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Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation

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Abbreviations

Acronym	Description
SCOPT	Supply Chain Optimization
SCDT	Supply Chain Digital Twin
GRETA	GREen TArgets
LCA	Life Cycle Assessment
TO BE	Future scenarios of pilot cases
CO_2	Carbon dioxide

Executive summary

The deliverable D3.8 *AI and Data-driven Supply Chain Optimisation M24* provides a description of the second phase of the development of the Supply Chain OPTimisation (SCOPT) component, with the first phase described in deliverable D3.7 *AI and Data-driven Supply Chain Optimisation M12*. The current deliverable reports the results of the activities undertaken from M12 until M24 under Task 3.4 *AI and Data-driven Supply Chain Optimisation,* in order to provide the second phase of the SCOPT as a Software-as-a-Service (SaaS) provided by CUT.

The second phase of the SCOPT development is focused on modeling, testing and analyzing supply chain arrangements of the CIRCULOOS pilot cases in order to identify and validate alternative circular solutions for the supply chains. Using appropriate abstraction models to represent supply chain arrangements, SCOPT proposes intra-factory and supply chain orchestrations to improve relevant circular economy indicators. The deliverable describes the progress of the second phase of the development of SCOPT, the supply chain scenarios for each pilot, as well as the interaction of the SCOPT component with other tools of the CIRCULOOS platform.

1 Introduction

1.1 Deliverable purpose

The scope of the deliverable D3.8 “AI and Data-driven Supply Chain Optimisation M24” is to report the progress of the second 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 D3.8 is the presentation and the description of scenarios raised by the CIRCULOOS pilots during the second stage in the development and implementation of the SCOPT component. The deliverable describes the models developed for the three pilots’ supply chains, their analysis and the solutions proposed by SCOPT.

The models for investigating and analyzing supply chain and intra-factory orchestrations were implemented using the SPECTER[1] symbolic AI task planner as the backbone system for the SCOPT CIRCULOOS service. The detailed description of the SCOPT component has been presented in the deliverable “D3.7 AI and Data-driven supply chain M12”. For the development of the models, a data collection template was developed and distributed to the pilots during the second phase. The received feedback was used primarily for the implementation of the pilots SCDTs (see deliverable “D3.4 3D Digital Twin of supply chain/production/product M24”), while the current deliverable leveraged the collected data in creating appropriate abstraction models for the supply chains and intra-factory logistics for the three pilots. The abstraction models are encoded in the SPECTER’s task specification language[2].

1.2 Positioning within the project

The deliverable D3.8 is the outcome of the efforts undertaken within the context of Task 3.4 “AI and data-driven supply chain optimisation”. The deliverable D3.8 is devoted to describe the second stage in the development and implementation of the Supply Chain OPTimisation (SCOPT) component at M24. The first stage report has been delivered at M12, as deliverable “D3.7 AI and Data-driven supply chain M12”.

1.3 Deliverable structure

The deliverable is organized as follows:

- In section 1, the purpose of the deliverable, the positioning with the CIRCULOOS Project and the related structure is presented.
- In section 2, an overview of the SCOPT component is provided.
- In section 3, two case studies based on the plastic pilot are presented, analysing supply chain optimization instances, utilizing the SCOPT component.

[1] A. A. Tziola and S. G. Loizou, "A Formal Framework for Multi-Agent Task Planning," in IEEE Transactions on Automatic Control, 2025, doi: 10.1109/TAC.2025.3601769. [Accepted version available at: https://ktisis.cut.ac.cy/handle/20.500.14279/35005]

[2] https://github.com/ramp-eu/Business_Process_Optimization/tree/master/docs

- In section 4, a case study based on the leather pilot is presented, analyzing supply chain stability with intra-factory logistics considerations, utilizing the SCOPT component.
- In section 5, a case study based on the wood pilot is presented, analyzing supply chain optimization instances, utilizing the SCOPT component.
- Section 6 concludes the document.

2 Supply Chain Optimization component

The Supply Chain OPTimisation component, developed by Cyprus University of Technology (CUT), determines an optimized solution to the optimized motion task sequencing problem. The SCOPT tool is provided as Software-as-a-Service (SaaS) module which leverages a model-based approach to:

i yield optimal (or optionally sub-optimal) results for intra-factory manufacturing logistics as well as for supply chain arrangements,
ii provide global (i.e. between the factories and suppliers) and local (within the factory) supply chain optimizations,
iii analyze the intra-factory manufacturing logistics and resources availability,
iv determine alternative supply chain arrangements,
v provide optimisation results of the current processes.

SCOPT builds on the BPO component, which was developed and evolved by the EU Projects L4MS and BETTER FACTORY to the SPECTER task planner. SCOPT aims to increase the reusability and scalability of SPECTER and CIRCULOOS and offers it, through the SCOPT tool, under a SaaS framework.

2.1 Task specification of the SPECTER task planner

SCOPT operates as follows: The abstraction model, called SPECTER's task specification, of the intra-factory logistics or the supply chain arrangement needs to be constructed in a language specifically developed for the needs of this SPECTER task planner. 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. From SCDT, SCOPT receives the data required to construct the abstraction model of the factory or the supply chain. From GRETA tool, SCOPT retrieves the relevant LCA indicators. Utilizing the abstraction model, SCOPT provides feasible and alternative solutions for the intra-factory logistics and supply chain optimization problems.

The abstraction model consists of the following entities:

- *Environment* consists of the *Areas of Interest* which are all possible areas or status that an agent could be, and the unique IDs correspond to each area of interest.
- *Agents* are the entities that are acting on or interacting with the environment or trigger event(s).
- *Capabilities* define the individual capabilities of each agent as the available agent's transitions with associated costs.
- *Constraints* define that individual constraints of each agent as the non-available agent's transitions.
- *Inter-Agent Capabilities* define the capabilities that emerge when multiple agents are present with the associated costs.
- *Inter-Agent Constraints* define the constraints that emerge when multiple agents are present.
- *Current position* is the starting position of agents.
- *Goal position* is the target position of agents.

For the construction of the SPECTER's task specification, agents are considered as the entities operating in the environment which act or interact with the surroundings and perform tasks (e.g. robots, humans, machines, items, materials, products etc.). Agents' capabilities contain the allowed state transitions (e.g. the robot could navigate from point A to point B, material could be transported from Warehouse to molding machine, or machine could be activated or turned off), whereas agents constraints contain the forbidden state transitions (e.g. robot could not visit point C, item cannot be stored at packing area, human-worker is not allowed to visit the Warehouse).

Utilizing the abstraction model, SCOPT provides the sequence of actions as steps of the shortest path from the initial state of the agents to a target state subject to the constraints imposed and the capabilities provided. The target state is considered as a logistic task (i.e. "Transport *item_1* to location *B*") provided by the production manager, while the starting state is considered the current state of the agents (i.e. the current location of each agent the time instant when the production manager submits the logistic task).

2.2 How to utilize the SCOPT component

The SCOPT component is provided as a Software-as-a-Service. A data collection template, presented in *D3.4 3D Digital Twin of supply chain/production/products M24*, was developed to describe a wide range of processes and factory setups, as well as interconnections between the actors in the supply chain. Retrieving data from template, the abstraction model of the intra-factory logistics and supply chain arrangement is constructed. The results, provided by SCOPT, are published to Orion LD server.

2.3 Interconnection between SCOPT, SCDT and other Circuloos tools

SCOPT interacts with the SCDT and GRETA tools through the Data Platform and Orion LD to retrieve data for the factory workflow models (including processes, input materials, output products, LCA costs) and supply chain arrangements (including suppliers, factories, consumers, LCA costs). The interaction of the SCOPT with the Circuloos tools is illustrated in Figure 1. SCOPT retrieves LCA indicators from GRETA through the Data Platform and proposes optimized solutions for intra-factory logistics scenarios and alternative options for supply chain arrangements. Solutions provided by SCOPT are published to Data Platform and to be visualized in SCDT. SCDT can visualize solutions provided by SCO for actors' collaboration in the supply chain and factory production processes monitoring and control.

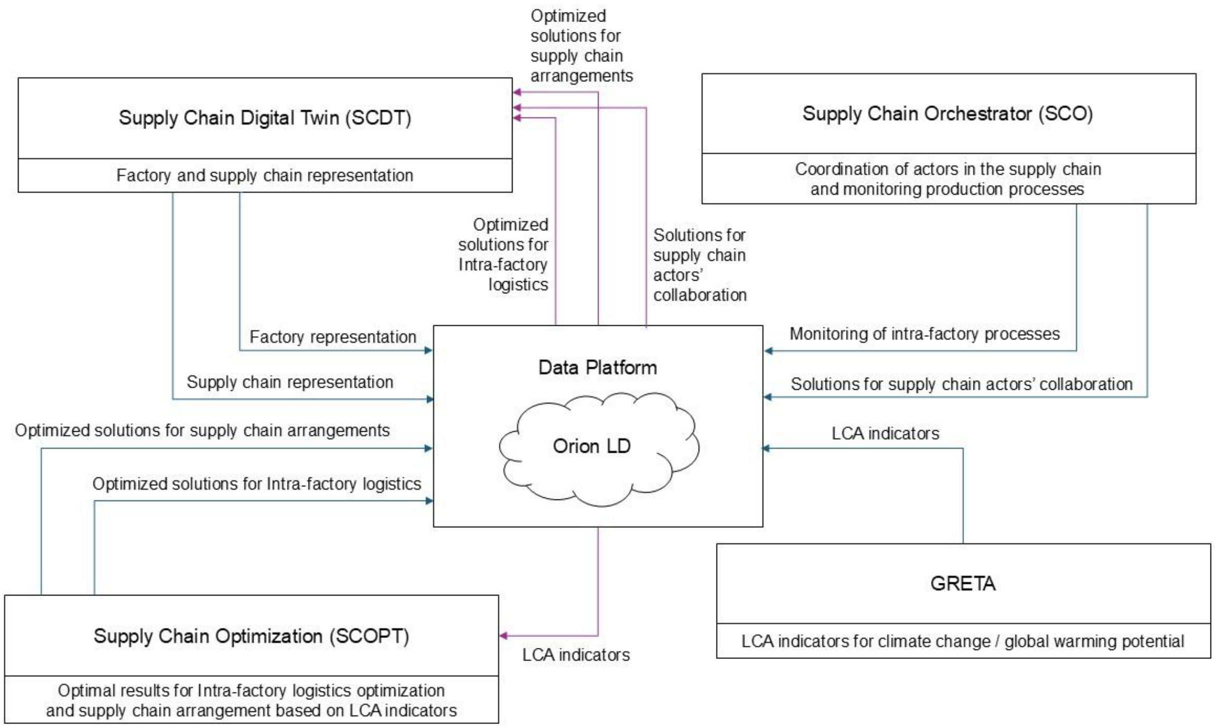

Figure 1: Connectivity of SCOPT with Circuloos tools.

