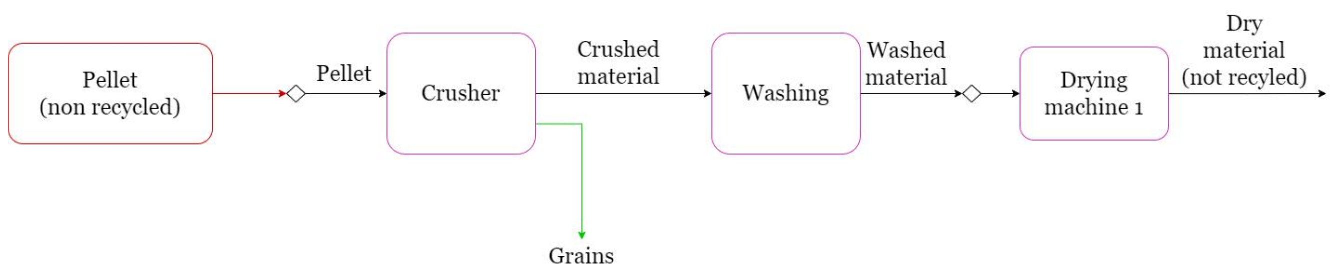

Figure 5: Factory arrangement based on the solution of use-case I.

The results are provided in a Json script and it is uploaded to the Orion LD as shown in Figure 6. In the second stage of the SCOPT development, the SCOPT will be integrated with SCDT so that the SCDT will simulate the sequence of actions that need to be performed in the factory to fulfill the given objective (i.e. produce a final product using (non-)recycled materials).

