# Production Planning and Scheduling of a Polymer Resin Production Facility using SchedulePro Cloud®

**INTELLIGEN, INC.**

*Simulation, Design, and Scheduling Tools for the Process Manufacturing Industries*

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# 1 Introduction

The purpose of this example is to demonstrate different ways to schedule a multiproduct facility using SchedulePro Cloud and how to use the outputs of the cloud application to optimize and update the schedule. Specifically, this example will guide users through the process of creating a production schedule from scratch. This task requires the declaration of the following items:

- A workspace and a scheduling board.
- A facility and its resources.
- At least one recipe with procedures and operations.
- At least one campaign.

It will also explain how to account for **equipment changeovers**. Changeover times may occur due to cleaning in between batches, and equipment changes. Moreover, this example will demonstrate the modeling of production suites (equipment trains) within a facility using the concept of **compatibility tags**. Finally, the representation and resolution of scheduling disruptions (such as delays, equipment failures, etc.) will be discussed. This example is intended for individuals that are in charge of planning and scheduling manufacturing activities for multiproduct facilities. Engineers involved in the design and debottlenecking of such facilities will find the material of value as well. The facility in this example produces synthetic polymer resins. The equipment diagram for this plant is shown in Figure 1.

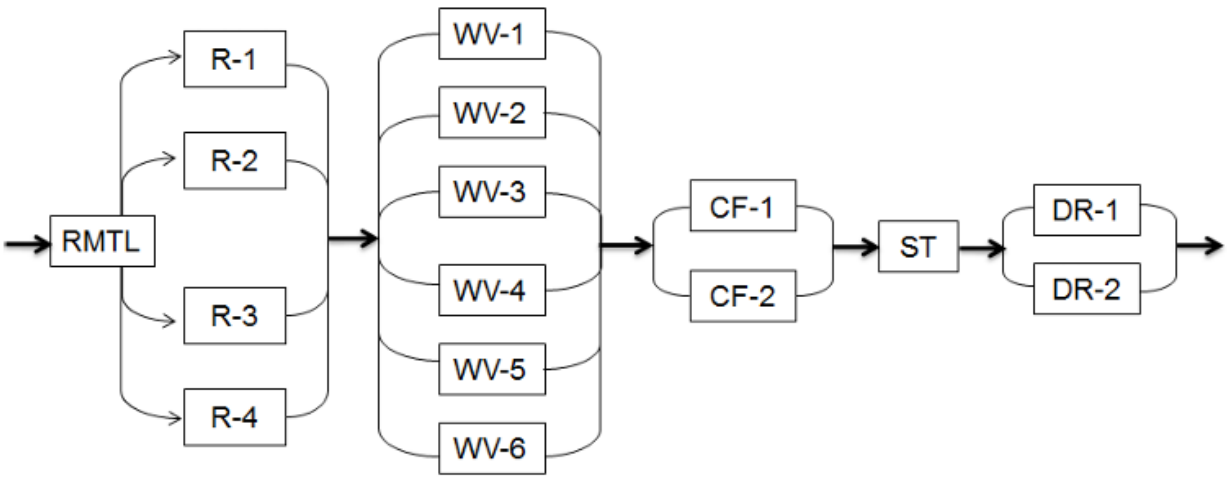



*Figure 1: Equipment diagram for polymer production facility.*

The raw materials are fed by a single transfer line (RMTL) into one of the four reactors (R-1 through R-4). Only one reactor can be charged at a time. When polymerization is completed, the solid particles are washed in one of the six wash vessels (WV-1 through WV-6) to remove the unreacted monomer and the catalyst. Then the material is centrifuged in one of the two centrifuges (CF-1 or CF-2) and subsequently stored in mobile totes (ST). Finally, the product is dried in one of the two dryers (DR-1 or DR-2). In Cases A and B (described below), a batch of a product can take any path (from left-to-right) through the equipment network. In other words, it is assumed that a batch can move from any of the four reactors to any of the six wash vessels, then to either of the two centrifuges, etc. It is also assumed that all reactors have the same capacity, all wash vessels have the same capacity, etc. Furthermore, all products can use any available equipment path (i.e., there isn't a dedicated equipment train associated with each specific product recipe). Cases C and D (described below) illustrate a more advanced scenario in which the equipment is split into two production lines.

**SchedulePro Cases Associated with this Example:**

A. **Case A** represents a 12-batch campaign for a single product. The campaign is free to use any of the equipment within the plant shown in Figure 1, and no other products are produced in the plant at this time. In other words, this case is representative of a single-product facility. The scheduling board associated with this case is named **Case-A1** and is part of the **Polymer Resin** sample workspace. This case also provides information on recipe creation and other basic scheduling concepts.
B. **Case B** shows how to represent production campaigns within a "multiproduct" facility. This facility runs campaigns of three different resins. This case also includes a sub-case which demonstrates the use of a "changeover matrix" that automatically determines the reactor cleaning times between batches. Case-B1 and Case-B2 are the two scheduling boards that correspond to this case.
C. **Case C** also represents a multiproduct facility schedule based on three different resins, but this time the equipment is separated into Suite 1 and Suite 2, as shown in Figure 28. This is a useful case for understanding how to use the compatibility tags in SchedulePro Cloud to model equipment trains (sometimes referred to as "production lines"). The scheduling board that corresponds to this case is named Case-C.
D. **Case D** explains how to track production activities and resolve conflicts on an on-going basis. It expands upon Case C to incorporate production delays and preventive maintenance activities. This case is useful for schedulers who will be working with SchedulePro Cloud on a daily basis to monitor and update

plant schedules and to plan new campaigns. Case-D1 and Case-D2 are the two scheduling boards that correspond to this case.

All of the above cases are described in greater detail in the following sections.

In order to load the complete examples into the application, go to the landing page, select the “Create Sample Workspace” option and navigate to the “Examples” tab. Select the desired example and click “Next”. On the final window, you may optionally edit the suggested name and then click “Create” to create the sample workspace.

The application creates the example workspace, which includes one scheduling board for each example case, and automatically switches to the first scheduling board. In order to navigate between the various example cases/scheduling boards, click the ⇄ icon in the information box at the middle-top of the page (see figure below) and select the desired scheduling board from the dropdown menu.

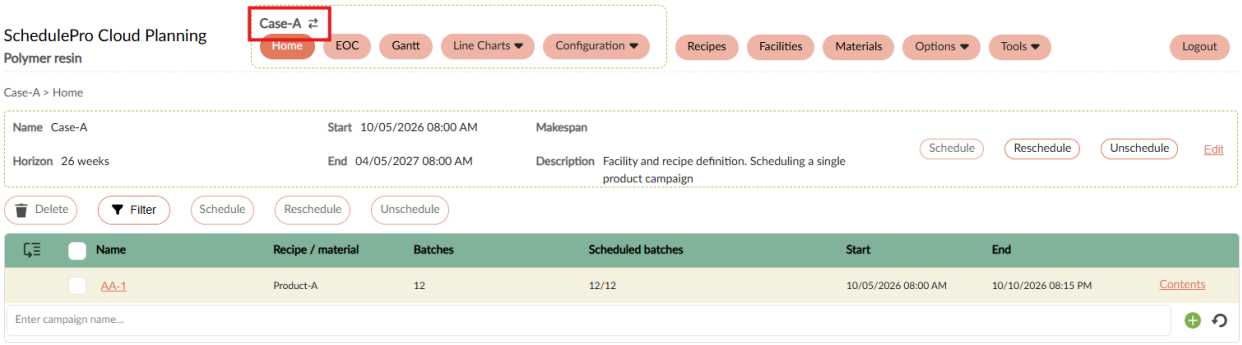



*Figure 2: Switching scheduling board in a a workspace*

# 2 Case A: Single Product Facility

Case A represents the production of a single resin utilizing the equipment network shown in Figure 1. The key pieces of information that describe a SchedulePro Cloud project can be classified into three categories: **Facilities**, **Materials** and **Recipes**. On the main menu view of the application, users can access and modify the data behind each category using the corresponding menu buttons, as shown in Figure 3.

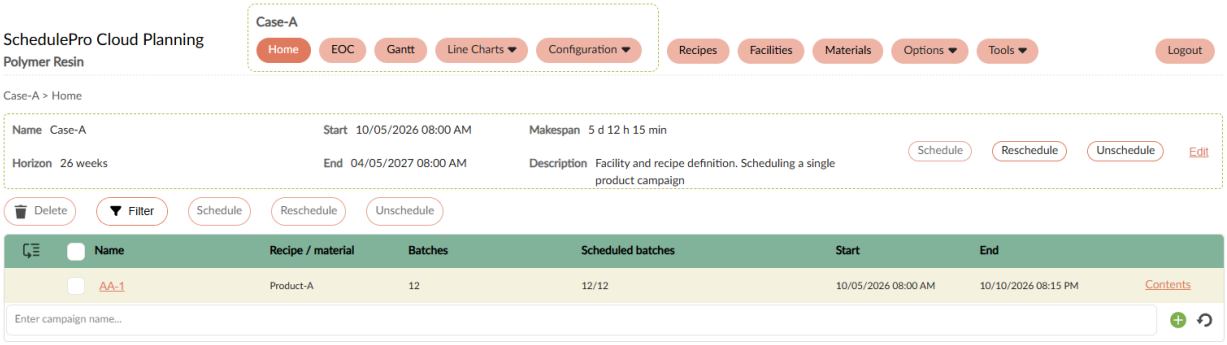



*Figure 3: View of the Home page of the scheduling board of Case A.*

The Home page of a scheduling board also contains the scheduling board's information box (below the main menu buttons). This box displays high level information related to the scheduling board's identity (name and description), and the **Scheduling Horizon** (start datetime, end datetime, length and makespan). This box also contains three action buttons that can be used to schedule, reschedule or unscheduled campaigns. The properties of the scheduling board's information box can be edited by clicking on the corresponding **Edit** button.