3 Supply chain optimization

3.1 Scenario A: Optimal supply chain arrangement

A supply chain scenario motivated by the CIRCULOOS plastic pilot case is presented Figure 2 showing the interconnections between the factories in the supply chain. There are four factories participating in the supply chain: the original pilot partners LOLO and Thermolympics, and two additional factories Z and B that were introduced to investigate the opportunities available via the SCOPT component utilization. The last two factories were introduced as possible options of plastic scrap suppliers to LOLO, and their introduction was motivated by the applicants' (anonymized) data that were made available to the consortium through CIRCULOOS Open Calls #2 and #3.1. Moreover, there are two buffer zones in the supply chain to store input materials and scraps and output products. The buffers in the supply chain represent an abstraction of the supply chain's capability to temporarily "store" a certain amount of goods e.g. while those are being transported between factories. The concept of supply chain buffer zones is captured by the "Logistics Factory" in the SCDT model. Using the "Logistics Factory" concept more complicated supply chains can be modelled. In the current analysis, each buffer collects the produced entities or scraps from the factories and serves them to other factories. This approach allows new factories to be included in the supply chain any time without disrupting the flow of goods between the factories. The factories receive input resources from the supply chain while pushing their output products in the supply chain. The objective is to produce two units of new product and store them at new product buffer.

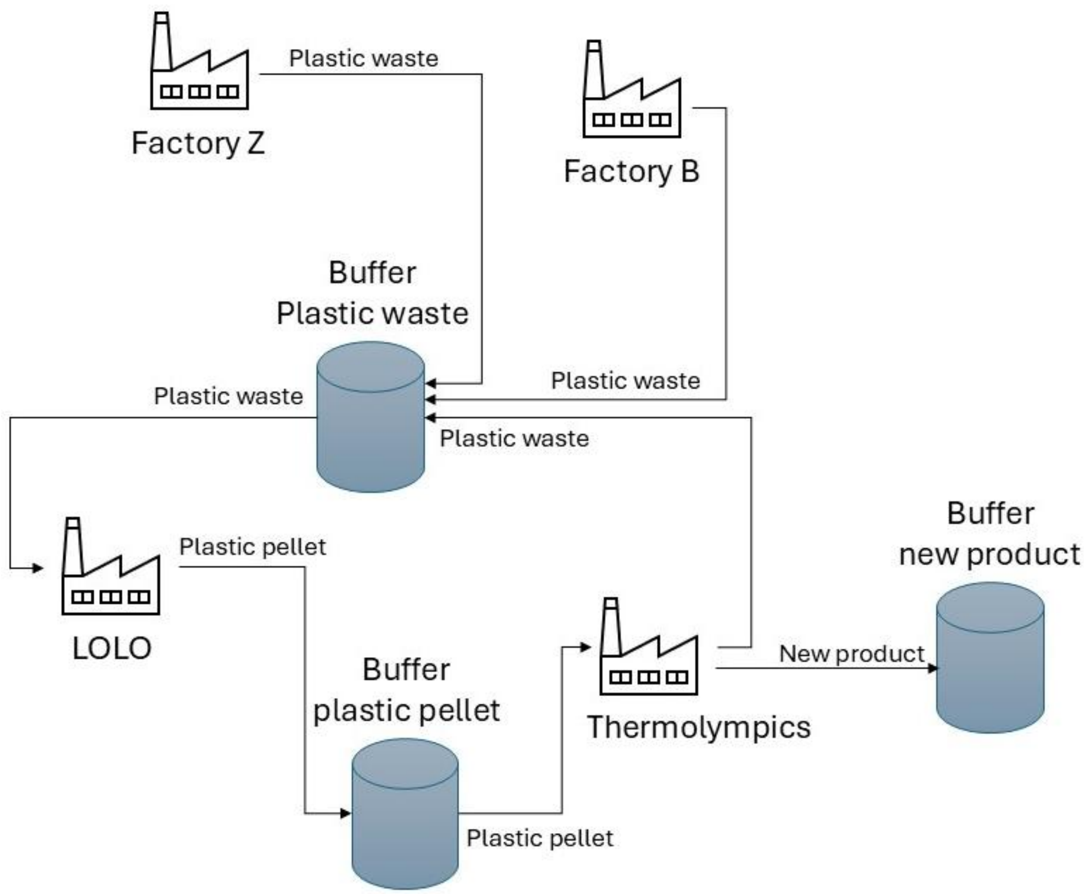

Figure 2: Supply chain scenario motivated by the CIRCULOOS plastic pilot.

To utilize SCOPT, the abstraction model of the supply chain needs to be constructed based on the SPECTER's language model. The supply chain abstraction model is presented in Annex 1: Abstraction model (SPECTER's task specification) of the supply chain. The approximate costs are related to the CO_2 emissions. The analysis of the abstraction model (see Annex 1 for the full abstraction model) of Scenario A is provided below.

In Scenario A, the possible positions that a material or a product could be, are modeled as "Areas of interest" as shown in Table 1. Actors of the supply chain are considered as areas of interest in this scenario and they are associated with a unique number. For example, the "Factory_Z" is indicated with the number #3. Using the unique indicators (ID) of the areas of interest, we can model the allowed transitions of the entities in the supply chain as we will describe in the sequel.

```
"Areas of interest": {
  "Name": [ "LOLO", "Thermolympics", "Factory_Z", "Factory_B" ],
  "Number": [ 1, 2, 3, 4 ]
```

Table 1: Areas of interest of Scenario A.

All input materials and output products utilized and produced by the factories in the supply chain are considered as agents. Using the unique ID of each area of interest, the possible transitions of input materials and output products among the actors in the supply chain can be defined. The possible positions that an input material or an output product could be, define the state space of the agent. Moreover, the buffers of the supply chain are also considered as agents. The state space of the buffers indicates the level of a buffer at a time instance. More specifically, as shown in the Table 2, the agents along with their state space are defined. The agents considered in Scenario A are: the plastic waste, the plastic pellet and the new product; as well as the plastic waste buffer, the plastic pellet buffer and the new product buffer. For instance, the line "plastic_pellet": [0, 1, 2] denotes that the plastic pellet agent can be utilized by Factory_X (ID: #1) and Factory_Y (ID: #2) or if no plastic pellet entity has been produced, this is modeled by the zero state (ID: #0). Another example is that the "plastic_waste_bf": [0, 1, 2, 3, 4, 5] states that the level of the plastic waste buffer varies from 0 (empty) to 5 (full). It is important to note that the level of a buffer could be a discrete or a continuous variable, while the abstraction model utilizes an appropriate discretization.

```
"agents": {
  "plastic_pellet": [ 0, 1, 2 ],
  "new_product": [ 0, 2 ],
  "plastic_waste": [ 0, 1, 2, 3, 4 ],
  "plastic_waste_bf": [ 0, 1, 2, 3, 4, 5 ],
  "plastic_pellet_bf": [ 0, 1, 2, 3, 4, 5 ],
  "new_product_bf": [ 0, 1, 2, 3, 4, 5 ]
```

Table 2: Agents' state space of Scenario A.

Having modeled the possible states that an agent could be in the supply chain at a time instant, we can now proceed with the modeling of the transitions conditioned on multiple agents at a time instant with a specific cost per transition. These allowed transitions are modeled as inter-agent capabilities presented in Table 19 in Annex 1: Abstraction model (SPECTER's task specification) of the supply chain. The inter-agent capabilities specify the production of a new item by a process of a factory utilizing other entities as input resources. Also, the storage of entities in the buffers is also considered as an inter-agent capability of the material agent and the relevant buffer agent. Parts of inter-agents capabilities are explicitly explained in the following tables. In the Table 3, the inter-agent capabilities from #20 to #26 models that LOLO utilizes four units of plastic waste from the plastic waste buffer to produce two units of plastic pellet and produces 5kg of CO_2. More specifically, the inter-agent capabilities #20 and #21 model the possible combinations of the plastic waste buffer level reduction by four units when the plastic waste is retrieved from the plastic waste buffer to be utilized as input material of LOLO; the inter-agent capability #22 models the operation of LOLO to produce plastic pellet utilizing plastic waste with cost 5kg of CO_2; the inter-agent capability #23 to #26 models the possible combinations of the plastic pellet buffer level increase by two units when the plastic pellet produced by LOLO is stored at the plastic pellet buffer. The transportation costs from/to the buffers are set in the model as 1kg of CO_2.

```
  "Inter-Agent Capabilities": {
<…>
    "20": {
      "cost":[1],
      "plastic_waste_bf": [ 5, 1 ],
      "plastic_waste": [ 0, 1 ]
    },
    "21": {
      "cost":[1],
      "plastic_waste_bf": [ 4, 0 ],
      "plastic_waste": [ 0, 1 ]
    },
    "22": {
      "cost":[5],
      "plastic_waste": [ 1, 0 ],
      "plastic_pellet": [ 0, 1 ]
    },
    "23": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 0, 2 ]
    },
    "24": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 1, 3 ]
    },
    "25": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 2, 4 ]
    },
    "26": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 3, 5 ]
    },
<…>
```

Table 3: Inter-agent capabilities modeling the utilization of four units of plastic waste from the plastic waste buffer by LOLO to produce two units of plastic pellet producing 5kg of CO_2.