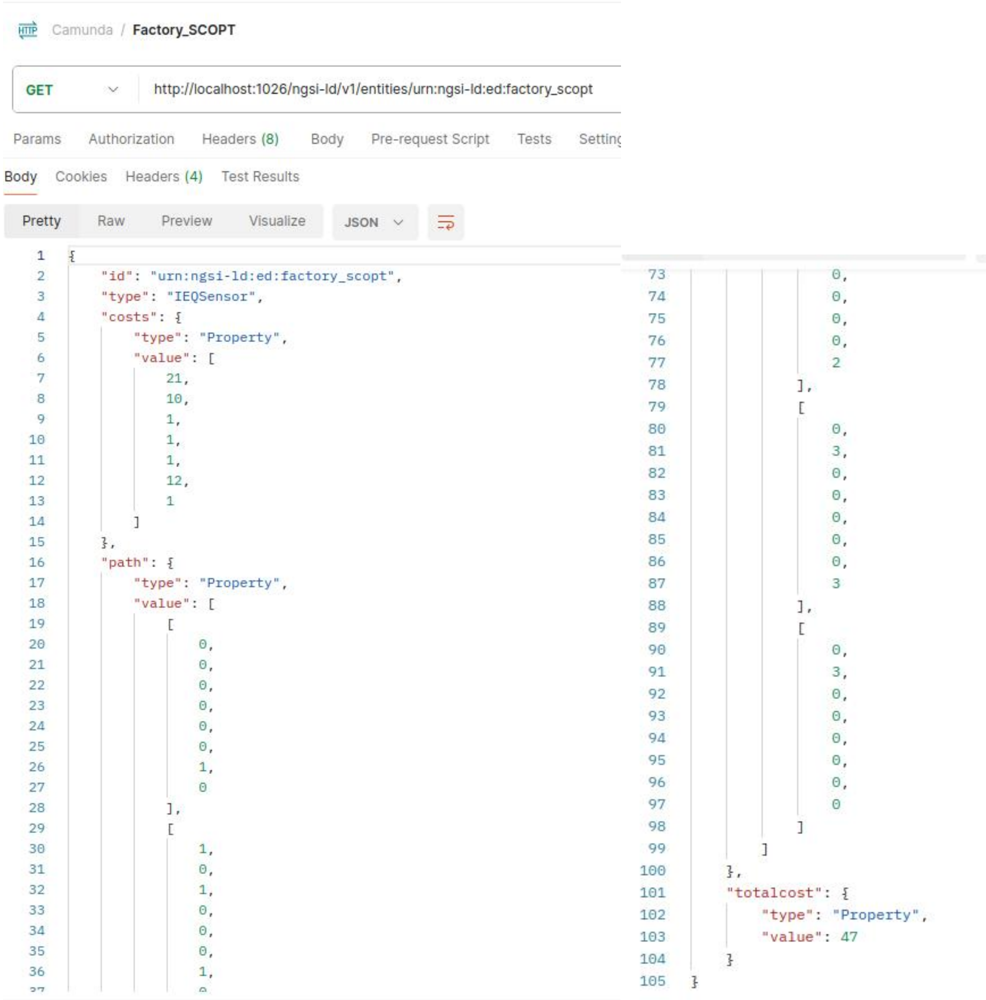

Figure 6: SCOPT results published in Orion LD showing the solution for the use-case I, utilizing pellet produced by non-recycled materials, for the production of the final product.

2.4.3 Use-case II: Produce final product utilizing recycled products

In the second scenario, the optimal sequence of actions to produce the final product is investigated utilizing pellet produced using recycled materials. In the first scenario, the optimal sequence of actions to produce the final product is investigated utilizing the non-recycled pellet material. Using the abstraction model of Table 1, the optimal solution computed by SCOPT is presented in Table 12. More specifically, the objective is fulfilled in 7 steps and the total CO_2 emissions to implement the solution is 39kg CO_2 per 1 unit of produced dry material.

Using the agents' projection table of Table 10, the result computed by SCOPT is "translated" as follows (see Figure 7 and Figure 8): In words, in the 1st step, the pellet produced by recycled misshaped products is utilized as input in the crusher machine. In the 2nd step, the crushed material is produced by crusher machine produced 10kg of CO_2 per unit of crushed material, while the scrap grains is produced. In the 3rd step, the crushed material is utilized as input in the washing machine to produce the washed material in the 4th step. In the 5th step, grains are transported to another factory for recycling, while in the 6th step the pellet produced by recycled misshaped product has been fully consumed. In the 7th step, the dry material has been produced by drying machine 4, while in the 8th step shows that the washed material is fully consumed.


```
{
    "costs" :
    [ 11, 10, 1, 1, 1, 14, 1 ],
    "path" :
    [
        [ 0, 0, 0, 0, 0, 1, 0, 0 ],
        [ 1, 0, 1, 0, 0, 1, 0, 0 ],
        [ 2, 0, 1, 0, 0, 1, 0, 2 ],
        [ 0, 0, 1, 0, 0, 1, 0, 2 ],
        [ 0, 0, 0, 0, 0, 1, 0, 2 ],
        [ 0, 0, 0, 0, 0, 0, 0, 2 ],
        [ 0, 4, 0, 0, 0, 0, 0, 4 ],
        [ 0, 4, 0, 0, 0, 0, 0, 0 ]
    ],
    "totalcost" : 39
}
```


Table 12: SCOPT results utilizing pellet produced using recycled materials.

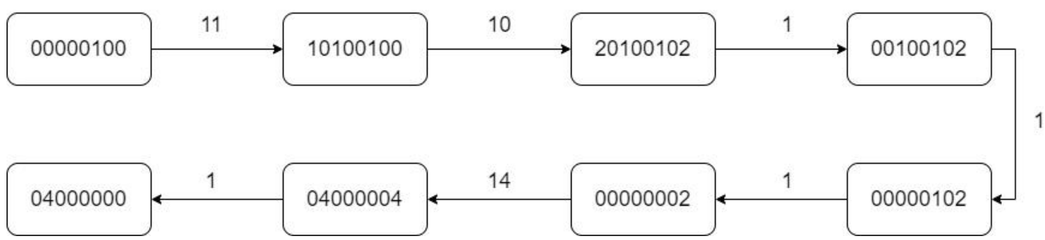

Figure 7: Solution of Use-Case II.