Recipes created in SchedulePro Cloud make use of facilities and their resources. Recipes, facilities and resources should all be part of the same workspace[1]. From a practical point of view, it is more convenient to declare the facility information first before the declaration of the recipes, especially if both are to be entered directly in SchedulePro Cloud. This is because recipes make use of resources declared at the facility level.

## 2.1 Defining a new facility

Facilities can be defined by selecting the **Facilities** menu item. In the facilities page that opens, users can enter the name of the facility and click on the add button, ⊕, or press Enter to create it (see Figure 4). At this point a new facility named "Resin-Plant" was created. Currently, the supported resources that a facility can have include **Equipment**, **Staff**, **Labor**, and **Storage Units**. Equipment is an essential resource that is required by every recipe. Hence, the specification of equipment units at the facility level is mandatory. The definition and inclusion of all the other resources in a model is optional.

[1] For more details regarding the organization of planning data in workspaces and scheduling boards please refer to the User's Manual

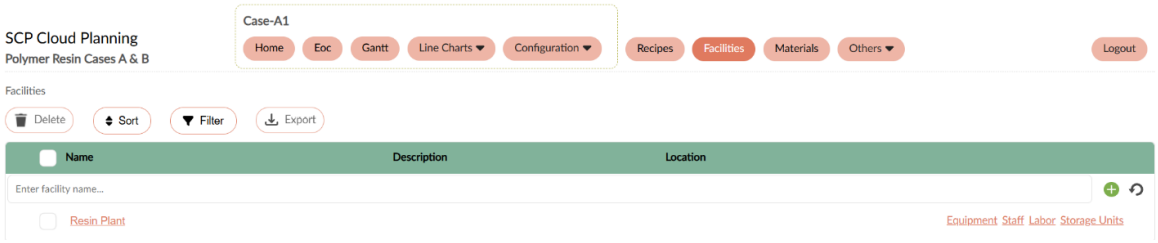



*Figure 4: View of the Facilities page of a SchedulePro Cloud project.*

## 2.2 Declaring equipment units

To declare Equipment units, click on the **Equipment** menu item to navigate to the Equipment list within the Resin-Plant Facility. Initially, the equipment list was empty. New equipment units can be created by typing the name of the unit in the "Enter equipment name…" field followed by clicking on the add button, , or by pressing the enter key on the keyboard. Optionally, users can specify the type of equipment too. After an equipment item has been created its type can be specified by typing the **Type** name (e.g. Reactor, Centrifuge etc.) in the combo box of the **Type** column. New equipment types are appended to the **Type** combo box and are available for selection during the creation of another similar equipment item (see Figure 5). The various equipment units that were declared within the Resin Plant facility are listed in Table 1 below.

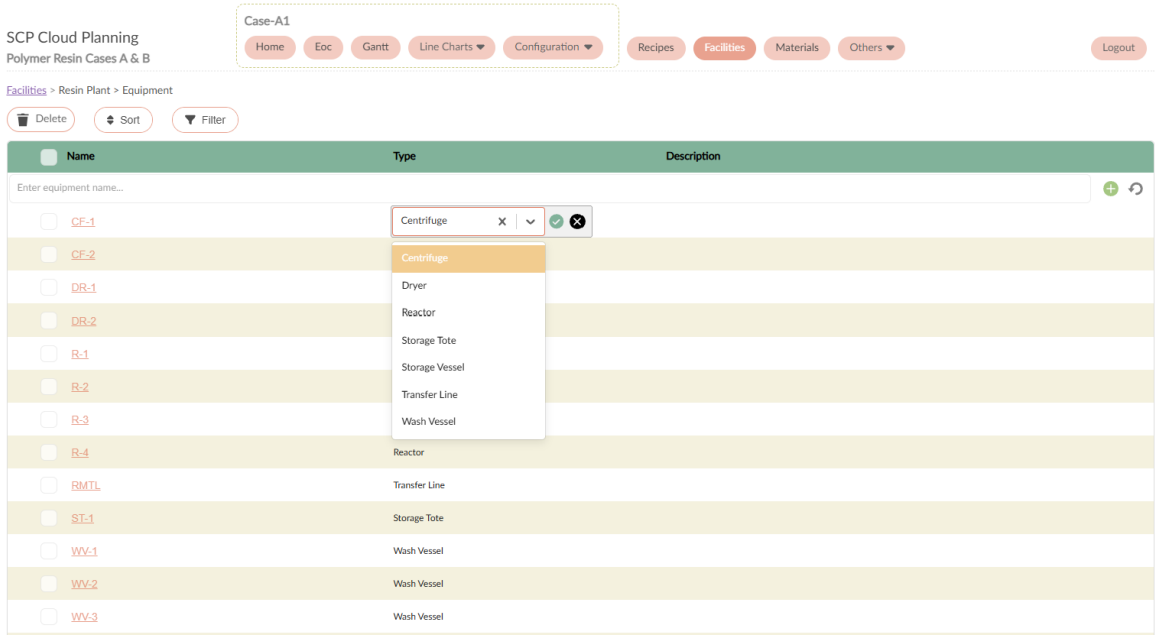



*Figure 5: View of the Equipment page of a SchedulePro Cloud project.*

*Table 1: List of the equipment units that are available in the Resin Plant Facility*

| Equipment Name | Equipment Type |
|---|---|
| R-1 | Reactor |
| R-2 | Reactor |
| R-3 | Reactor |
| R-4 | Reactor |
| CF-1 | Centrifuge |
| CF-2 | Centrifuge |
| WV-1 | Wash Vessel |
| WV-2 | Wash Vessel |
| WV-3 | Wash Vessel |
| WV-4 | Wash Vessel |
| WV-5 | Wash Vessel |
| WV-6 | Wash Vessel |
| ST-1 | Storage Tote |
| DR-1 | Dryer |
| DR-2 | Dryer |
| RMTL | Transfer Line |

## 2.3 Defining a new recipe

To create a new recipe, click on the **Recipes** menu item which will redirect you to the Recipes page. A new recipe can be created by typing its name in the "Enter recipe name..." field. Optionally, a description of the recipe can be added by clicking on the **Edit** button ( ) that appears when hovering over the **Name** column of the recipes table.

In this example the first recipe that was created was given the name **Product-A.** The contents of the **Product-A** recipe can be viewed by clicking on the **Contents** button, which is located in the right-hand side of the Product-A recipe row in the recipes table. The **Product-A** recipe contents page contains the recipe information box (below the main menu buttons). This box displays high level information related to the Name, Size, Batch Time, Minimum Cycle Time, Description and the status of the recipe (valid or invalid). The recipe information can be edited by clicking on the **Edit** button located on the right-hand side of the recipe information box. Using the side-panel that pops up from the right side of the screen, users can edit the general information about the recipe (identification, recipe tags and recipe attributes) and information related to its size and its adaptive inputs / outputs, as shown in Figure 6.

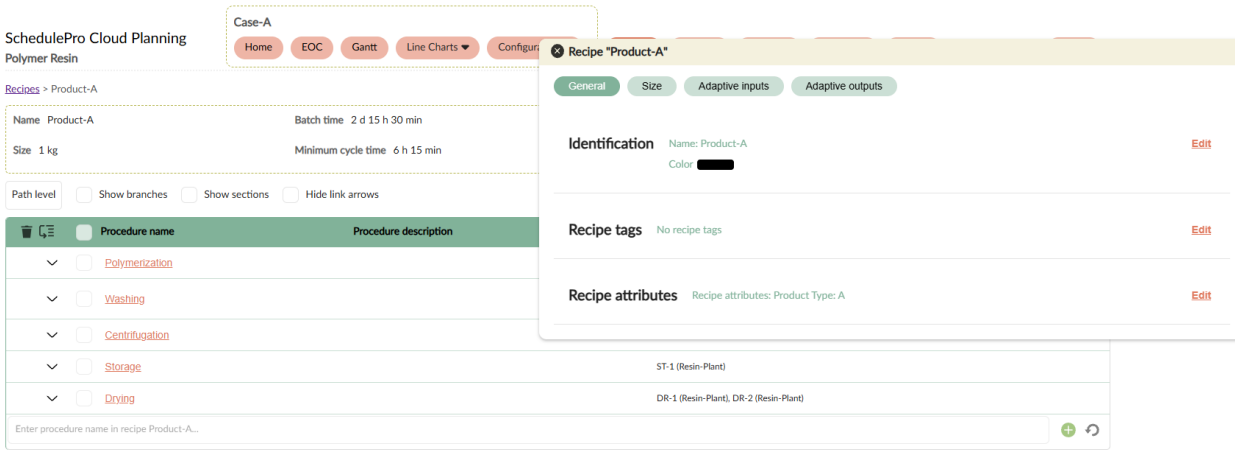



*Figure 6: View of the "Edit Recipe" side-panel.*

The size of the recipe can be specified on a mass, volume or discrete entity basis. SchedulePro Cloud utilizes size information for recipe scaling, equipment selection based on batch-size and size-based operation duration calculations. Specifying the recipe size is optional and outside of the scope of this example. The use of recipe tags, adaptive inputs and adaptive outputs is also outside the scope of this example. Lastly, the recipe the recipe attributes feature will be utilized in the *3.3 Case B2: Considering* Changeover sub-section of this example.