Another option is that Thermolympics utilizes four units of plastic pellet to produce one unit of new product and one unit of plastic waste and produces 10kg of CO_2. More specifically, in the Table 4, the inter-agent capabilities #27 and #28 model the possible combinations of the plastic pellet buffer level reduction by four units when the plastic pellet is retrieved from the plastic pellet buffer to be utilized as input material of Thermolympics. The inter-agent capability #29 models the operation of Thermolympics to produce new product and plastic waste utilizing plastic pellet with cost 10kg of CO_2. The inter-agent capabilities from #30 to #34 model the possible combinations of the new product buffer level increase by one unit when the new product is produced by Thermolympics and it is stored at the new product buffer. The inter-agent capabilities from #35 to #39 model the possible combinations of the plastic waste buffer level increase by one unit when the plastic waste is produced by Thermolympics and it is stored at the plastic waste buffer.


```
  "Inter-Agent Capabilities": {
<…>
    "27": {
      "cost":[1],
      "plastic_pellet_bf": [ 5, 1 ],
      "plastic_pellet": [ 0, 2 ]
    },
    "28": {
      "cost":[1],
      "plastic_pellet_bf": [ 4, 0 ],
      "plastic_pellet": [ 0, 2 ]
    },
    "29": {
      "cost":[10],
      "plastic_pellet": [ 2, 0 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 2 ]
    },
    "30": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
    "31": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
    "32": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 2, 3 ]
    },
    "33": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 3, 4 ]
    },
    "34": {
      "cost":[1],
      "new_product": [ 2, 0 ],
```

```
      "new_product_bf": [ 4, 5 ]
    },
    "35": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 0, 1 ]
    },
    "36": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 1, 2 ]
    },
    "37": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 2, 3 ]
    },
    "38": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 3, 4 ]
    },
    "39": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 4, 5 ]
    }
}
```

Table 4: Inter-agent capabilities modeling the utilization of four units of plastic pellet from the plastic pellet buffer by Thermolympics to produce one unit of new product and one unit of plastic waste producing 10kg of CO_2.

We also consider an alternative supplier of plastic waste, Factory Z, that provides 1 unit of plastic waste to the plastic waste buffer and produces 8kg of CO_2. This alternative is modeled by the inter-agent capabilities from #9 to #14 of Table 5, where the plastic waste is produced by Factory Z with cost 8kg of CO_2, when the level of the plastic waste buffer is reduced to zero.

```
  "Inter-Agent Capabilities": {
<…>
    “9”: {
      "cost":[8],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 3 ]
    },
    "10": {
      "cost":[8],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 3 ]
    },
    "11": {
      "cost":[8],
      "plastic_waste_bf": [ 2, 2 ],
```

```
      "plastic_waste": [ 0, 3 ]
    },
    "12": {
      "cost":[8],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 3 ]
    },
    "13": {
      "cost":[8],
      "plastic_waste_bf": [ 4, 4 ],
      "plastic_waste": [ 0, 3 ]
    },
    "14": {
      "cost":[8],
      "plastic_waste_bf": [ 5, 5 ],
      "plastic_waste": [ 0, 3 ]
    },
<…>
```

Table 5: Inter-agent capability modeling the production of 1 unit of plastic waste by the Factory Z to the plastic waste buffer.

Furthermore, Factory B is considered as an alternative supplier of plastic waste that provides 2 units of plastic waste to the plastic waste buffer and produces 15kg of CO_2. This alternative is modeled by the inter-agent capabilities from #1 to #4 of Table 6, where the plastic waste is produced by Factory B with cost 15kg of CO_2, when the level of the plastic waste buffer is reduced to zero.

```
  "Inter-Agent Capabilities": {
    "1": {
      "cost":[15],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 4 ]
    },
    "2": {
      "cost":[15],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 4 ]
    },
    "3": {
      "cost":[15],
      "plastic_waste_bf": [ 2, 2 ],
      "plastic_waste": [ 0, 4 ]
    },
    "4": {
      "cost":[15],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 4 ]
    },
<…>
```

Table 6: Inter-agent capability modeling the production of 1 unit of plastic waste by Factory B to the plastic waste buffer.

Utilizing the SCOPT tool, the optimization problem is to find the optimal supply chain arrangement in order to store 2 units of new product by Thermolympics in the new product buffer. To utilize the SCOPT tool, the abstraction model of the supply chain is constructed, and it is shown in Annex 1: Abstraction model (SPECTER's task specification) of the supply chain. Assuming that all buffers are empty, the optimal supply chain that SCOPT provides utilizing Factory B, LOLO, Thermolympics and Factory Z can be summarized as follows. The goal is to store two units of new product produced by Thermolympics at new product buffer. This means that the objective is to increase the level of the new product buffer from zero to two. To do so,

Step 1	Factory B provides four units of plastic waste to the plastic waste buffer to increase the level of the buffer from zero to four.
Step 2	LOLO utilizes those entities (plastic waste buffer now is empty) to produce two units of plastic pellet and store them in the relevant buffer.
Step 3	Factory B provides four units of plastic waste to the plastic waste buffer to increase the level of the buffer from zero to four.
Step 4	LOLO utilizes those entities (plastic waste buffer now is empty) to produce two units of plastic pellet and store them in the relevant buffer (level of the plastic waste buffer is four).
Step 5	Since plastic pellet buffer contains four units, then Thermolympics retrieves those entities (plastic pellet buffer is empty) to produce new product and plastic waste and store them in the relevant buffers.
Step 6	Thus, the buffer of new product contains one unit and the buffer of plastic waste contains one unit, too.
Step 7	Now, Factory B provides four units of plastic waste to the plastic waste buffer to increase the level of the buffer from one to five.
Step 8	Then, LOLO utilizes four units (plastic waste buffer contains one unit) to produce two units of plastic pellet and store them in the relevant buffer to increase its level from zero to two.
Step 9	Now, Factory B provides two units of plastic waste to the plastic waste buffer to increase the buffer's level from one to three; and Factory Z provides one unit of plastic waste to the plastic waste buffer to increase the buffer's level from three to four.
Step 10	Now, Thermolympics retrieves those entities (plastic pellet buffer is empty) to produce new product and plastic waste and store them in the relevant buffers.

Thus, the buffer of new product contains two units and the buffer of plastic waste contains one unit. The objective is fulfilled since there are two units of new product stored at new product buffer.

Moreover, the solution can be described in more detail as follows. Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is two. Factory B provides more two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is four. Now, LOLO retrieves four units of plastic waste from the buffer to produce two units of plastic pellet and store them at the plastic pellet buffer. The plastic waste buffer is now empty and the level of plastic pellet buffer is two. Now, Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is two. Factory B provides again two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is four. Now, LOLO retrieves four units of plastic waste from the buffer to produce two units of plastic pellet and store them at the plastic pellet buffer. The level of plastic waste buffer is zero and the plastic pellet buffer is four. Then, Thermolympics retrieves four units of plastic pellet from the buffer to produce one new product with one unit of plastic waste. Now, the level of plastic pellet buffer is zero, the new product buffer is one and the plastic waste buffer is one. Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is three. Factory B provides again two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is five. Then, LOLO retrieves four units of plastic waste from the buffer to produce two units of plastic pellet and store them in plastic pellet buffer. The level of plastic pellet buffer is two and the plastic waste buffer is one. Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is three. Now, Factory Z provides one unit of plastic waste to the plastic waste buffer. The level of plastic waste buffer is four. Then, LOLO retrieves four units of plastic waste from the buffer to produce two units of plastic pellet and store them to plastic pellet buffer. The plastic waste buffer is empty and the level of plastic pellet buffer is four. Then, Thermolympics retrieves four units of plastic pellet from the buffer to produce one new product with one unit of plastic waste. Thus, the level of new product buffer is two and the plastic waste buffer is one.

3.1.1 Conclusion

In this scenario, utilization of the SCOPT tool for a supply chain motivated by the CIRCULOOS plastic pilot case is presented. An abstraction model of the supply chain has been constructed to model key features of the supply chain, and the resulting model abstraction was implemented on the SCOPT tool. A scenario has been investigated utilizing four factories and two buffer zones in the supply chain, capturing the supply chain's temporary storage level. The resulting supply chain arrangement solution proposes iterations over the production of two units of new product followed by their storage at new product buffer engaging Factory B, LOLO, Thermolympics and Factory Z.

To conclude, the solution provided by SCOPT in this scenario, proposes alternative suppliers for the CIRCULOOS plastic pilot that provide plastic waste to the pilot in order to produce new products from recycled plastic waste, as well as to identify the interconnections between the actors in the supply chain proposed by SCOPT.

3.2 Scenario B: Incorporation of alternative suppliers

In this scenario, we aim to show how alternative suppliers can be incorporated into the supply chain as proposed in Scenario A. Following a recommendation by pilot partners, we included in our investigation an alternative supplier for the plastic pellet, that is Factory A, that produces plastic pellets and serves them to the plastic pellet buffer. Thus, the supply chain of Figure 2 and be extended to the supply chain of Figure 3. Factory A provides 1 unit of plastic pellet to the plastic pellet buffer and produces 5 kg of $C0_2$. In this case, the objective, again, is to find the supply chain arrangement to store 2 units of new product by Thermolympics in the new product buffer utilizing SCOPT tool. Motivated by the applicants of CIRCULOOS Open Calls #2 and #3.1, Factory A was utilized to demonstrate the capabilities of the SCOPT component utilization.