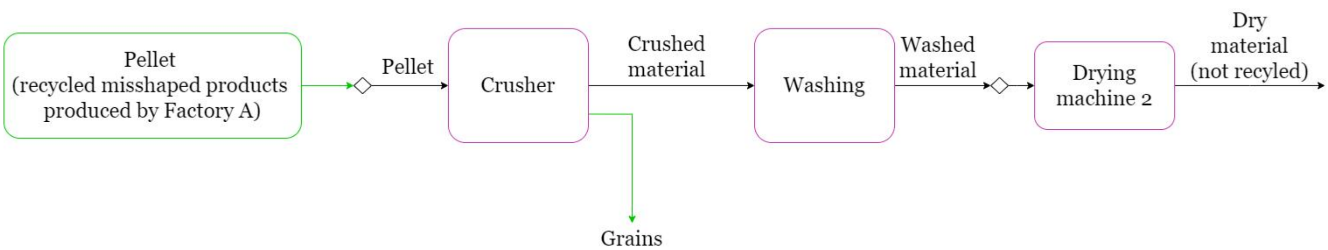

Figure 8: Factory arrangement based on the solution of use-case II.

The results are provided in a Json script and it is uploaded to Orion LD as shown in Figure 9. In the second stage of the SCOPT development, the SCOPT will be integrated with SCDT so that the SCDT will simulate the sequence of actions that need to be performed in the factory to fulfill the given objective (i.e. produce a final product using recycled materials).