Similarly to a SchedulePro recipe, a recipe in SchedulePro Cloud includes one or more unit **procedures**, and each unit procedure is composed of one or more **operations**. For simplicity, the term *procedure* will be used hereafter to refer to a *unit procedure*, unless otherwise specified. A procedure typically represents a processing step that is carried out in a piece of equipment (e.g., reaction, centrifugation, drying, etc.). Operations represent the tasks executed during a procedure. For instance, a reaction procedure may include the following operations: **Charge Materials, React, Transfer Materials Out, Clean Reactor**. Moreover, recipes make use of equipment units, materials, labor and other resources that are available within a facility. Hence, before creating any recipes it is practical to declare a facility and its resources.

Procedures may be optionally organized into **Sections** and **Branches**. SchedulePro Cloud, Sections and Branches represent two intermediate hierarchical levels. A Branch sits below the overall recipe and above Sections. In turn, a Section sits below a Branch and above individual procedures. Sections are typically used to group procedures dedicated to a common processing objective (such as purification) or that rely on the same resource (such as a production suite). Branches are simply a group of related Sections. The specification and use of Sections and Branches is outside the scope of this introductory example. Users can choose whether to display recipe Branches and Sections by selecting the corresponding checkboxes.

To add a new procedure to the recipe, enter its name in the “Enter procedure name in recipe…” field. The first procedure of this example was named **Polymerization**. Select the **Polymerization** procedure to display the Procedure Properties side-panel. Switch to the Main Equipment Pool tab and use the **Edit** button to define the equipment units required to execute this procedure. Select the **R-1**, **R-2**, **R-3**, and **R-4** reactors (in Resin-Plant) using the dropdown list and click on the **SAVE** button to add the four reactors to the Equipment in Pool (see Figure 7). Note that R-1, R-2, R-3, and R-4 are now associated with the **Polymerization** procedure in the Main Equipment Pool column of the procedures table.

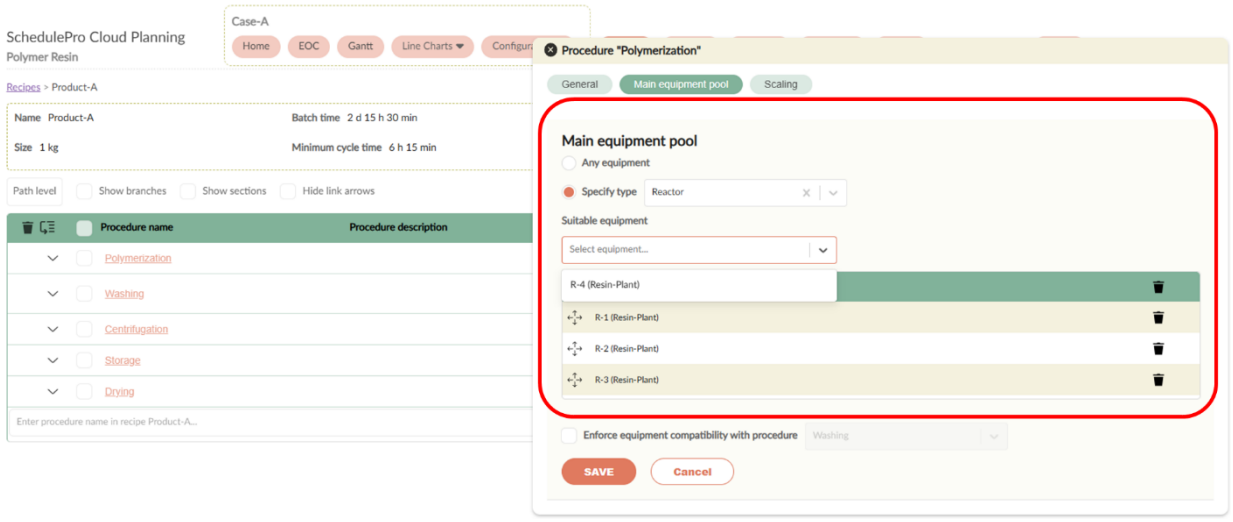



*Figure 7: View of the Main Equipment Pool tab in the Polymerization Procedure Properties side-panel.*

Next, click the downward arrow to the left of the **Polymerization** procedure to expand its operations. To add the first operation, enter **Charge Materials** in the “Enter operation name in procedure Polymerization” field. Then, select the newly created operation to open the operation details side-panel. Open the **Duration** tab and use the **Edit** button to set the duration to **120 minutes**, as shown in Figure 8.

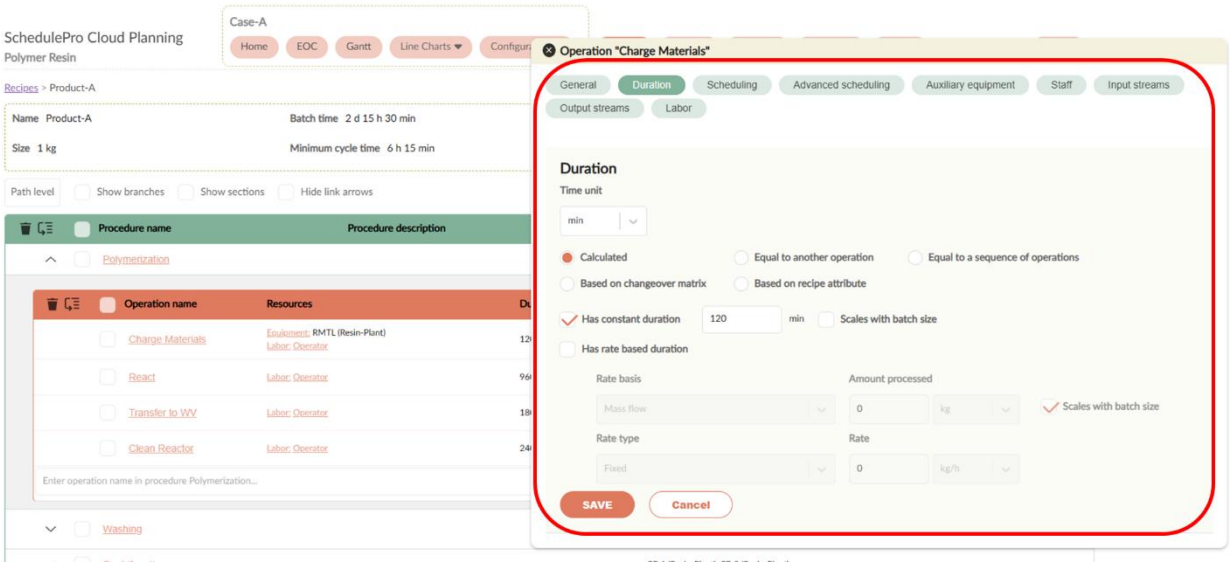



*Figure 8: View of the Duration tab in the **Charge Materials** operation properties side-panel.*

Switch to the **Scheduling** tab and verify that the start of the **Charge Materials** coincides with the start of the batch. By default, SchedulePro Cloud assumes that the first operation in a procedure starts with batch start, which in this case aligns with the intended timing.

To finalize the Polymerization procedure, create the following operations: **React**, **Transfer to WV**, and **Clean Reactor**. These operations will be added sequentially below **Charge Materials**. Select the second operation, **React**, and open its properties dialog to specify its timing parameters. Set the duration to a fixed value of 16 hours, with the start time defined, by default, at the completion of the preceding operation (**Charge Materials**). Since this default start condition matches the intended scheduling, no adjustments are required in the **Scheduling** tab.

Operation timing in SchedulePro Cloud is defined by two parameters: start time and duration. The start time can be referenced to the batch start or to the start or completion of another operation. The duration can be specified as a fixed value, calculated from batch size and processing rate, or defined to match the duration of another operation or a sequence of operations.

Usually, operation schedules are interdependent, hence it is generally more efficient to first define all procedures and operations within the recipe and then configure the scheduling parameters in each operation's properties dialog. The procedures along with their corresponding operations that constitute the entire recipe are listed in Table 2. Follow the method outlined above to create the entire recipe. Also,

make sure to assign the equipment units listed in the **Equipment** column of Table 2 to the corresponding procedures.

The duration of most operations can be explicitly set to the values shown in the **Duration** column of Table 2. The only exceptions are the following operations: **Receive Crude** (in Washing), **Feed Centrifuge** (in Washing), **Receive from Centrifuge** (in Storage) and **Load Dryer** (in Drying). Their duration is equal and dependent on the duration of **Transfer to WV** (in Polymerization), **Centrifuge** (in Centrifugation), **Centrifuge** (in Centrifugation), and **Transfer to Dryer** (in Storage) respectively.