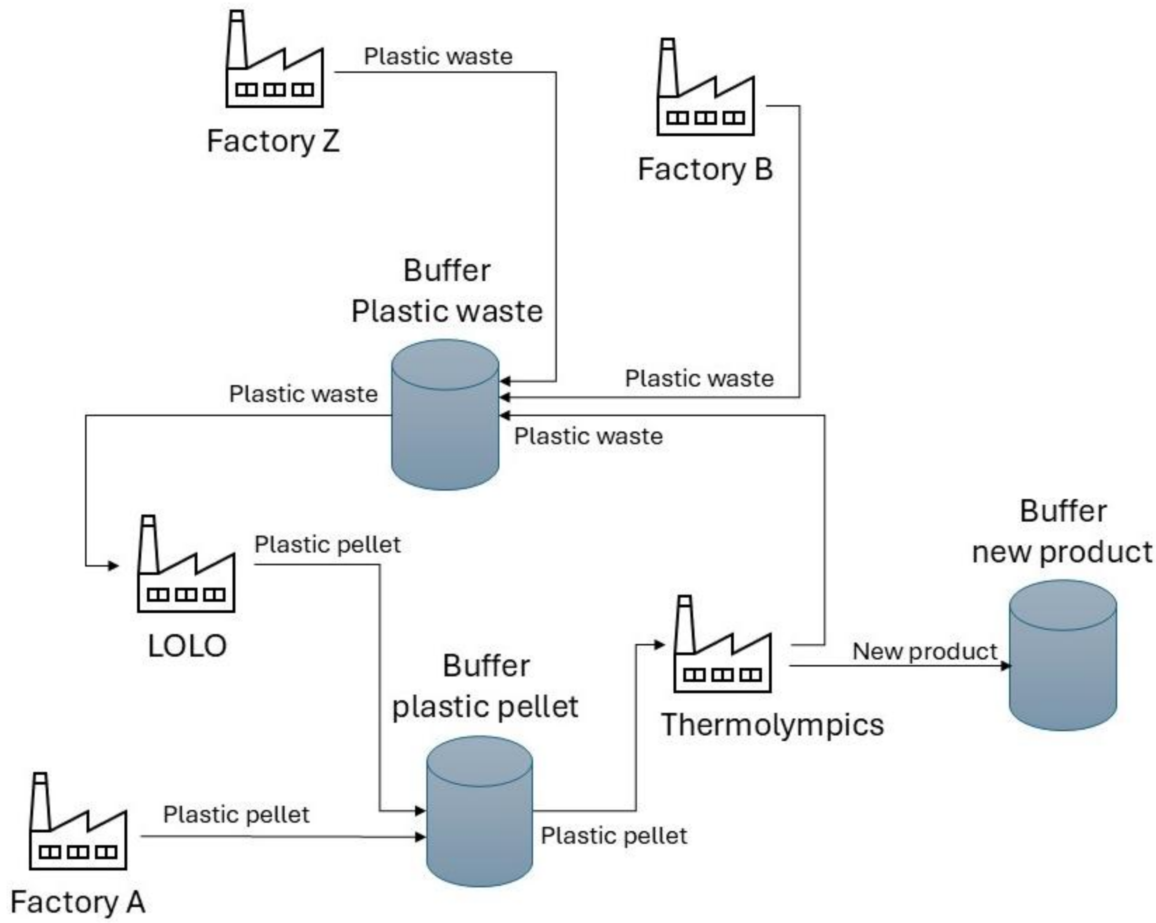

Figure 3: Supply chain scenario motivated by the CIRCULOOS plastic pilot incorporating an additional actor in the supply chain arrangement.

The abstraction model of the supply chain for Scenario B is presented in Table 20 in Annex 2. Comparing the abstraction model of Scenario B with the abstraction model of Scenario A, in this case, we have added Factory A to the areas of interest as shown in Table 7. Factory A is considered as one of the areas of interest with the unique ID #5.

```
"Areas of interest": {
  "Name": ["LOLO", "Thermolympics", "Factory_Z", "Factory_B", "Factory_A"],
  "Number": [ 1,  2,  3,  4,  5 ]
```

Table 7: Areas of interest of Scenario B.

The agents considered in this scenario are the same as in Scenario A. Since Factory A produces plastic pellet and store the produced entities in the plastic pellet buffer, we need to add Factory A as a possible position of the plastic pellet. As shown in Table 8, the plastic pellet can be utilized by Factory_X (ID: #1), Factory_Y (ID: #2) and Factory_A (ID: #5) or if no plastic pellet entity has been produced, this is modeled by the zero state (ID: #0).

```
    "agents": {
      "plastic_pellet": [ 0, 1, 2, 5 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 1, 2, 3, 4 ],
      "plastic_waste_bf": [ 0, 1, 2, 3, 4, 5 ],
      "new_product_bf": [ 0, 1, 2, 3, 4, 5 ],
      "plastic_pellet_bf": [ 0, 1, 2, 3, 4, 5 ]
```

Table 8: Agents' state space of Scenario B.

Having modeled the agents' state space, we can now proceed with the modeling of the transitions conditioned on multiple agents at a time instant with a specific cost per transition. Compared with the inter-agent capabilities defined for Scenario A, in this case, we need to include the production of plastic pellet from Factory A. As shown in the inter-agent capabilities from #26 to #30 in the Table 9, Factory A can produces plastic pellet producing 5kg of CO_2 and store them in the plastic pellet buffer.

```
  "Inter-Agent Capabilities": {
<…>
    "26": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 0, 1 ]
    },
    "27": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 1, 2 ]
    },
    "28": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 2, 3 ]
    },
    "29": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 3, 4 ]
    },
    "30": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 4, 5 ]
    },
<…>
```

Table 9: Inter-agent capability modeling the production of plastic pellet from Factory A producing 5kg of CO_2.

The optimal supply chain provided by SCOPT utilizes Factory B, LOLO, Thermolympics and Factory A. The objective of Scenario B is the same as it is in Scenario A, but the difference here is the optimal solution provided by SCOPT utilizes Factory A and omits Factory Z. The proposed solution can be summarized as follows. Assuming that all buffers are empty, the goal is to store two units of new product produced by Thermolympics at new product buffer. This means that the objective is to increase the level of the new product buffer from zero to two. To do so, the process is described in the following steps.

Step 1	Factory B provides four units of plastic waste to the plastic waste buffer to increase the level of the buffer from zero to four.
Step 2	LOLO utilizes those entities (plastic waste buffer now is empty) to produce two units of plastic pellet and store them in the relevant buffer.
Step 3	Factory B provides four units of plastic waste to the plastic waste buffer to increase the level of the buffer from zero to four.
Step 4	LOLO utilizes those entities (plastic waste buffer now is empty) to produce two units of plastic pellet and store them in the relevant buffer (level of the plastic waste buffer is four).
Step 5	Since plastic pellet buffer contains four units, then Thermolympics retrieves those entities (plastic pellet buffer is empty) to produce new product and plastic waste and store them in the relevant buffers
Step 6	The buffer of new product contains one unit and the buffer of plastic waste contains one unit.
Step 7	Factory B provides four units to plastic waste buffer to increase the buffer level to five, since LOLO requires four units of plastic waste as input
Step 8	LOLO retrieves four units of plastic waste from the buffer (plastic waste buffer contains one unit) and produces two units of plastic pellet (plastic pellet buffer level is two)
Step 9	Factory A provides two units of plastic pellet and increases the level of plastic pellet buffer from two to four
Step 10	Thermolympics retrieves four units of plastic pellet (plastic pellet buffer is empty) and produces one unit of new product and one unit of plastic waste (plastic waste buffer contains two units)

Thus, the objective is fulfilled since there are two units of new product stored in the buffer.

Comparing the results of Scenario B with the results of Scenario A, an important result here is that incorporating Factory A in the supply chain arrangement, in order to produce two units of new product, could increase the plastic waste. This can be shown from the level of the plastic waste buffer where the final result in Scenario B is two, whereas the final result in Scenario A is one.

Moreover, the solution can be described in more detail as follows. Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is two. Factory B provides again two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer four. LOLO retrieves four units of plastic waste for the plastic waste buffer to produce two units of plastic pellet. Plastic pellet produced by LOLO are stored at plastic pellet buffer. The level of the plastic waste is zero and the level of the plastic pellet buffer is two. Factory B provides two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is two. Factory B provides again two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer four and the level of the plastic waste is zero. LOLO retrieves four units of plastic waste for the plastic waste buffer to produce two units of plastic pellet. Plastic pellet produced by LOLO are stored at plastic pellet buffer. The level of plastic pellet buffer is four. Thermolympics retrieves four units of plastic pellet from the plastic pellet buffer in order to produce one unit of new product and one unit of plastic waste. The level of plastic pellets reduces to zero, the level of plastic waste buffer increases to one and the level of new product increases to one. Factory B serves two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is three. Factory B serves two units of plastic waste to the plastic waste buffer. The level of plastic waste buffer is five. LOLO retrieves four units of plastic waste for the plastic waste buffer to produce two units of plastic pellet. The level of plastic waste reduces to one and the level of plastic pellet buffer increases to two. Now, Factory A provides one unit of plastic pellet to the plastic pellet buffer. The level of plastic pellet buffer is three. Factory A provides one unit of plastic pellet to the plastic pellet buffer. The level of plastic pellet buffer is four. Thermolympics retrieves four units of plastic pellet from the plastic pellet buffer to produce one unit of new product and one unit of plastic waste. Thus, the level of the new product buffer increases to two and the level of plastic waste is two.

3.2.1 Conclusion

In this scenario, the supply chain presented in Section 3.1 has been extended incorporating an alternative supplier for the plastic pellet. The new abstraction model has been constructed to model the key features of the new supply chain and the resulting model abstraction was implemented on the SCOPT tool. The scenario investigated presents how alternative suppliers can be incorporated in an existing supply chain model. The results concluded that the supply chain arrangement to produce two units of new product and store them at new product buffer engaged Factory B, LOLO and Thermolympics, whereas Factory A is involved instead of Factory Z.

To conclude, the analysis provided by SCOPT in this scenario, showcases how the proposed supply chain arrangement of Scenario A is affected by incorporating a new supplier that provides additional units of plastic pellet in the supply chain to enhance the circularity of the CIRCULOOS plastic pilot. Comparing the results of Scenario B with the results of Scenario A, an important result here is that incorporating Factory A in the supply chain arrangement, could increase the plastic waste. This can be seen from the level of the plastic waste buffer where the result in Scenario B is two, whereas the result in Scenario A is one.