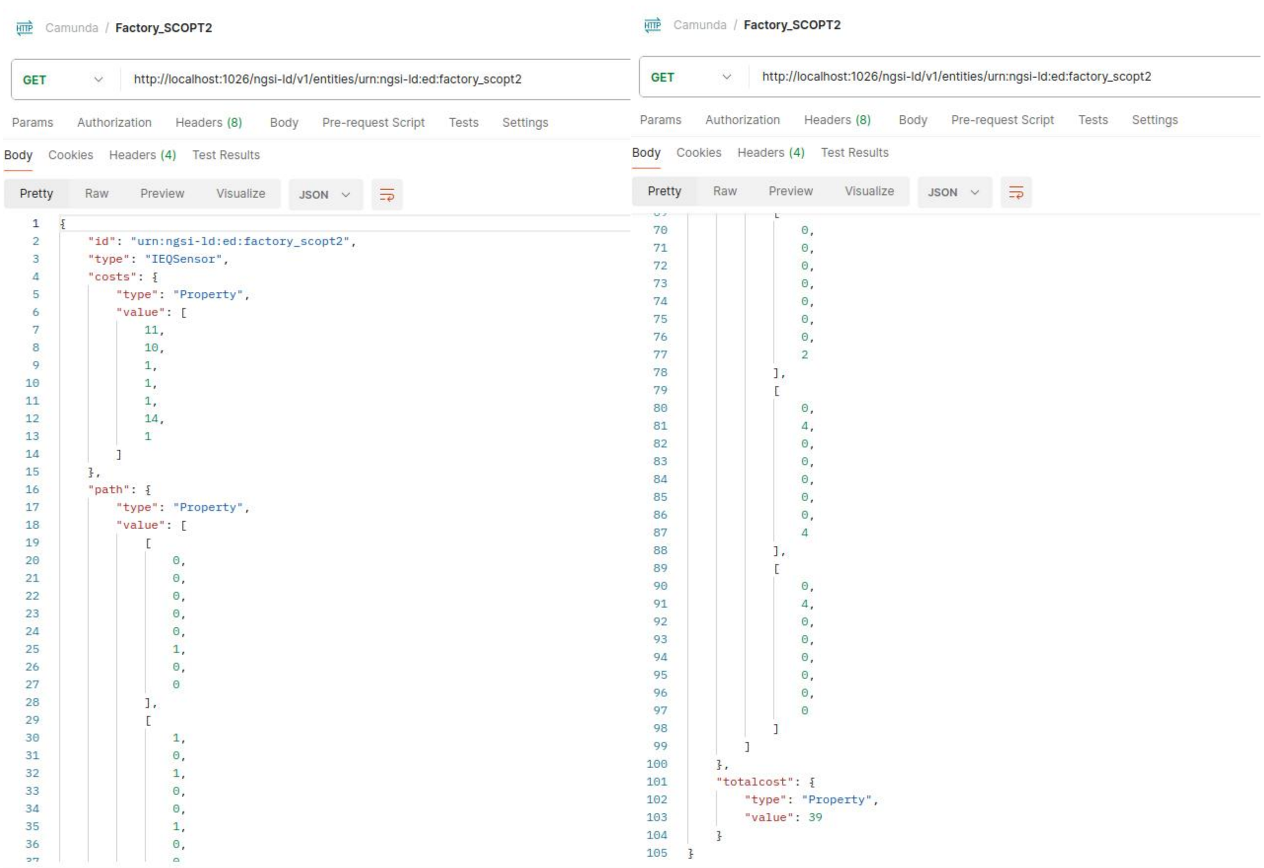

Figure 9: SCOPT results published in Orion LD showing the solution for the use-case II, utilizing pellet produced by recycled materials, for the production of the final product.

2.5 Supply Chain Arrangement Optimisation

Supply chain optimisation ensures the improvement and effectiveness of overall business performance and the cost reduction through the suppliers. The SCOPT component formulates the supply chain optimisation problems as mathematical models to maximize or minimize specified objectives in the supply chain. This section presents the description of the SCOPT procedure to yield optimisation results using an non trivial example of a supply chain as shown in Figure 10 to illustrate the interconnections and the interaction between the factories in the supply chain.

In this case, the interaction between 3 factories is presented showing the input/output products/scraps from each factory. The Factory X produces the 2 types of scraps: the grains and the misshaped products. The Factory B produces 1 type of scrap: the dysfunctional products. The Factory A receives the scraps produced by Factory X and Factory B to produce pellet from recycled products. The pellet units produced by Factory A are transported to Factory A and Factory B for production of other products.