*Table 2: List of the procedures that model the Polymer Resin Recipe in Case A.*

| Procedure | Equipment | Operation | Duration | Start Link |
|---|---|---|---|---|
| Polymerization | R-1, R-2, R-3, R-4 | Charge Materials | 2 h | Batch Start |
| | | React | 16 h | Charge Materials (Finish to Start) |
| | | Transfer to WV | 3 h | React (Finish to Start) |
| | | Wash reactor | 4 h | Transfer to WV (Finish to Start) |
| Washing | WV-1, WV-2, WV-3, WV-4, WV-5, WV-6 | Receive Crude | Set by Transfer to WV in Polymerization | Transfer to WV in Polymerization (Start to Start) |
| | | Wash | 28 h | Receive Cure (Finish to Start) |
| | | Feed Centrifuge | Set by Centrifuge in Centrifugation | Wash (Finish to Start) |
| Centrifugation | CF-1, CF-2 | Centrifuge | 3h 30 min | Feed Centrifuge (Start to Start) |
| Storage | ST-1 | Receive from centrifuge | Set by Centrifuge in Centrifugation | Centrifuge (Start to Start) |
| | | Transfer to Dryer | 1 h | Receive from centrifuge (Finish to Start) |
| Drying | DR-1, DR-2 | Load Dryer | Set by Transfer to Dryer in Storage | Transfer to Dryer (Start to start) |
| | | Dry | 9 h | Load Dryer (Finish to Start) |
| | | Unload | 1h | Dry (Finish to Start) |

To model this coupling of operations, in terms of duration, SchedulePro Cloud offers the *Master-Follower* option. This relationship can be set-up by navigating to the **Duration** tab of the Follower operation and switching the specification option from “Calculated” to “Equal to another Operation”. Then select the

procedure that the Master operation is a part of and, of course, the *Master* operation itself. Similarly, the duration of the *Follower* operation may be tied to the duration of a sequence of operations. Figure 9 demonstrates the setup of the *Master-Follower* relationship between the **Transfer to WV** (*Master*) and **Receive Crude** (*Follower*) operations. The *Master-Follower* relationships between the **Centrifuge** and **Feed Centrifuge, Centrifuge** and **Receive** from **Centrifuge,** and **Transfer to Dryer** and **Load Dryer** can be set up in a similar manner.

On the plant floor, the unloading of the reactor (represented by the **Transfer to WV** operation) and the loading of the wash vessel (represented by the **Receive Crude** operation) are virtually the same task. Hence, it is safe to assume that the **Transfer to WV** and **Receive Crude** not only have the same duration (which was fixed using the *Master-Follower relationship*), but they also share the same start time. To account for that, navigate to the Scheduling tab of the **Receive Crude** operation and select the option "With Respect to Another Operation". Then use the dropdown lists to select the **Polymerization** procedure as the reference procedure and the **Transfer to WV** operation as the reference operation. Lastly, select the "Starts with Start of Reference Task" option as the Link Relationship, as shown in Figure 10. Click on the **SAVE** button to exit the Scheduling settings. Similarly, the **Centrifuge** operation (in Centrifugation) starts with the start of the **Feed Centrifuge** operation (in Washing), the **Receive from Centrifuge** operation (in Storage) starts with the start of the **Centrifuge** operation (in Centrifugation), and the **Load Dryer** operation (in Drying) starts with the start of the **Transfer to Dryer** operation (in Storage).

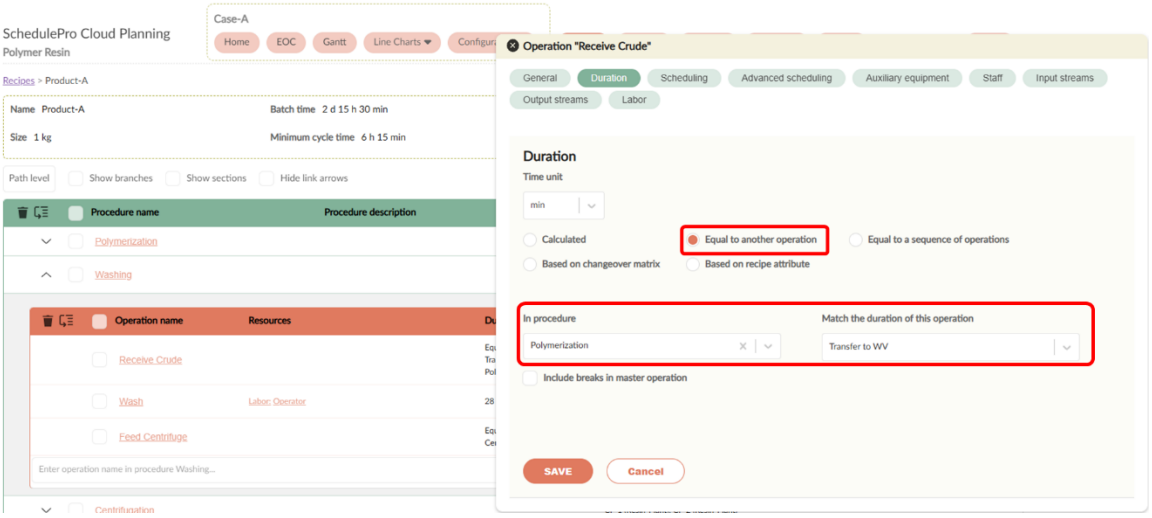



*Figure 9: View of the Duration tab in the **Receive Crude** operation properties side-panel.*

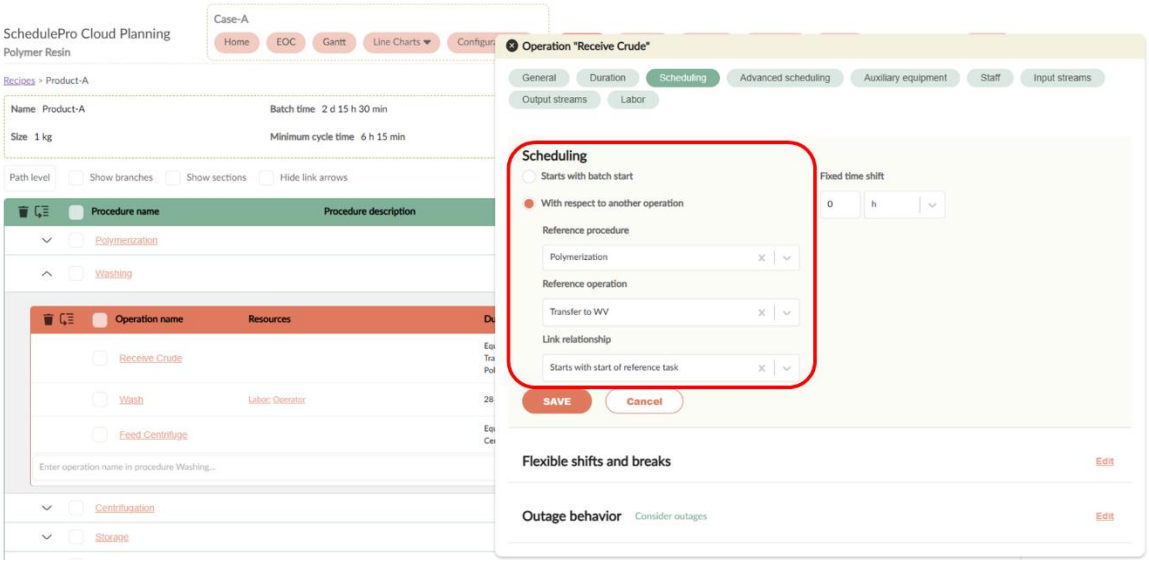



*Figure 10: View of the Scheduling tab in the **Receive Crude** operation properties side-panel.*

## 2.4 Assigning auxiliary equipment to operations

Previously, it was mentioned that main equipment unit(s) is/are assigned to the procedure that makes use of them. Additionally, there is the option to specify auxiliary equipment (such as a CIP skid, a SIP panel etc.) at the operation level. In this example a raw material transfer line (RMTL) was assigned to the **Charge Materials** operation in the **Polymerization** procedure. This task was done via the **Auxiliary Equipment** tab of the **Charge Materials** operation, by clicking on the **Edit** button and selecting the pre-defined RMTL (in Resin-Plant) using the "Suitable Equipment" combo box. Users may optionally use the **Specify Type** dropdown list to refine their search for suitable auxiliary equipment based on their type, as shown in Figure 11. Remember that equipment types can be created during the process of declaring the main equipment or by selecting **Options** / **Equipment** Types from the main menu.

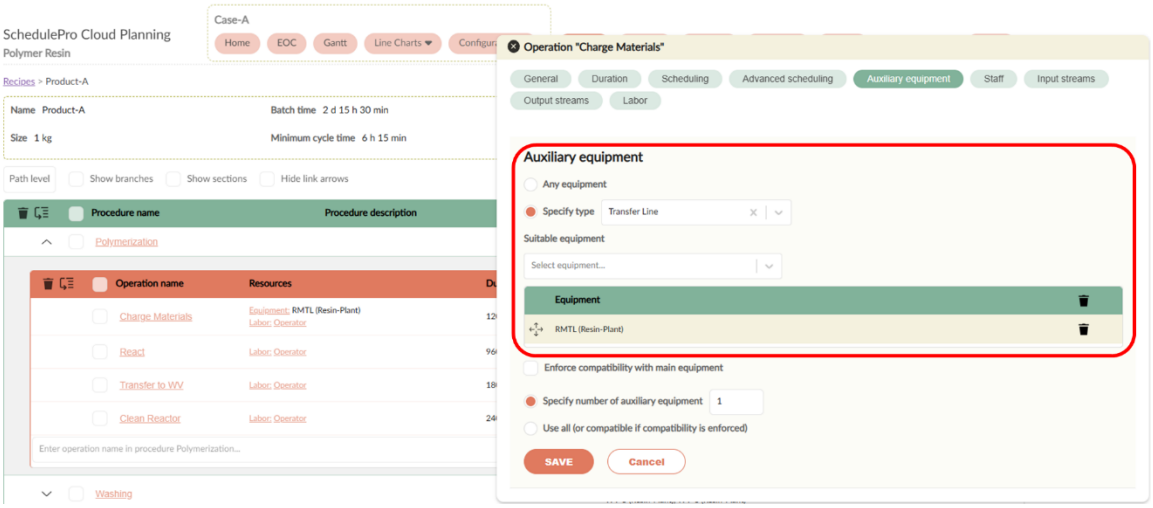



*Figure 11: View of the Auxiliary Equipment tab in the **Charge Materials** operation properties side-panel.*

## 2.5 Assigning labor to operations

Similarly, with auxiliary equipment, labor is another resource that can be used by an operation. Labor resources are declared at the facility level before being available for assignment to the various operations. To insert a new labor type, navigate to the **Facilities** menu and click on the **Labor** menu item of the Resin Plant facility. That brings up the table that contains the various labor types available in the Resin Plant Facility. Initially, the table is empty. To insert a new Labor type, simply type its name in the "Enter labor name…" field. In this example a labor type named "Operator" was created. Then, click on the "Operator" button to toggle its properties side-panel. Next, go to the **General** tab and, using the **Edit** button, open the "Base Availability" group and verify that the "Has Unlimited Persons" box is checked, as shown in Figure 12. Checking this option means that this Labor resource is not constrained. If, on the other hand, someone is interested in modeling a recipe using finite amount of labor resources (i.e., persons) then they can simply uncheck the "Has Unlimited Persons" box and specify the number of persons that are available to the facility. In any case, the changes should be saved by clicking the **SAVE** button.