4 Scenario C: Supply chain stability with intra-factory logistics optimization

In this scenario, the SCOPT tool is utilized to provide an optimal solution for supply chain stability. The Factory visualization in the SCDT tool provides valuable information regarding particular instances of the factory workflow during the simulation. As shown in Section 3.3 in D3.4 3D Digital Twin of supply chain/production/product M24, the factory could run out of particular input material that will cause loss of productivity and revenues. Using a use-case scenario motivated by the CIRCULOOS leather pilot, this scenario aims to show that the SCOPT tool can be utilized both as a verification tool and an optimizer, in order to prevent the running out of input materials and provide valid scheduling plan.

In this scenario, buffers have been added in the factory workflow as essential stabilizers that allow the supply chain to absorb unexpected disruptions and continue flowing smoothly. Following this approach, SCOPT considers the buffers' level and the time required for the quantities to be absorbed by the workflow; and calculates the optimal solution to minimize the time cost of process operation while keeping the system stable. Supplier B was introduced as a hypothetical option to investigate the opportunities available via the SCOPT component utilization.

The scenario considered is the following. Assuming that a part of the sewing procedure of B&A, the process of assembly and stitching additional components, considers the sewing of the buttons up to the seamed bags. As illustrated in the Figure 4, this stage of the process utilizes buttons and polished parts of seamed bags as input materials retrieved by the buttons buffer and seamed bags buffer in order to produce bags and store them in the bags buffer. Assuming that at this point, the process of assembly and stitching utilizes one button and one polished seamed bag and requires 30 minutes to sew the button up to the seamed bag. The maximum capacity of the buttons buffer is 3500 buttons. Supplier B can provide 3000 buttons to the factory requiring 18 days (start counting from the day when B&A sends the order request to Supplier B) to construct and deliver them to B&A.

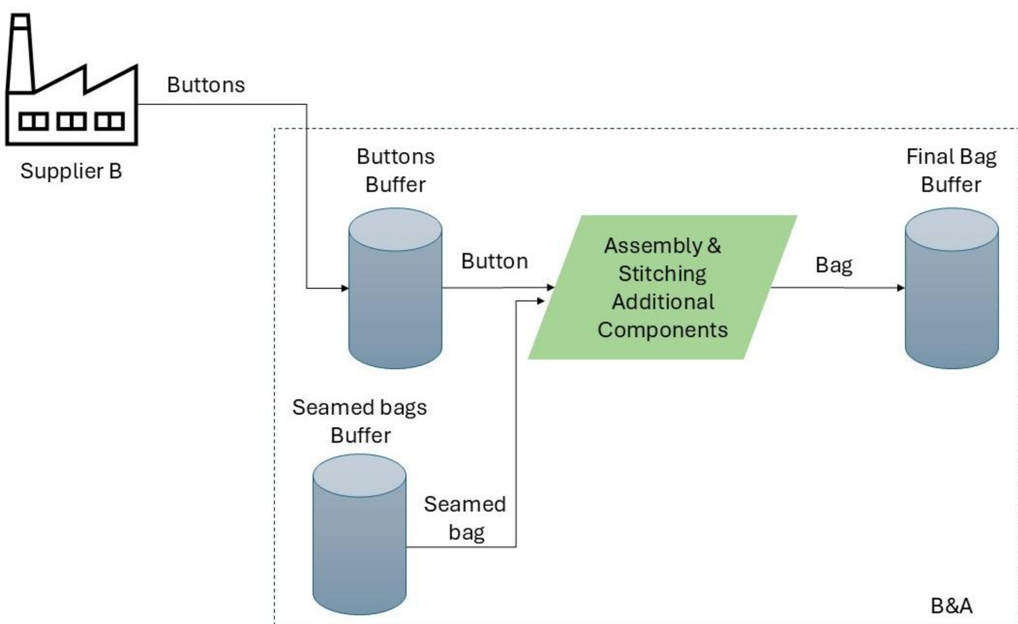

Figure 4: Intra-factory scenario motivated by CIRCULOOS leather pilot (B&A).

To build the abstraction model of the workflow of Figure 4, we need to define a scale to categorize the button capacity of the buffers. In this case, we assumed that level #0 represents the empty buffer, level #1 represents 1-700 buttons, level #2 represents 701-1400 buttons, level #3 represents 1401-2100 buttons, level #4 represents 21001-2800 buttons and level #5 (full) represents 2801-3500 buttons. Assuming that B&A has a 24-h operation, this means that the buffer's level is reduced by 1 per 2100 minutes, since 700 buttons are utilized in 2100 minutes of factory's operation.

The abstraction model of this scenario is presented in the Table 21 of Annex 3. In this case, the process of assembly and stitching of B&A and Supplier B are considered as areas of interest. As shown in Table 10, Process_A is assigned with the ID #1 and Supplier B is assigned with the ID #2.

```
    "Areas of interest": {
      "Name": [ "Assembly_Stitching", " Supplier_B" ],
      "Number": [ 1, 2 ]
```

Table 10: Areas of interest of Scenario C.

The agents considered in this scenario are: the button, the button buffer, the bag and the bag buffer. As shown in Table 11, the button can be utilized in the process of assembly and stitching or can be provided by Supplier B or if there are no button available this is indicated with #0. The bags can also be utilized in the process of assembly and stitching or if there are no bags available, this is indicated with #0. Also, the capacity of the button buffer and the capacity of the bags buffer vary from 0 (empty) to 5 (full).

```
    "agents": {
      "button": [ 0, 1, 2 ],
      "bags": [ 0, 1 ],
      "button_bf": [ 0, 1, 2, 3, 4, 5 ],
      "bags_bf": [ 0, 1, 2, 3, 4, 5 ]
```

Table 11: Agents' state space of Scenario C.

We continue the construction of the abstraction model for Scenario C by modeling the transitions of input materials and products between suppliers, processes and buffer. To do so, we proceed with the modeling of the inter-agent capabilities to define these operations. The inter-agent capabilities specify the production of a new item by a process of a factory utilizing other entities as input resources. Also, the storage of entities in the buffers is also considered as an inter-agent capability of the material agent and the relevant buffer agent. Starting from the button utilization as input in the process of assembly and stitching, the inter-agent capabilities from #1 to #5 in the Table 12 model the reduction of the button buffer level, when the process of assembly and stitching retrieves 1 discrete unit (equals to 700 buttons per 2100 min) from the button buffer and utilize them as input. Furthermore, in case that there are no available buttons to be utilized by B&A, the inter-agent capability #12 models the buttons' order by Supplier B.

```
  "Inter-Agent Capabilities": {
    "1": {
      "cost":[350],
      "button_bf": [ 5, 4 ],
      "button": [ 0, 1 ]
    },
    "2": {
      "cost":[350],
      "button_bf": [ 4, 3 ],
      "button": [ 0, 1 ]
    },
```

```
    "3": {
      "cost":[350],
      "button_bf": [ 3, 2 ],
      "button": [ 0, 1 ]
    },
    "4": {
      "cost":[350],
      "button_bf": [ 2, 1 ],
      "button": [ 0, 1 ]
    },
    "5": {
      "cost":[350],
      "button_bf": [ 1, 0 ],
      "button": [ 0, 1 ]
    },
<…>
    "12": {
      "cost":[70],
      "button_bf": [ 0, 5 ],
      "button": [ 2, 0 ]
    }
```

Table 12: Inter-agent capability of utilization of buttons from the button buffer by the process of assembly and stitching of B&A.

Then, we proceed to model the process of assembly and stitching that utilizes 1 discrete unit of buttons to produce 1 discrete unit of bags (representing 700 bags per 2100 min~17h). The inter-agent capability #6 in Table 13 models the operation of the process of assembly and stitching of B&A.

```
    "6": {
      "cost":[17],
      "button": [ 1, 0 ],
      "bags": [ 0, 1 ]
    },
```

Table 13: Inter-agent capability modeling the operation of the process of assembly and stitching.

Then, the bags produced by the process of assembly and stitching are stored at the bags buffer. The inter-agent capabilities from #7 to #11 in Table 14 model the bags buffer level increase by 1 discrete unit (700 bags).

```
    "7": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 0, 1 ]
    },
    "8": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 1, 2 ]
    },
    "9": {
      "cost":[1],
      "bags": [ 1, 0 ],
```

```
      "bags_bf": [ 2, 3 ]
    },
    "10": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 3, 4 ]
    },
    "11": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 4, 5 ]
    },
```


Table 14: Inter-agent capability of modeling bags storage at the bags buffer.

The solution provided by SCOPT calculates that B&A will run out of buttons after 73 days. Thus, B&A should send an order request to Supplier B on the 59th day of the factory's production.

4.1 Conclusion

In this scenario, an intra-factory logistics scenario motivated by the CIRCULOOS leather pilot case utilizing the SCOPT tool is presented. An abstraction model of a part of the sewing process has been constructed to model the key features of this part of the workflow and the resulting model abstraction was implemented on the SCOPT tool. An abstraction model of a part of sewing process has been constructed to model the key features of this part of the workflow and the resulting model abstraction was implemented on the SCOPT tool. The Factory visualization in the SCDT tool provides valuable information regarding particular instances of the factory workflow during the simulation.

To conclude, this scenario presents the utilization of SCOPT to determine when (or whether) a factory or a process will run out of a specific material in order to prevent disruptions in the supply chain. In this case, the factory will run out of specific input material, that will consequently cause loss of productivity and revenues. Also, in this scenario, SCOPT provides a scheduling plan that resolves potential disruptions in the supply chain.