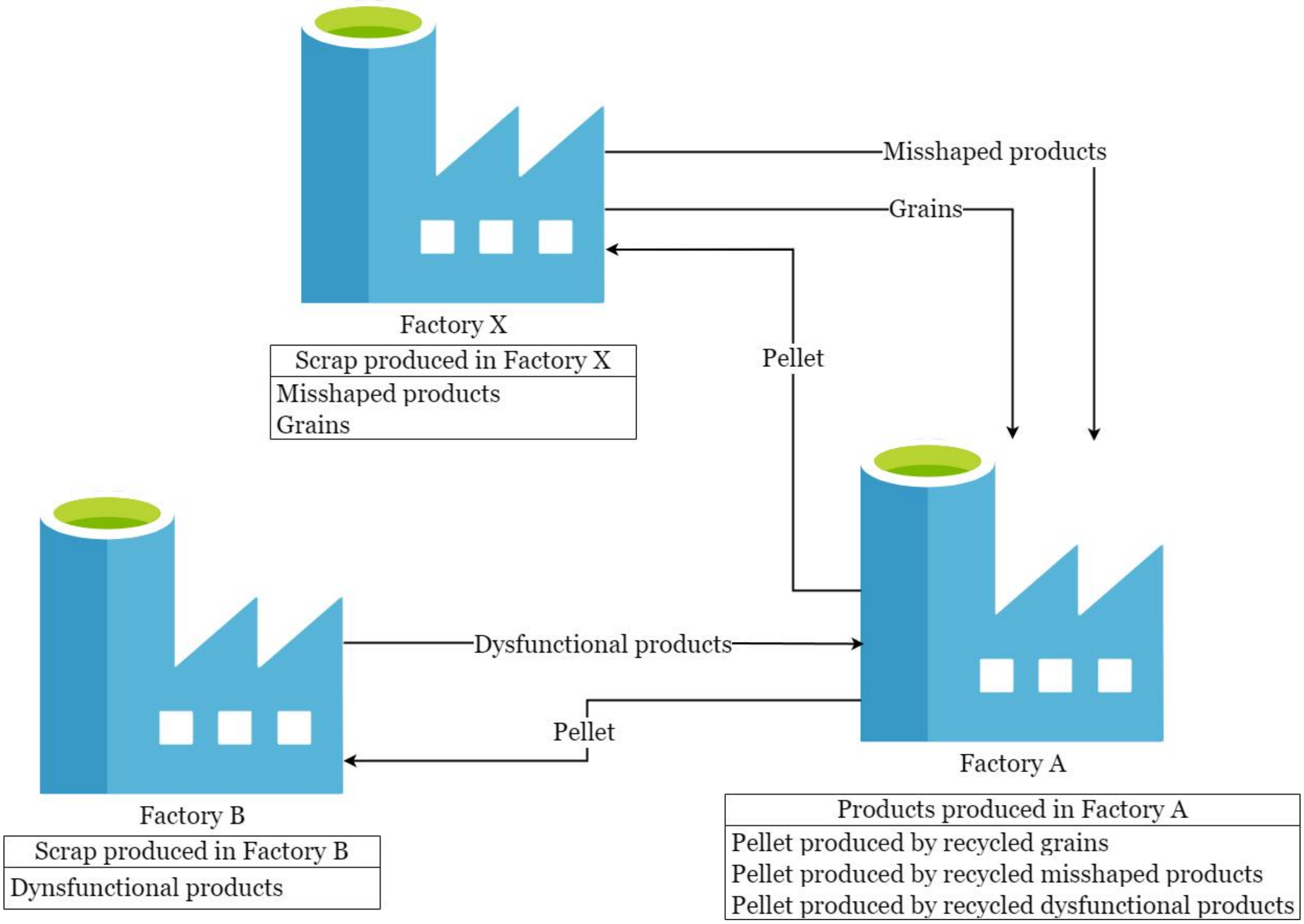

Figure 10: An example of a supply chain.

Through the SCDT, the factories representation is deployed. The data representation is converted to a json script that is uploaded to the Orion LD server. Using the factories presentation provided by SCDT, the abstraction of the supply chain is constructed as follows.

2.5.1 Abstraction model of the supply chain

Using the factories representation json script provided by SCDT through the Orion LD, the SCOPT creates the abstraction of the supply chain as shown in Table 13. The abstraction model of the supply chain, called "Environment model", is provided in a json file with 7 entities: "Areas of interest", "Agents", "Capabilities", "Constraints", "Inter-Agent Capabilities", "Inter-Agent Constraints", "Current Positions", "Goal Positions".

The "Areas of interest" entity defines the factories involved in the supply chain. The "Agents" entity defines the scrap and the products that are produced or recycled by the factories. The "Capabilities" entity defines the individual capabilities of each scrap and product that is the allowed transitions of the products/scraps between the factories. The "Constraints" entity defines the individual constraints of each agent that is the prohibited transitions of the products/scraps between the factories. The "Inter-Agent Capabilities" defines the capabilities that emerge when multiple agents are present, i.e. product's transportation from a factory to another. The "Inter-Agent Constraints" entity defines the constraints that emerge when multiple agents are present, i.e. multiple products are not allowed to be transported in a specific location at the same time. The "Current Positions" entity defines the starting position of each agent at the time when the scenario is running. The "Goal Positions" defines the objective stating the goal position of the agents. If there is a change in the supply chain arrangement, then the abstraction model should be modified accordingly. Otherwise, the "Current position" and the "Goal position" are changed based on the objective of each scenario, while the rest of the entities remain unchanged. In this case, the "Constraints" and the "Inter-Agent Constraints" are omitted, since there is not any restriction in the allowed transitions between the factories.