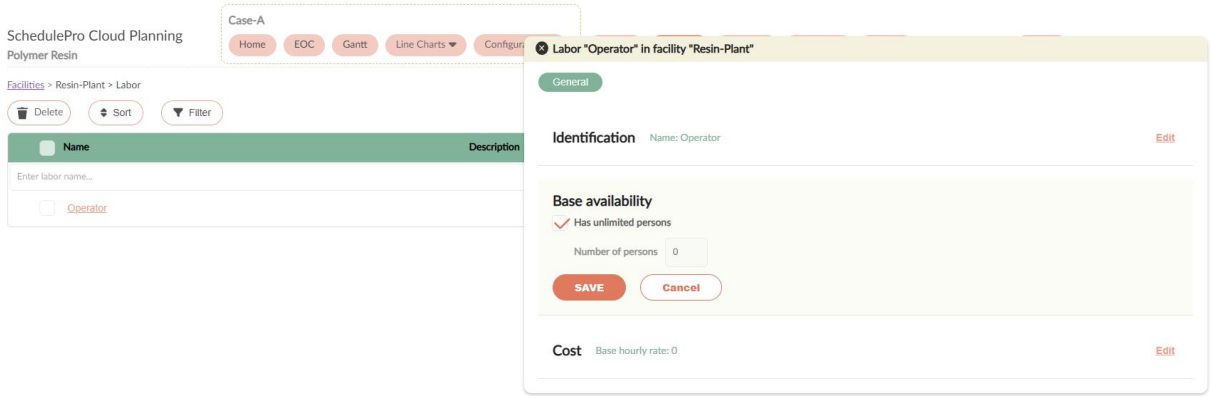



*Figure 12: View of the General tab in the properties side-panel of the **"Operator"** labor type in the **Resin Plant** facility.*

After a labor type is created, it is available for assignment to the various operations that make use of this particular labor type. Demand for labor is specified through the operation's "Labor" tab. The labor demand specification process starts by typing the labor resource name in the "Enter labor usage name…" field. Next, click on the add button, ⊕, or press the enter key on the keyboard to create the new labor resource. Click on the name of the resource, which is now editable, to access its side-panel (see Figure 13). Use the **Edit** button to expand the **Usage Information** group. Using the dropdown list, select the appropriate Labor type (in this example the only available Labor type is the *Operator* type). Finally, specify either the rate or the amount of labor required. For example, if a rate of 2 people is defined, then this operation requires the constant presence of 2 people, and the total amount of required person hours depends on the operation's duration. The labor requirements of the Product-A recipe are listed in Table 3.

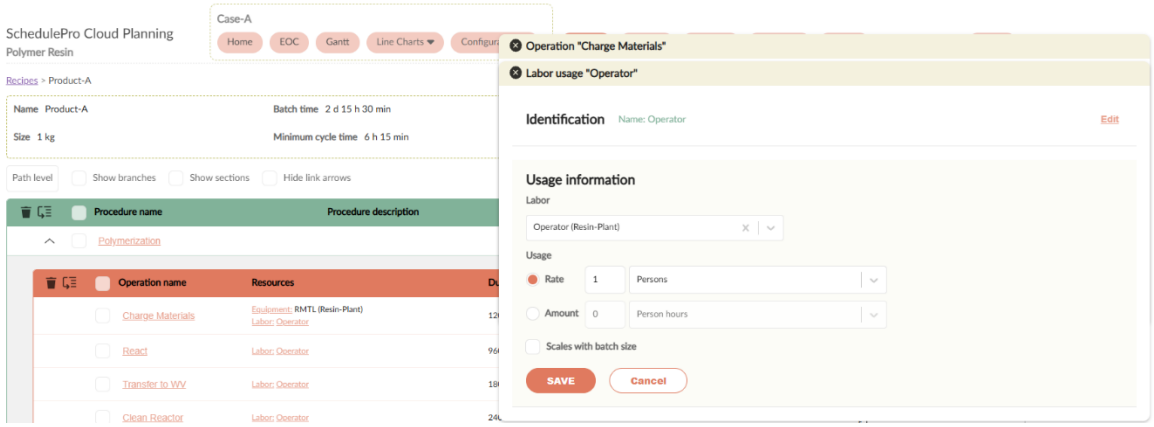



*Figure 13: View of the Labor usage information group of the **Operator** labor type in the **Charge Materials** operation properties side-panel*

*Table 3: List of labor demand per operation of recipe Product-A.*

| Procedure | Operation | Operator Rate (Persons) |
|---|---|---|
| Polymerization | Charge Materials | 1.0 |
| | React | 0.1 |
| | Transfer to WV | 1.0 |
| | Wash reactor | 1.0 |
| Washing | Receive Crude | NA |
| | Wash (28 h) | 0.1 |
| | Feed Centrifuge | NA |
| Centrifugation | Centrifuge | 1.0 |
| Storage | Receive from centrifuge | NA |
| | Transfer to Dryer | 1.0 |
| Drying | Load Dryer | NA |
| | Dry | 0.1 |
| | Unload | 1 |

## 2.6 Visualizing the recipe using the Gantt Chart

Once a recipe has been defined, it can be visualized using a Gantt chart that can be brought up by clicking on the **Gantt** menu item on the right-hand side of the Product-A recipe row in the Recipes table. The Gantt chart visualizes a single batch of a given recipe. Figure 14 below corresponds to the Gantt chart of the Product-A recipe. The soft blue and strong cyan bars depict the duration of procedures and operations, respectively. Note that, in accordance with the above specifications, the operations that have a *Master-Follower* relationship and share the same start time are represented in the Gantt chart by parallel blocks that start at the same time and are the same length. Two of these pairs are highlighted with red a red outline in Figure 14.

A recipe Gantt chart cannot be displayed unless the recipe is declared in a complete and self-consistent way. If this is not the case, the recipe status in the information box will appear as **Invalid**. By clicking on the **Invalid** button, a message with more detailed information on the recipe status will appear. Make sure that all recipes are fully declared before scheduling production campaigns based on those recipes.

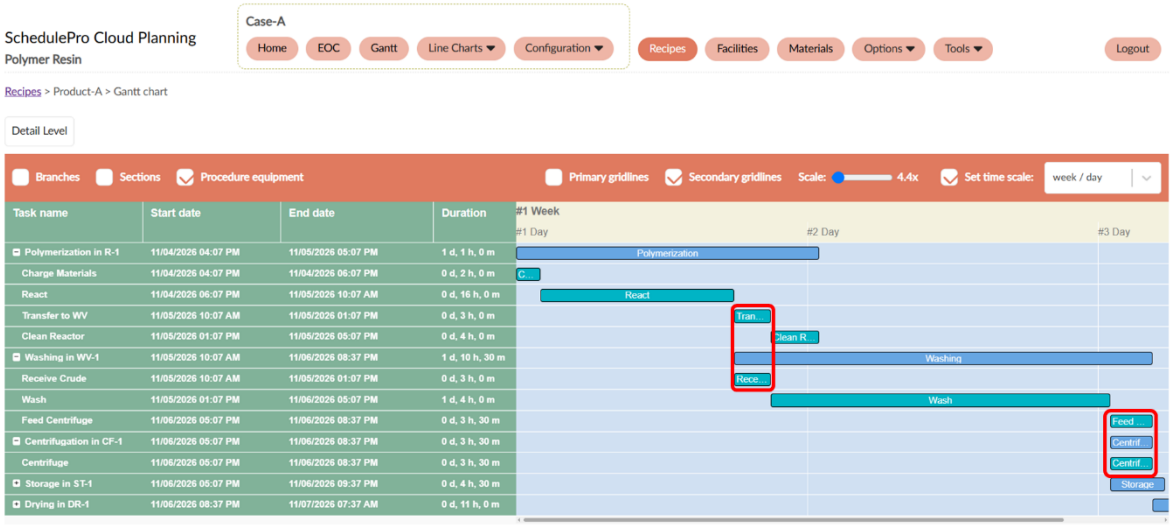



*Figure 14 The Gantt chart of the Product-A Recipe.*

## 2.7 Planning and Scheduling Campaigns

A campaign represents a production or work order, and it is simply a set of one or more batches of a particular recipe. In SchedulePro Cloud, each scheduled batch represents the realization of a recipe at a given time that utilizes specific equipment units and other resources. Unless otherwise stated by the user, the only constraint that SchedulePro Cloud considers in generating a schedule is the availability of equipment and facilities.