5 Scenario D: Supply chain optimization keeping the wood pilot supply chain

A supply chain scenario motivated by the CIRCULOOS wood pilot case is presented in Figure 5: Supply chain scenario motivated by the CIRCULOOS wood pilot. showing the interconnections between the factories in the supply chain. There are five factories participating in the supply chain: the original pilot partners HERSO, Plennid and Circuleren and two additional factories D and E, that were introduced to investigate the opportunities available via the SCOPT component utilization. The last two factories were introduced as possible options that consume wood scrap from Plennid and Circuleren, and produce new products, and their introduction was motivated by the applicants' (anonymized) data that were made available to the consortium through CIRCULOOS Open Calls #2 and #3.1. There are also two buffers in this supply chain: the new product buffer and the wood scrap buffer. The new product buffer is considered as the warehouse of a retailer in Europe, whereas the wood scrap buffer is considered as a common location where the wood scraps produced by Plennid and Circuleren are collected. Assuming that the raw wood entities are infinitely available at HERSO. HERSO utilizes 1 unit of raw wood and produces 1 unit of reusable wood and produces 3kg of CO_2. Plennid receives reusable wood from HERSO and produces 1 unit of reusable wood products with 2kg of CO_2. Circuleren receives reusable wood products from Plennid and produces 1 unit of new product and 1 unit of wood scrap with 5kg of CO_2. The wood scrap entities produced by Plennid and Circuleren are collected to the wood scrap buffer and the new product entities produced by Circuleren are collected to the new product buffer. Also, Factory D retrieves 1 unit of wood scrap from the wood scrap buffer and produces new product 1 unit of new product and 1 unit of reusable wood product. Factory E retrieves 1 unit of wood scrap from the wood scrap buffer and produces 1 unit of new product and 1 unit of reusable wood. The new products produced by Factory D and Factory E are stored at the new product buffer, whereas the reusable wood products produced by Factory D and the reusable wood produced by Factory E are absorbed immediately in the market. In this scenario, the objective is to find the supply chain arrangement to minimize the buffer level of the wood scrap produced, producing new products from recycled wood scrap or recycled wood materials, while keeping the current supply chain arrangement of the wood pilot as the core of the proposed solution.

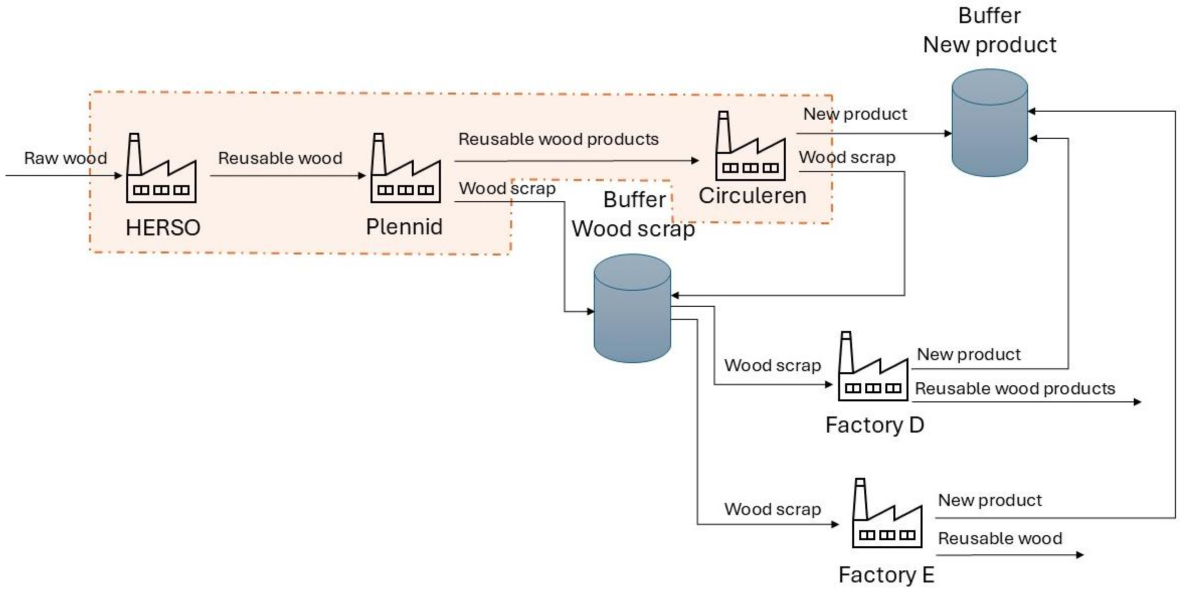

Figure 5: Supply chain scenario motivated by the CIRCULOOS wood pilot.

The abstraction model of Scenario D is presented in Table 22 of Annex 4. The factories participating in the supply chain are considered as the areas of interest. As shown in Table 15: Areas of interest of Scenario D., each factory has a unique ID, e.g. HERSO has the ID #1.

```
    "Areas of interest": {
      "Name": ["HERSO", "Plennid", "Circuleren", "Factory_D", "Factory_E"],
      "Number": [ 1,        2,           3,              4,          5     ]
```

Table 15: Areas of interest of Scenario D.

The agents considered in this scenario, shown in Table 16, are defined as follows: the raw wood, the reusable wood, the wood scrap, the reusable wood products, the new product and the buffers of new product and wood scrap. In this case, the size of the buffers varies, e.g. the maximum capacity for the new product buffer is 3 units, while the maximum capacity of the wood scrap buffer is 5 units.

```
    "agents": {
      "raw_wood": [ 0, 1 ],
      "reusable_wood": [ 0, 1, 2, 5 ],
      "wood_scrap": [ 0, 2, 3, 4, 5 ],
      "reusable_wood_products": [ 0, 2, 3, 4 ],
      "new_product": [ 0, 3, 4, 5 ],
      "new_product_bf": [ 0, 1, 2, 3 ],
      "wood_scrap_bf": [ 0, 1, 2, 3, 4, 5 ]
```

Table 16: Agents' state space of Scenario D.

In this scenario, we need to define also some individual capabilities regarding the raw wood agent, the reusable wood agent and reusable wood products. The individual capabilities enables the transition of a material or a product from a factory to another factory/supplier/consumer directly without the need to store it for a period of time to warehouse or a buffer zone. The individual capabilities are presented in Table 17. In this case, the infinite entities of raw wood in HERSO are defined, the transportation of reusable wood from HERSO to Plennid is defined and the transportation of reusable wood products are defined.

```
  "Capabilities": {
```

```
    "raw_wood": {
      "0": { "1": 14 }
    },
    "reusable_wood": {
      "1": { "2": 8}
    },
    "reusable_wood_products": {
      "2": { "3": 10 }
    }
```

Table 17: Individual capabilities of Scenario D.

To continue, we define the transitions of input materials, output products and scraps between the factories. The inter-agent capabilities specify the production of a new item by a process of a factory utilizing other entities as input resources. Also, the storage of entities in the buffers is also considered as an inter-agent capability of the material agent and the relevant buffer agent. Part of the inter-agent capabilities of Annex 4 are presented in Table 18. For example, the inter-agent capability #1 defines the production of reusable wood by HERSO utilizing raw wood producing 3kg of CO_2. The inter-agent capability #23 defined the production of reusable wood products and new product at Factory D utilizing wood scrap. The inter-agent capabilities from #24 to #26 define the storage of 1 unit of the produced new products by Factory D to the new product buffer, while the buffer's level is increased by 1. The inter-agent capability #27 defines the utilization of 1 unit of wood scrap by Factory E from the wood scrap buffer, while the buffer's level is reduced by 1.

```
  "Inter-Agent Capabilities": {
    "1": {
      "cost":[3],
      "raw_wood": [ 1, 0 ],
      "reusable_wood": [ 0, 1 ]
    },
```

```
<…>
    "23": {
      "cost":[12],
      "wood_scrap": [ 4, 0 ],
      "reusable_wood_products": [ 0, 4 ],
      "new_product": [ 0, 4 ]
    },
     "24": {
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
     "25": {
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
     "26": {
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 2, 3 ]
    },
    "27": {
      "cost":[1],
      "wood_scrap_bf": [ 5, 4 ],
      "wood_scrap": [ 0, 5 ]
<…>
```

Table 18: Part of inter-agent capabilities of Scenario D.

Assuming that there are available resources of raw wood at HERSO and all the buffers are empty. The solution provided by SCOPT is analyzed as follows.

Step 1	HERSO utilizes 1 unit of raw wood to produce 1 unit of reusable wood.
Step 2	The reusable wood entity is transported to Plennid to be utilized as input to produce 1 unit of reusable wood product and 1 unit of wood scrap.
Step 3	The wood scrap is stored at the wood scrap buffer (the level of the wood scrap buffer is increased to 1).
Step 4	Factory E retrieves wood scrap from the wood scrap buffer (wood scrap buffer level is reduced to 0) and produces 1 unit of new product that is stored to the new product buffer (new product buffer's level is increased to 1) and reusable wood that is provided to the market.
Step 5	The reusable wood product from Plennid is utilized as input material from Circuleren to produce 1 unit of new product and 1 unit of wood scrap.
Step 6	The new product is stored at the new product buffer (new product buffer's level is increased to 2) and the wood scrap is stored at the wood scrap buffer (wood scrap buffer's level is increased to 1).
Step 7	Factory D retrieves wood scrap from the wood scrap buffer to produce 1 unit of new product and 1 unit of reusable wood product.
Step 8	The new product is stored at the new product buffer (new product buffer level is increased to 3) and the reusable wood product is provided to the market.

The objective is fulfilled since the core of the supply chain remains unchanged (HERSO, Plennid and Circuleren are included in the solution), 3 new products have been produced and stored at the new product buffer and the wood scrap has been eliminated to 0.

5.1 Conclusion

In this section, a supply chain scenario motivated by the CIRCULOOS wood pilot case is presented utilizing the SCOPT tool. An abstraction model of the supply chain has been constructed to model the key features of the supply chain and the resulting model abstraction was implemented on the SCOPT tool. A scenario has been investigated to find the supply chain arrangement to eliminate the wood scrap produced and produce new products from recycled wood scrap or recycled wood materials while keeping the current supply chain arrangement of the wood pilot as the core of the proposed supply chain. Utilizing SCOPT, the supply chain arrangement provided engaging the main Factories of the supply chain (HERSO, Plennid and Circuleren) while introducing Factory D and Factory E to recycle the scrap produced by HERSO, Plennid and Circuleren in order to produce new products from recycled scrap.