The cost is related to the CO_2 emissions per 1 unit of a specific product/scrap. For these case studies, the costs have been set approximately to present the capabilities of the SCOPT tool and validate its performance. In the second stage of the SCOPT development, these costs will be obtained from the GRETA tool through the Orion LD. The individual and inter-agent capabilities and constraints are defined based on the capabilities and constraints of the supply chain.


```
{
 "Environment": {
  "Areas of interest": {
   "Name": [ "Factory_X", "Factory_A", "Factory_B" ],
   "Number": [ 1,              2,              3 ]
  },
  "Agents": {
   "misshaped_pr": [ 0, 1, 2 ],
   "grains": [ 0, 1, 2 ],
   "dynsfunctional_pr": [ 0, 1, 3 ],
   "pellet": [ 0, 1, 2, 3 ]
  }
 },
 "Capabilities": {
  "grains": {
   "1": { "2":9 }
  },
  "misshaped_pr": {
   "1": { "2":13 }
  },
  "dynsfunctional_pr": {
   "3": { "2":12 }
  },
  "pellet": {
   "2": { "1":11, "3":10 }
  }
 },
 "Inter-Agent Capabilities": {
  "1": {
   "cost":[14],
   "grains": [ 2, 0 ],
   "pellet": [ 0, 2 ]
  },
  "2": {
```

```
    "cost":[14],
    "misshaped_pr": [ 2, 0 ],
    "pellet": [ 0, 2 ]
   },
   "3": {
    "cost":[14],
    "dynsfunctional_pr": [ 2, 0 ],
    "pellet": [ 0, 2 ]
   }
  },
  "Current positions": {
    "pellet": [ 0 ],
    "misshaped_pr": [ 0 ],
    "grains": [ 1 ],
    "dynsfunctional_pr": [ 0 ]
  },
  "Goal positions": {
    "pellet": [ 2 ],
    "misshaped_pr": [ 0 ],
    "grains": [ 0 ],
    "dynsfunctional_pr": [ 0 ]
  }
}
```


Table 13: Abstraction model of the supply chain.

The break-down explanation of the abstraction model of the supply chain of Table 13 follows.

The "Areas of interest" shown in Table 14 presents the possible positions that a scrap or a product could be in the supply chain at a time instant. The factories are considered as the areas of interest in this scenario, and they are associated with a unique number. For example, the "Factory X" is indicated with the number "1".


```
   "Areas of interest": {
    "Name": [ "Factory_X", "Factory_A", "Factory_B" ],
    "Number": [ 1,              2,              3 ]
   },
```


Table 14: Areas of interest of the supply chain.

All scraps and products involved in the supply chain are considered as agents. Using the numbering of the areas of interest, the possible positions of each agent are defined representing the state space of each agent. The agents considered, shown in Table 15, are the "misshaped_pr" represents the misshaped product produced as a scrap by Factory X, the "grains" represents the scrap grains produced by Factory X, the "dysfunctional_pr" represents the dysfunctional product produced as a scrap by Factory B and the "pellet" represents the pellet produced by recycled products in Factory A. The position "0" denotes that there is not any available unit of an agent or the product/scrap is not available yet. An example of an agent's state space is that the "misshaped_pr" could be found in Factory X or in Factory A or it could not be available (i.e. resources fully consumed).

```
  "Agents": {
    "misshaped_pr": [ 0, 1, 2 ],
    "grains": [ 0, 1, 2 ],
    "dynsfunctional_pr": [ 0, 1, 3 ],
    "pellet": [ 0, 1, 2, 3 ]
  }
```


Table 15: Agents of supply chain and agents' state space.