To add a new campaign, first select the scheduling board's **Home** menu item and then type the campaign name in the "Enter campaign name…" field. In case A, only one campaign was created, and it was given the name AA-1. The AA-1 campaign is shown in Figure 3. Click on the AA-1 campaign to toggle its properties side-panel. The **General** tab contains the **Identification** group, which allows users to change the name, description and color of the campaign and the associated the recipe, the **Amount** section which allows the specification of the number of batches as well as the Batch size, and the Others section which currently enables the specification of Post (Equipment) Changeover. The description and usage of the features in the Timing/Sequencing and Cycling tabs are outside the scope of this tutorial and they will be analyzed in a future SchedulePro Cloud tutorial. Alternatively, users can edit basic campaign information such as the associated recipe and the number of batches by clicking the **Edit** button ( ) that appears when hovering over a column of the campaigns table. Using the **Identification** and **Amount** groups of the General tab, associate the Product-A recipe with the AA-1 campaign and specify a number of 12 batches.

After the campaign definition is completed, the production schedule can be generated. To do this, click on the black downwards arrow that appears when hovering over the AA-1 row in the campaigns table. In the list that appears click on the “Schedule” option. Alternatively, you may click on the **Schedule** button located in the information box of the scheduling board. Note, however, that the effect of the **Schedule** button is global, which means that all the specified campaigns will be scheduled.

The production schedule is displayed by clicking on the **Contents** button, which is located on the right side of the campaign’s table. On this page, users can access the duration, start and end of each scheduling entity (batch, procedure, operation), as well as the equipment (main or auxiliary), that processes each processing task (see Figure 15).

Users can use the **Path** dropdown to set the level of detail to be displayed on the screen. For example, selecting the “Procedure Entry” option expands the display of scheduling information at the procedure level. Similarly, selecting the “Operation Entry” option displays the scheduling of all operation entries across all the scheduled batches of the campaign. In contrast, selecting the “Batch” option collapses the report of the production schedule, where only the scheduling information for each batch is visible.

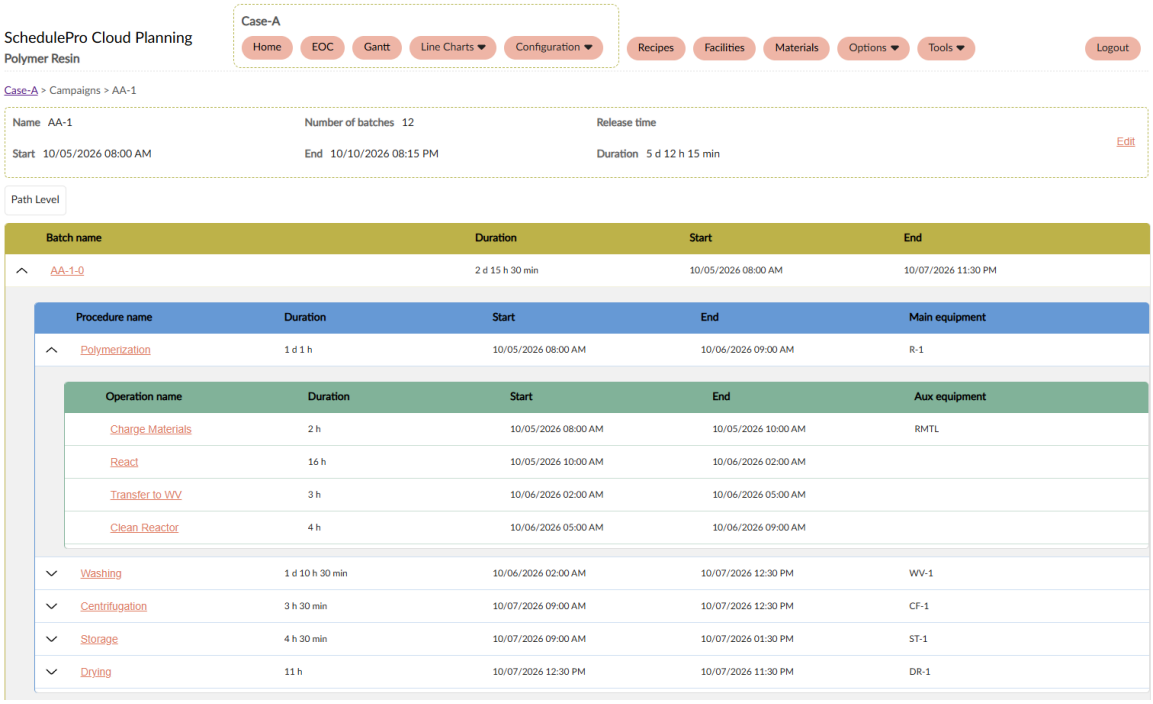



*Figure 15: View of the production schedule page for campaign AA-1.*

## 2.8 Visualizing the Production Schedule using the Equipment Occupancy Chart

In addition to the scheduled campaign view, the schedule can also be visualized in an Equipment Occupancy Chart (EOC) that can be accessed by clicking on the **Home** menu item in main menu of the Scheduling Board. The EOC of Case A is shown in Figure 16 below.

As the name suggests, the EOC chart visualizes the occupancy of equipment in time. The x-axis is the time axis, and the y-axis lists all the equipment items that are used during the campaign. Different batches are denoted by different colors. The view of the EOC can be customized by clicking on the **Facility**, **Procedure Label**, **Arrows** and **Current Time**, **Primary Gridline**, **Secondary Gridlines** and **UTC Time** checkboxes. The chart's time scale can be adjusted by checking the **Set time scale** checkbox and changing the scale using the dropdown menu. Lastly, users can zoom in and out of the chart using the dedicated slider.

The top line of the EOC corresponds to the Raw Material Transfer Line (RMTL), which is engaged during the execution of the "Charge" operations in the four production reactors (R-1, R-2, R-3 and R-4). Under the conditions of this scenario, the four reactors (R-1 through R-4) are the current cycle time bottleneck. This is because as soon as one reactor is free (i.e., after it has processed a batch of material), another batch is immediately started within that reactor. As a result, there is no idle time between batches in the reactors. In theory, the throughput of this plant could be increased by adding another reactor. However, due to the relatively tight scheduling of various other equipment items (especially the wash vessels, WV-1 through WV-6), adding another reactor would not greatly increase overall plant throughput.

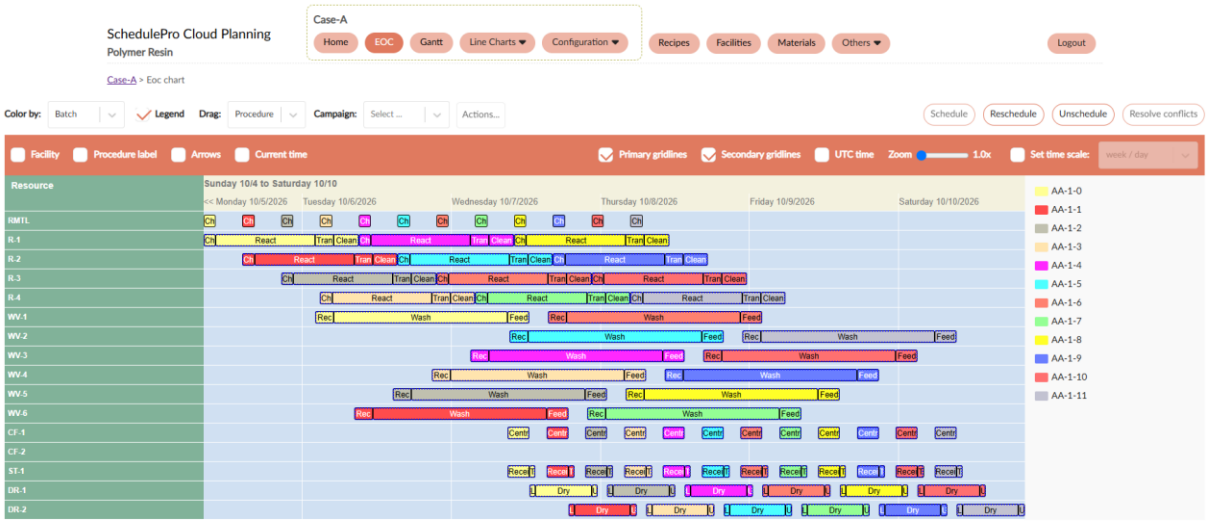



*Figure 16: View of the Equipment Occupancy Chart of Case A*

## 2.9 Considering Non-Equipment Resources

In addition to equipment unavailability, other types of resource constraints can have a substantial impact on the actual capacity of a batch manufacturing plant. These resources can include labor, utilities, raw materials, etc. If insufficient resources are available at a given time, processing of a batch may be delayed, leading to decreased plant efficiency and throughput, as well as late orders. In this example, the "Operator" labor type has been added to many of the operations in this process. For instance, one operator was assigned to the **Charge Materials** operation in the Polymerization procedure. Other operations, such as the React operation in the **Polymerization** procedure, require less labor, hence a partial operator was assigned (refer to Table 3 for the exact labor specifications of each operation).

SchedulePro Cloud keeps track of the demand for materials (consumption and generation), inventory and labor. The dynamic profiles of materials and labor demand can be visualized by selecting the corresponding option from the **Line Charts** dropdown list in the main menu of the Scheduling Board. To visualize the demand for labor, select the Resource Chart option in the **Line Charts** dropdown list. Then, use the **Resource Type** dropdown list to select the **Labor** resource, the **Resource** dropdown to select the **Operator (Resin-Plant)** labor type, the **Amount unit** dropdown list to set the "Person Hours" unit, and the **Rate** dropdown list to set the rate unit in "Persons". Click the **Refresh Chart** button to generate the chart.