To conclude, in this scenario SCOPT is leveraged to provide a feasible solution to a scenario that maintains a core of three companies in a supply chain while exploring the benefits of possibly including additional companies in the supply chain in order to reduce the wood scrap.

6 Conclusions

This deliverable describes the second stage of the SCOPT development and the implementation of SCOPT component to scenarios motivated by the CIRCULOOS pilots (plastic, leather, wood). Scenarios present the capabilities of SCOPT tool to tackle several supply chain optimization problems as well as intra-factory logistics optimization problems. The proposed solutions provide:

- Alternatives to include additional suppliers in the existing supply chains,
- Feasible solutions for supply chain stability inspected by SCDT,
- Supply chain arrangements keeping the core of the existing supply chain unchanged providing the capability to include additional suppliers in the existing model.

The abstraction model is a simplified representation, capturing key aspects of a supply chain or intra-factory logistics, while keeping the computational complexity at a tractable level. It is utilized by SCOPT to tackle optimization problems and provide valid arrangements and scheduling plans for the actors of the supply chain. Investigation of possible solutions for supply chain arrangements and scheduling problems and intra-factory logistics problems, depends on the level of the abstraction model. The more data the factories provide, the more detailed analysis of the CIRCULOOS pilots can be. It is important for the modelling process to determine the necessary details of the actual system for achieving the model's purpose ensuring that the abstract model still retains that critical information needed to serve its purpose.

Implementation of the SCOPT recommendations to the CIRCULOOS pilots can potentially provide several benefits to the organizations, including:

- Supply chain arrangements for the CIRCULOOS plastic pilot to produce a certain number of products reducing the leather waste.
- Supply chain arrangements for the CIRCULOOS plastic pilot including additional actors, that serve as alternative suppliers in the existing supply chain model.
- Scheduling plans for the CIRCULOOS leather pilot to prevent potential disruptions in the supply chain due to running out of materials/products that are utilized in a specific process of the factory.
- Supply chain arrangements for the CIRCULOOS wood pilot, keeping the supply chain of the CIRCULOOS wood pilot as the core of the proposed supply chain, to produce final products while reducing the wood scrap.

Annex 1: Abstraction model (SPECTER's task specification) of the supply chain of Scenario A


```
{
  "Environment": {
    "Areas of interest": {
      "Name": [ "LOLO", "Thermolympics", "Factory_Z", "Factory_B" ],
      "Number": [ 1, 2, 3, 4 ]
    },
    "agents": {
      "plastic_pellet": [ 0, 1, 2 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 1, 2, 3, 4 ],
      "plastic_waste_bf": [ 0, 1, 2, 3, 4, 5 ],
      "plastic_pellet_bf": [ 0, 1, 2, 3, 4, 5 ],
      "new_product_bf": [ 0, 1, 2, 3, 4, 5 ]
    }
  },
  "Inter-Agent Capabilities": {
    "1": {
      "cost":[15],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 4 ]
    },
    "2": {
      "cost":[15],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 4 ]
    },
    "3": {
      "cost":[15],
      "plastic_waste_bf": [ 2, 2 ],
      "plastic_waste": [ 0, 4 ]
    },
    "4": {
      "cost":[15],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 4 ]
    },
    "5": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 0, 2 ]
    },
    "6": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 1, 3 ]
    },
    "7": {
```

```
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 2, 4 ]
    },
    "8": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 3, 5 ]
    },
    "9": {
      "cost":[8],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 3 ]
    },
    "10": {
      "cost":[8],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 3 ]
    },
    "11": {
      "cost":[8],
      "plastic_waste_bf": [ 2, 2 ],
      "plastic_waste": [ 0, 3 ]
    },
    "12": {
      "cost":[8],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 3 ]
    },
    "13": {
      "cost":[8],
      "plastic_waste_bf": [ 4, 4 ],
      "plastic_waste": [ 0, 3 ]
    },
    "14": {
      "cost":[8],
      "plastic_waste_bf": [ 5, 5 ],
      "plastic_waste": [ 0, 3 ]
    },
    "15": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 0, 1 ]
    },
    "16": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 1, 2 ]
    },
    "17": {
      "cost":[1],
```

```
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 2, 3 ]
    },
    "18": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 3, 4 ]
    },
    "19": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 4, 5 ]
    },
    "20": {
      "cost":[1],
      "plastic_waste_bf": [ 5, 1 ],
      "plastic_waste": [ 0, 1 ]
    },
    "21": {
      "cost":[1],
      "plastic_waste_bf": [ 4, 0 ],
      "plastic_waste": [ 0, 1 ]
    },
    "22": {
      "cost":[5],
      "plastic_waste": [ 1, 0 ],
      "plastic_pellet": [ 0, 1 ]
    },
    "23": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 0, 2 ]
    },
    "24": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 1, 3 ]
    },
    "25": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 2, 4 ]
    },
    "26": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 3, 5 ]
    },
    "27": {
      "cost":[1],
      "plastic_pellet_bf": [ 5, 1 ],
```

```
      "plastic_pellet": [ 0, 2 ]
    },
    "28": {
      "cost":[1],
      "plastic_pellet_bf": [ 4, 0 ],
      "plastic_pellet": [ 0, 2 ]
    },
    "29": {
      "cost":[10],
      "plastic_pellet": [ 2, 0 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 2 ]
    },
    "30": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
    "31": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
    "32": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 2, 3 ]
    },
    "33": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 3, 4 ]
    },
    "34": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 4, 5 ]
    },
    "35": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 0, 1 ]
    },
    "36": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 1, 2 ]
    },
    "37": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
```

```
      "plastic_waste_bf": [ 2, 3 ]
    },
    "38": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 3, 4 ]
    },
    "39": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 4, 5 ]
    }
  },

  "Current positions": {
      "plastic_pellet": [ 0 ],
      "new_product": [ 0 ],
      "plastic_waste": [ 0 ],
      "plastic_waste_bf": [ 0 ],
      "plastic_pellet_bf": [ 0 ],
      "new_product_bf": [ 0 ]
  },

  "Goal positions": {
      "new_product_bf": [ 2 ]
  }
}
```


Table 19: Abstraction model of Scenario A.

Annex 2: Abstraction model (SPECTER's task specification) of the supply chain of Scenario B.


```
{
  "Environment": {
    "Areas of interest": {
      "Name": ["LOLO", "Thermolympics", "Factory_Z", "Factory_B", "Factory_A"],
      "Number": [ 1,  2,  3,  4,  5 ]
    },
    "agents": {
      "plastic_pellet": [ 0, 1, 2, 5 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 1, 2, 3, 4 ],
      "plastic_waste_bf": [ 0, 1, 2, 3, 4, 5 ],
      "new_product_bf": [ 0, 1, 2, 3, 4, 5 ],
      "plastic_pellet_bf": [ 0, 1, 2, 3, 4, 5 ]
    }
  },

  "Inter-Agent Capabilities": {
    "1": {
      "cost":[15],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 4 ]
    },
    "2": {
      "cost":[15],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 4 ]
    },
    "3": {
      "cost":[15],
      "plastic_waste_bf": [ 2, 2 ],
      "plastic_waste": [ 0, 4 ]
    },
    "4": {
      "cost":[15],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 4 ]
    },
    "5": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 0, 2 ]
    },
    "6": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 1, 3 ]
    },
```

```
    "7": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 2, 4 ]
    },
    "8": {
      "cost":[1],
      "plastic_waste": [ 4, 0 ],
      "plastic_waste_bf": [ 3, 5 ]
    },
    "9": {
      "cost":[8],
      "plastic_waste_bf": [ 0, 0 ],
      "plastic_waste": [ 0, 3 ]
    },
    "10": {
      "cost":[8],
      "plastic_waste_bf": [ 1, 1 ],
      "plastic_waste": [ 0, 3 ]
    },
    "11": {
      "cost":[8],
      "plastic_waste_bf": [ 2, 2 ],
      "plastic_waste": [ 0, 3 ]
    },
    "12": {
      "cost":[8],
      "plastic_waste_bf": [ 3, 3 ],
      "plastic_waste": [ 0, 3 ]
    },
    "13": {
      "cost":[8],
      "plastic_waste_bf": [ 4, 4 ],
      "plastic_waste": [ 0, 3 ]
    },
    "14": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 0, 1 ]
    },
    "15": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 1, 2 ]
    },
    "16": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 2, 3 ]
    },
```

```
    "17": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 3, 4 ]
    },
    "18": {
      "cost":[1],
      "plastic_waste": [ 3, 0 ],
      "plastic_waste_bf": [ 4, 5 ]
    },
    "19": {
      "cost":[1],
      "plastic_waste_bf": [ 5, 1 ],
      "plastic_waste": [ 0, 1 ]
    },
    "20": {
      "cost":[1],
      "plastic_waste_bf": [ 4, 0 ],
      "plastic_waste": [ 0, 1 ]
    },
    "21": {
      "cost":[5],
      "plastic_waste": [ 1, 0 ],
      "plastic_pellet": [ 0, 1 ]
    },
    "22": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 0, 2 ]
    },
    "23": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 1, 3 ]
    },
    "24": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 2, 4 ]
    },
    "25": {
      "cost":[1],
      "plastic_pellet": [ 1, 0 ],
      "plastic_pellet_bf": [ 3, 5 ]
    },
    "26": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 0, 1 ]
    },
```

```
    "27": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 1, 2 ]
    },
    "28": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 2, 3 ]
    },
    "29": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 3, 4 ]
    },
    "30": {
      "cost":[5],
      "plastic_pellet": [ 5, 0 ],
      "plastic_pellet_bf": [ 4, 5 ]
    },
    "31": {
      "cost":[1],
      "plastic_pellet_bf": [ 5, 1 ],
      "plastic_pellet": [ 0, 2 ]
    },
    "32": {
      "cost":[1],
      "plastic_pellet_bf": [ 4, 0 ],
      "plastic_pellet": [ 0, 2 ]
    },
    "33": {
      "cost":[10],
      "plastic_pellet": [ 2, 0 ],
      "new_product": [ 0, 2 ],
      "plastic_waste": [ 0, 2 ]
    },
    "34": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
    "35": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
    "36": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 2, 3 ]
```

```
    },
    "37": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 3, 4 ]
    },
    "38": {
      "cost":[1],
      "new_product": [ 2, 0 ],
      "new_product_bf": [ 4, 5 ]
    },
    "39": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 0, 1 ]
    },
    "40": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 1, 2 ]
    },
    "41": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 2, 3 ]
    },
    "42": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 3, 4 ]
    },
    "43": {
      "cost":[1],
      "plastic_waste": [ 2, 0 ],
      "plastic_waste_bf": [ 4, 5 ]
    }
  },

  "Current positions": {
      "plastic_waste_bf": [ 0 ]
  },

  "Goal positions": {
      "plastic_pellet_bf": [ 5 ],
      "new_product_bf": [ 2 ]
  }
}
```


Table 20: Abstraction model of Scenario B.