The "Capabilities" entity defines the individual possible transitions of agents derived from the agents' state space. A part of agents' capabilities is shown in Table 16. For example, "pellet" is able to be transported from Factory A to Factory X producing 11kg of CO_2 emissions per unit of "pellet" or from Factory A to Factory B producing 10kg of CO_2 emissions per unit of "pellet".


```
 "Capabilities": {
<…>
  "pellet": {
    "2": { "1":11, "3":10 }
  }
 },
```


Table 16: A part of agents' capabilities of supply chain.

The "Inter-Agent Capabilities" enable transitions of multiple agents simultaneously at a time instant with a specific cost per each transition. As shown in Table 17, for example, in the inter-agent capability "1", the "grains" can be used as input in the Factory A to produce "pellet" producing 14kg of CO_2 per 1 unit of pellet.


```
 "Inter-Agent Capabilities": {
  "1": {
    "cost":[14],
    "grains": [ 2, 0 ],
    "pellet": [ 0, 2 ]
  },
<…>
 },
```


Table 17: A part of inter-agent capabilities of supply chain.

The current positions of the agents are considered as shown in Table 18. More specifically, "grains" scrap has been produced by Factory X.


```
 "Current positions": {
    "pellet": [ 0 ],
    "misshaped_pr": [ 0 ],
    "grains": [ 1 ],
    "dynsfunctional_pr": [ 0 ]
 },
```


Table 18: Current positions of agents in the supply chain.

The objective of the presented supply chain use-case, shown in Table 19, is to construct pellet and transported to Factory X. The positions of the rest of the agents are set to "0" in order to define that these agents is not mandatory to be produced.


```
"Goal positions": {
  "pellet": [ 1 ],
  "misshaped_pr": [ 0 ],
  "grains": [ 0 ],
  "dynsfunctional_pr": [ 0 ]
}
```


Table 19: Goal position of agents in the supply chain to produce pellet in and transported to Factory X.

2.5.2 Use-case III: Produce pellet and transport to Factory X

Using the environment model of Table 13 that represents the abstraction model of the supply chain, the objective is to calculate the sequence of actions that need to be performed in order to produce and transport pellet in Factory X. The optimal solution computed by SCOPT is presented in Table 21. The objective is fulfilled in 3 steps and the total CO_2 emissions to implement the solution is 34kg CO_2 per 1 unit of pellet.

In the SCOPT results, the "path" entity is a list of lists containing the positions of each agent at any time instant until the objective is fulfilled. Each list contains as many elements as there are the agents that have been considered. Each element of the list is a projection of the position of a specific agent. For example, the 1st step "[0, 1, 0, 0]" presents the starting positions of the agents as they are defined in the "Current positions" entity of the abstraction in Table 18. The projection of elements in this use-case is as shown in Table 20.

crushed_ material	dry_material _nr	grains	pellet_by dysfpr	pellet_by grains	pellet_by shapedpr	pellet_nr	washed_ material
1st element	2nd element	3rd element	4th element	5th element	6th element	7th element	8th element

Table 20: Agents' projection in the supply chain use-case.

Using the agents' projection of Table 20, the result computed by SCOPT is "translated" as follows (see Figure 11 and Figure 12): In words, in the 1st step, scrap grains produced in Factory X are transported to Factory A producing 9kg of CO_2 per unit of grains. In the 2nd step, the pellet is produced in the Factory A producing 14kg of CO_2 per unit of pellet. In the 3rd step, the objective is fulfilled, the pellet is transported to Factory X producing 11kg of CO_2 per unit of pellet.


```
{
        "costs" :
        [ 9, 14, 11 ],
        "path" :
        [
                [ 0, 1, 0, 0 ],
                [ 0, 2, 0, 0 ],
```

```
            [ 0, 0, 0, 2 ],
            [ 0, 0, 0, 1 ]
      ],
      "totalcost" : 34
}
```


Table 21: SCOPT results producing and transporting pellet at Factory X.