The resulting chart should look similar to the chart of Figure 17. The black line denotes instantaneous demand in "persons" units. The blue line, which corresponds to the right (secondary) y-axis, denotes cumulative demand in "person hours" units over the entire period. Using the + and – buttons you can zoom in and out in the graph respectively. Using the **Reset** button reverts the zoom level back to the default level. Finally, you can move in the x-axis by using the scrollbar under the chart (grey part denotes current time frame).

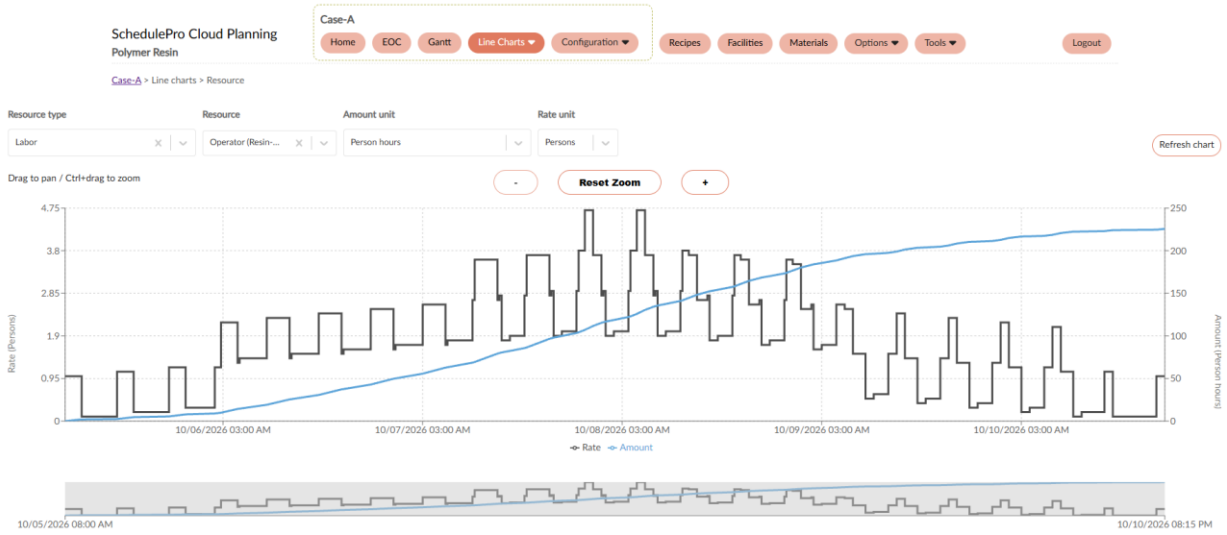



*Figure 17: View of the Labor Demand chart during the execution of the AA-1 campaign.*

As can be seen in Figure 17, the labor demand for this production schedule peaks on day 3 at a maximum of 4.7 operators. In other words, 4.7 operators (or more realistically, 5 operators) would be required in order to perform the activities that are scheduled for this particular time. If fewer than 5 operators are available, certain operations will have to be delayed. In some cases, this may delay a batch and reduce plant throughput. In other cases, batch completion will not be delayed, because the operation shift does not impact an activity on the critical path. SchedulePro Cloud has the ability to generate schedules that respect labor constraints, which may vary with work shifts, and weekends. Other constraints that may optionally be considered include the limited availability of materials. These constraints can be set via the Scheduling Mode page.

The Scheduling Mode page can be accessed by selecting the **Scheduling** option in the **Configuration** dropdown list in the main menu of the Scheduling Board. In the **General** tab, users can set the **Scheduled Operation timing propagation mode**, which is essentially the mechanism by which timing change to a scheduled operation affects other depended operations on it. The three available modes are described below:

- Full (Timing change will propagate to all dependent operations): Any timing change propagates to all dependent operations, adjusting their scheduled times as needed to maintain the defined scheduling constraints.
- Forward only (Timing change will propagate only to dependent operations that need to move forward): A timing change propagates only to dependent operations that need to move later in the schedule. Dependent operations that do not need to move later remain unchanged.

- Independent (Timing change will not propagate to any dependent operation): A timing change affects only the current operation. No timing changes are propagated to dependent operations, even if this causes the defined scheduling constraints to be violated.

In the **Conflicts** tab, users can access options to account for scheduling conflicts. Conflicts can be identified, ignored or resolved. Similarly to conflicts, Schedule Pro Cloud can be configured to identify, ignore or resolve the resource constraints. The default behavior is to resolve all the constraints. Resource constraints are categorized in two tabs: the **Primary Constraints** and **Secondary Constraints** tab. The **Primary Constraints** tab list the *Main Equipment*, *Auxiliary Equipment* and *Staff* constraints. The **Secondary Constraints** tab lists the *Labor*, *Supply/Reception rate limits* and *Inventory limits* constraints.

Note that in order for SchedulePro to automatically adjust the schedule based on resource constraints, these constraints must be first configured, appropriate conflict resolution options should be chosen, limits should be specified for the relevant constraints, and there must be flexibility built into the schedule (e.g., flexible shifts assigned to various operations).

# 3 Case B: Multi Product Facility

Case B represents a series of production campaigns within a "multiproduct" facility. This facility runs campaigns of three different resin recipes. In order to keep the campaigns of Case B isolated from the campaign of Case A, a new scheduling board was created within the **Polymer Resin** workspace. The new scheduling board was given the name **Case-B1.**

## 3.1 Creating New Recipes

Two new recipes were created to represent the manufacturing of two additional resins, namely **Product-B** and **Product-C**. These recipes were quickly built by duplicating and editing recipe Product-A. To duplicate the Product-A recipe, click on the black downwards arrow that appears when hovering over the Product-A row in the recipes table. In the list that appears click on the "Duplicate" option. Rename the new recipe to **Product-B** and repeat the same process to create recipe **Product-C**.

The recipes for products B and C have the same basic structure as recipe Product-A, including the same procedures and operations. However, the durations of some operations are different. The durations of all operations in each of the three recipes are listed in Table 4. Operations with differing durations in the three recipes are highlighted in green.

*Table 4: List of the procedures that model the Polymer Resin Recipes Product-B and Product-C.*

| Procedure | Equipment | Operation | Duration h) | | |
|---|---|---|---|---|---|
| | | | Product A | Product B | Product C |
| Polymerization | R-1, R-2, R-3, R-4 | Charge Materials | 2.00 | 2.00 | 2.00 |
| | | React | 16.00 | 14.00 | 14.00 |
| | | Transfer to WV | 3.00 | 3.00 | 3.00 |
| | | Wash reactor | 4.00 | 4.00 | 4.00 |
| Washing | WV-1, WV-2, WV-3, WV-4, WV-5, WV-6 | Receive Crude | 3.00 | 3.00 | 3.00 |
| | | Wash | 28.00 | 36.00 | 28.00 |
| | | Feed Centrifuge | 3.50 | 3.00 | 4.00 |
| Centrifugation | CF-1, CF-2 | Centrifuge | 3.50 | 3.00 | 4.00 |
| Storage | ST-1 | Receive from centrifuge | 3.50 | 3.00 | 4.00 |
| | | Transfer to Dryer | 1.00 | 1.00 | 1.00 |
| Drying | DR-1, DR-2 | Load Dryer | 1.00 | 1.00 | 1.00 |
| | | Dry | 9.00 | 9.00 | 12.00 |
| | | Unload | 1.00 | 1.00 | 1.00 |

## 3.2 Case B1: Adding and Scheduling the New Campaigns

Let's assume that the relative demand for the three products is: A / B / C = 2 / 4 / 1. Consequently, the plant tends to schedule two batches of Product A, followed by four batches of Product A, followed by one batch of Product C in a repeating pattern. Switch to the **Home** view of the Scheduling Board and, by following the steps outlined in section 2.7 Planning and Scheduling Campaigns, create a campaign for product A, a campaign for product B and a campaign for product C. The number of batches in each campaign should satisfy the relative demand for the three products. Repeat the same process two times to ultimately create nine campaigns in total (three for each product) as shown in Figure 18.

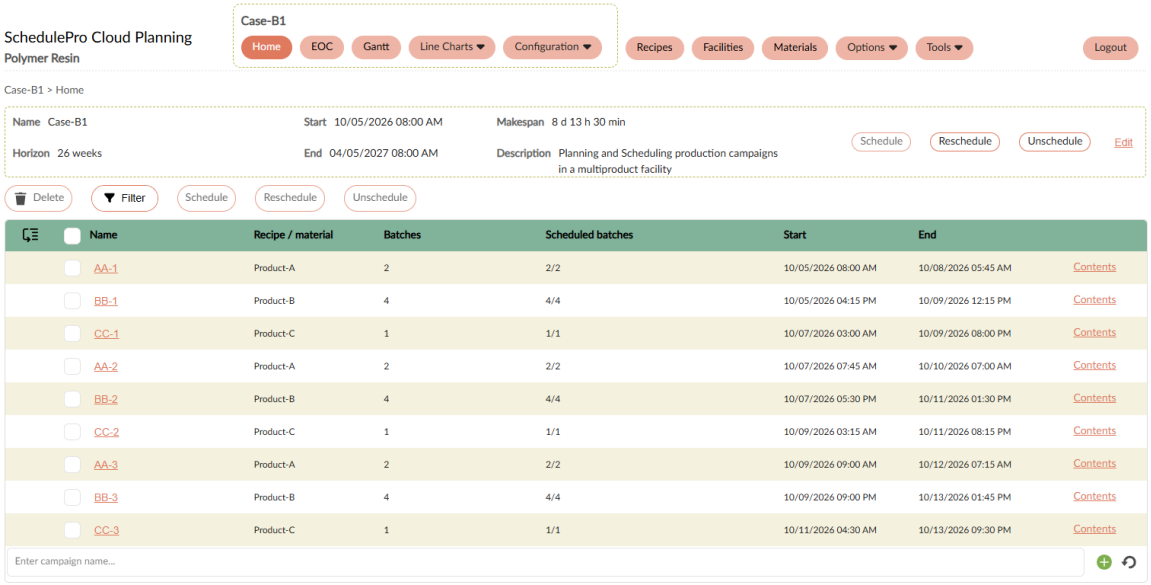



*Figure 18: View of the Home page in Case-B2.*

Once the campaigns are scheduled, the full production schedule can be viewed using the EOC (see Figure 19). The EOC displays the repeating 2 / 4 / 1 pattern of products A / B / C.