Annex 3: Abstraction model (SPECTER's task specification) of the supply chain of Scenario C


```
{
  "Environment": {
    "Areas of interest": {
      "Name": [ "Assembly_Stitching", " Supplier_B" ],
      "Number": [ 1, 2 ]
    },
    "agents": {
      "button": [ 0, 1, 2 ],
      "bags": [ 0, 1 ],
      "button_bf": [ 0, 1, 2, 3, 4, 5 ],
      "bags_bf": [ 0, 1, 2, 3, 4, 5 ]
    }
  },


  "Inter-Agent Capabilities": {
    "1": {
      "cost":[350],
      "button_bf": [ 5, 4 ],
      "button": [ 0, 1 ]
    },
    "2": {
      "cost":[350],
      "button_bf": [ 4, 3 ],
      "button": [ 0, 1 ]
    },
    "3": {
      "cost":[350],
      "button_bf": [ 3, 2 ],
      "button": [ 0, 1 ]
    },
    "4": {
      "cost":[350],
      "button_bf": [ 2, 1 ],
      "button": [ 0, 1 ]
    },
    "5": {
      "cost":[350],
      "button_bf": [ 1, 0 ],
      "button": [ 0, 1 ]
    },
    "6": {
      "cost":[17],
      "button": [ 1, 0 ],
      "bags": [ 0, 1 ]
    },
```

```
    "7": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 0, 1 ]
    },
    "8": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 1, 2 ]
    },
    "9": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 2, 3 ]
    },
    "10": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 3, 4 ]
    },
    "11": {
      "cost":[1],
      "bags": [ 1, 0 ],
      "bags_bf": [ 4, 5 ]
    },
    "12": {
      "cost":[70],
      "button_bf": [ 0, 5 ],
      "button": [ 2, 0 ]
    }
  },

  "Current positions": {
      "button_bf": [ 5 ]
  },

  "Goal positions": {
      "button_bf": [ 4 ],
      "button": [ 1 ],
      "bags_bf": [ 5 ]
  }
}
```


Table 21: Abstraction model of Scenario C.

Annex 4: Abstraction model (SPECTER's task specification) of the supply chain of Scenario D


```
{
  "Environment": {
    "Areas of interest": {
      "Name": [ "HERSO", "Plennid", "Circuleren", "Factory_D", "Factory_E"],
      "Number": [ 1,              2,           3,           4,          5      ]
    },
    "agents": {
      "raw_wood": [ 0, 1 ],
      "reusable_wood": [ 0, 1, 2, 5 ],
      "wood_scrap": [ 0, 2, 3, 4, 5 ],
      "reusable_wood_products": [ 0, 2, 3, 4 ],
      "new_product": [ 0, 3, 4, 5 ],
      "new_product_bf": [ 0, 1, 2, 3 ],
      "wood_scrap_bf": [ 0, 1, 2, 3, 4, 5 ]
    }
  },

  "Capabilities": {
    "raw_wood": {
      "0": { "1": 14 }
    },
    "reusable_wood": {
      "1": { "2": 8}
    },
    "reusable_wood_products": {
      "2": { "3": 10 }
    }
  },

  "Inter-Agent Capabilities": {
    "1": {
      "cost":[3],
      "raw_wood": [ 1, 0 ],
      "reusable_wood": [ 0, 1 ]
    },
    "3": {
      "cost":[2],
      "reusable_wood": [ 2, 0 ],
      "reusable_wood_products": [ 0, 2 ],
      "wood_scrap": [ 0, 2 ]
    },
    "4": {
      "cost":[1],
      "wood_scrap": [ 2, 0 ],
      "wood_scrap_bf": [ 0, 1 ]
    },
    "5": {
```

```
      "cost":[1],
      "wood_scrap": [ 2, 0 ],
      "wood_scrap_bf": [ 1, 2 ]
    },
    "6": {
      "cost":[1],
      "wood_scrap": [ 2, 0 ],
      "wood_scrap_bf": [ 2, 3 ]
    },
    "7": {
      "cost":[1],
      "wood_scrap": [ 2, 0 ],
      "wood_scrap_bf": [ 3, 4 ]
    },
    "8": {
      "cost":[1],
      "wood_scrap": [ 2, 0 ],
      "wood_scrap_bf": [ 4, 5 ]
    },
    "9": {
      "cost":[5],
      "reusable_wood_products": [ 3, 0 ],
      "new_product": [ 0, 3 ],
      "wood_scrap": [ 0, 3 ]
    },
    "10": {
      "cost":[1],
      "new_product": [ 3, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
    "11": {
      "cost":[1],
      "new_product": [ 3, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
    "12": {
      "cost":[1],
      "new_product": [ 3, 0 ],
      "new_product_bf": [ 2, 3 ]
    },
    "13": {
      "cost":[1],
      "wood_scrap": [ 3, 0 ],
      "wood_scrap_bf": [ 0, 1 ]
    },
    "14": {
      "cost":[1],
      "wood_scrap": [ 3, 0 ],
      "wood_scrap_bf": [ 1, 2 ]
    },
    "15": {
```

```
      "cost":[1],
      "wood_scrap": [ 3, 0 ],
      "wood_scrap_bf": [ 2, 3 ]
    },
    "16": {
      "cost":[1],
      "wood_scrap": [ 3, 0 ],
      "wood_scrap_bf": [ 3, 4 ]
    },
    "17": {
      "cost":[1],
      "wood_scrap": [ 3, 0 ],
      "wood_scrap_bf": [ 4, 5 ]
    },
    "18": {
      "cost":[1],
      "wood_scrap_bf": [ 5, 4 ],
      "wood_scrap": [ 0, 4 ]
    },
    "19": {
      "cost":[1],
      "wood_scrap_bf": [ 4, 3 ],
      "wood_scrap": [ 0, 4 ]
    },
    "20": {
      "cost":[1],
      "wood_scrap_bf": [ 3, 2 ],
      "wood_scrap": [ 0, 4 ]
    },
    "21": {
      "cost":[1],
      "wood_scrap_bf": [ 2, 1 ],
      "wood_scrap": [ 0, 4 ]
    },
    "22": {
      "cost":[1],
      "wood_scrap_bf": [ 1, 0 ],
      "wood_scrap": [ 0, 4 ]
    },
    "23": {
      "cost":[12],
      "wood_scrap": [ 4, 0 ],
      "reusable_wood_products": [ 0, 4 ],
      "new_product": [ 0, 4 ]
    },
     "24": {
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
     "25": {
```

```
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
     "26": {
      "cost":[1],
      "new_product": [ 4, 0 ],
      "new_product_bf": [ 2, 3 ]
    },
    "27": {
      "cost":[1],
      "wood_scrap_bf": [ 5, 4 ],
      "wood_scrap": [ 0, 5 ]
    },
    "28": {
      "cost":[1],
      "wood_scrap_bf": [ 4, 3 ],
      "wood_scrap": [ 0, 5 ]
    },
    "29": {
      "cost":[1],
      "wood_scrap_bf": [ 3, 2 ],
      "wood_scrap": [ 0, 5 ]
    },
    "30": {
      "cost":[1],
      "wood_scrap_bf": [ 2, 1 ],
      "wood_scrap": [ 0, 5 ]
    },
    "31": {
      "cost":[1],
      "wood_scrap_bf": [ 1, 0 ],
      "wood_scrap": [ 0, 5 ]
    },
    "32": {
      "cost":[10],
      "wood_scrap": [ 5, 0 ],
      "reusable_wood": [ 0, 5 ],
      "new_product": [ 0, 5 ]
    },
    "33": {
      "cost":[1],
      "new_product": [ 5, 0 ],
      "new_product_bf": [ 0, 1 ]
    },
    "34": {
      "cost":[1],
      "new_product": [ 5, 0 ],
      "new_product_bf": [ 1, 2 ]
    },
    "35": {
```

```
      "cost":[1],
      "new_product": [ 5, 0 ],
      "new_product_bf": [ 2, 3 ]
    }
  },

  "Current positions": {
      "raw_wood": [ 0 ],
      "reusable_wood": [ 0 ],
      "wood_scrap": [ 0 ],
      "reusable_wood_products": [ 0 ],
      "new_product": [ 0 ],
      "new_product_bf": [ 0 ],
      "wood_scrap_bf": [ 0 ]
  },

  "Goal positions": {
      "raw_wood": [ 0 ],
      "reusable_wood": [ 5 ],
      "wood_scrap": [ 0 ],
      "reusable_wood_products": [ 4 ],
      "new_product": [ 0 ],
      "new_product_bf": [ 3 ],
      "wood_scrap_bf": [ 0 ]
  }
}
```


Table 22: Abstraction model of Scenario D.

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