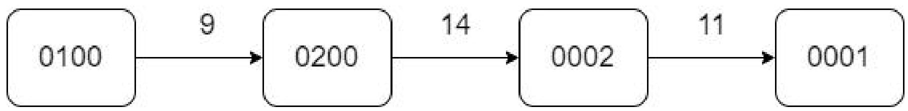

Figure 11: Solution of Use-Case III.

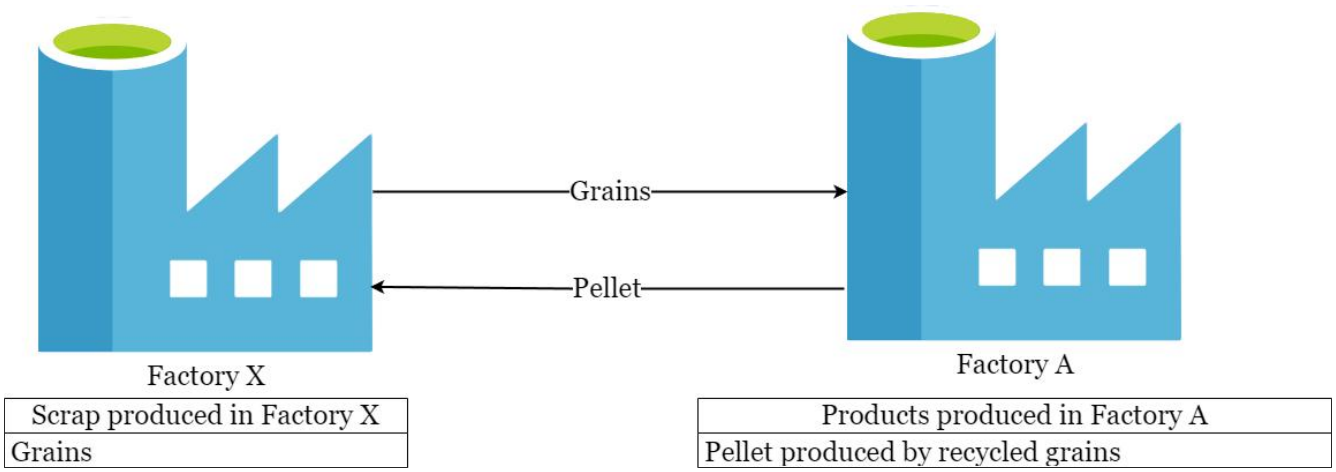

Figure 12: Supply chain arrangement based on the solution of use-case III.

The results are provided in a json script and it is uploaded to Orion LD. In the second stage of the SCOPT development, the SCOPT will be integrated with SCDT so that the SCDT will simulate the sequence of actions that need to be performed in the supply chain in order to fulfill the given objective.

3 Conclusions

The Supply Chain OPTimisation (SCOPT) is the component developed for the manufacturing logistics and supply chain optimisation problems. Using the factory and the supply chain representation, the abstraction models of the factory workflow and the supply chain arrangements are constructed so that the SCOPT calculates the optimal sequence of actions that need to be implemented in order to fulfil local (i.e. within the factory) and global (i.e. between the factories and suppliers) objectives. The overview of the SCOPT architecture, the progress of the first stage of the development of the SCOPT component as well as the interaction of the component with the other tools of the CIRCULOOS platform are described. Several scenarios are presented tackling manufacturing logistics optimization problems and also, supply chain optimization problems.

Following activities includes the interconnections of the SCOPT with the SCDT and GRETA tool to obtain real-time for the tool through the Orion LD; and the integration of SCOPT with the Pilot Application Experiments. These activities will be presented in the deliverable D3.8 AI and Data-driven Supply Chain Optimisation in M24 reporting the second stage development of the SCOPT and its integration in the Pilot Application Experiments.

CIRCULOOS

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