Notice that the equipment bottleneck shifts, depending on the specific sequence of batches. For instance, sometimes adjacent batches of the same product create equipment bottlenecks (e.g., tanks WV-4 and WV-5 are used continuously for consecutive batches of product B), while sometimes adjacent batches of different products are bottlenecks (e.g., reactor R-1 has idle time between batches BB-3-1 and CC-3-0, but there is no idle time between AA-1-0 and BB-1-3 and between AA-2-1 and BB-2-0). In fact, the start of a batch can be constrained by any of the following: the single RMTL transfer line, one of the reactors, one of the wash vessels, or one of the dryers. The complexity of bottleneck shifting within this simple example illustrates the difficulty of generating schedules using traditional tools such as Excel, MS Project, etc.

Incorporating additional constraints, such as labor requirements, cleaning skids, utility constraints, etc., would be prohibitively time-consuming using these tools. In contrast, SchedulePro Cloud generates acceptable solutions for complex scheduling scenarios in seconds.

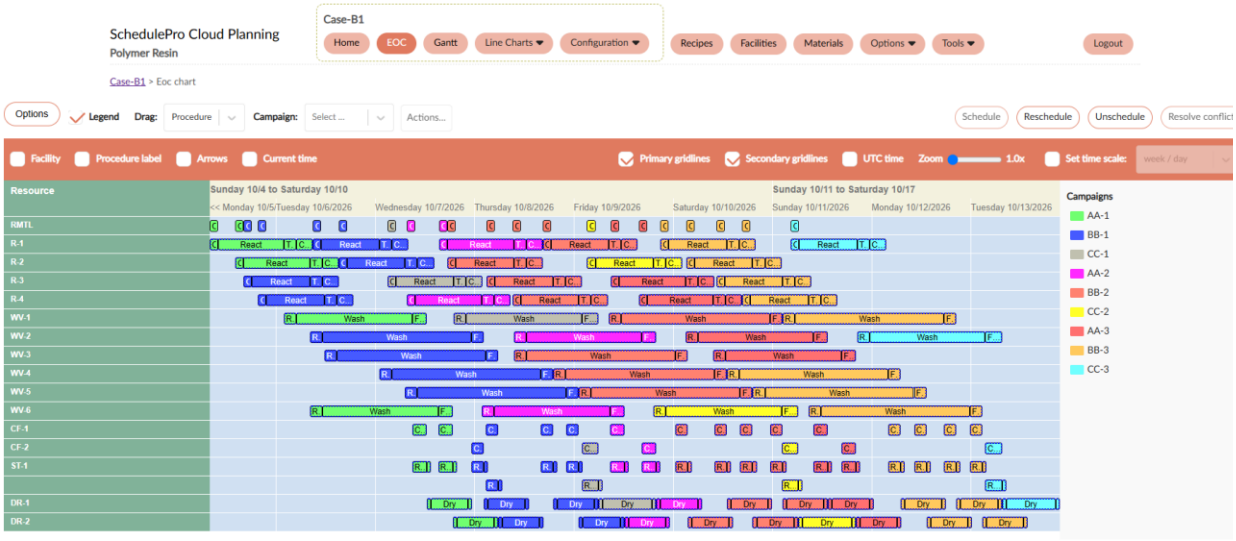



*Figure 19: View of the Equipment Occupancy Chart (EOC) of Case B1*

The operations Gantt chart offers an alternative way of visualizing production schedules. It is brought up by clicking on the **Gantt Chart** menu item of the scheduling board. Figure 20 corresponds to this case (Case B1).

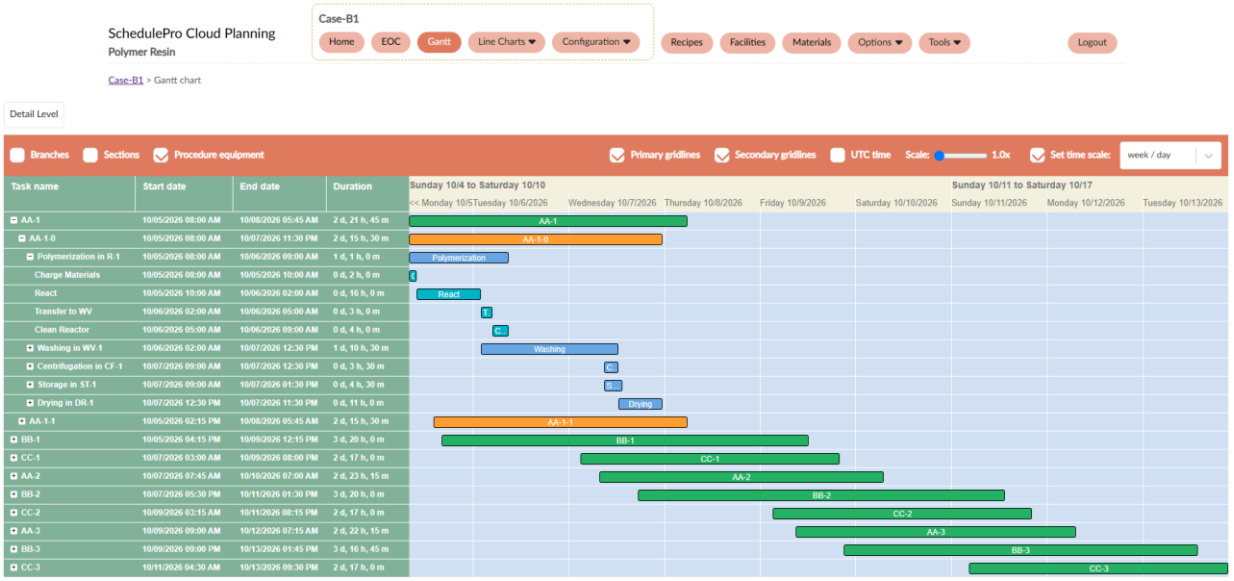



*Figure 20: Gantt chart of Case B1*

The green bars represent campaigns, and the orange bars represent the batches of their corresponding campaigns. It is also possible to display the procedures of the various batches as well as the operations of the various procedures. This can be done for the entire schedule by selecting the appropriate level of detail through the "Detail Level" dropdown list on the chart's main toolbar. The level of detail of individual activities can be adjusted using the [+] and [-] signs in front of the names of the various activities (Task column of grid on the LHS). For instance, in this figure batch AA-1-1 has been expanded in order to show its procedures (shown by the blue bars).

The advanced visualization and scheduling capabilities of the EOC and Gantt chart (as well as supporting charts for various resources) enable practitioners to readily generate production schedules that increase asset utilization and plant throughput.

## 3.3 Case B2: Considering Changeover

Changeover times can be specified at the campaign level or at the operation level. At the campaign lever, the changeover duration can be fixed and applied globally to every equipment item, or it can be based on equipment specific changeover time. At the operation level, the changeover time may depend on a changeover matrix or on a recipe attribute. Campaign-level changeovers take place when a campaign is completed. In contrast, operation-level changeovers may take place between batches of a campaign, rather than simply between campaigns.

Case B2 of this example features an equipment changeover matrix that determines the time needed for cleaning between different batches in the reactor vessels. In this case, the changeover duration is variable and depends on the sequence of products within a given reactor.

Applying changeover-matrix based duration requires editing of the respective operation(s) within each recipe. Hence, to keep the Case B2 results isolated from the results of the other cases in this example, the three product recipes were duplicated and renamed to **Product-A-Changeover Matrix**, **Product-B-Changeover Matrix** and **Product-C-Changeover Matrix**. The scheduling board of this case exclusively uses the above recipes.

Changeover matrixes are implemented in SchedulePro Cloud via **recipe attributes**. The recipe attributes feature of SchedulePro Cloud enables grouping recipes so that common options can be configured for entire recipe groups, rather than for individual recipes. Each recipe attribute defines a list of possible values and each recipe can be assigned at most one value per available attribute. To learn more about

recipe attributes, please refer to the **Recipe attributes / changeover matrices** section of the SchedulePro Cloud User's Manual.

In this example a new recipe attribute, named "Product Type" was created and three different values were defined, namely A, B and C. To create the "Product Type" recipe attribute, select **Options / Recipe Attributes** from the main menu. Next, type the recipe attribute name in the "Add recipe tag name…" field. Finally, click on the add button, ⊕, to create it. The recipe attribute table, containing the "Product Type" recipe attribute is shown in Figure 21 below.

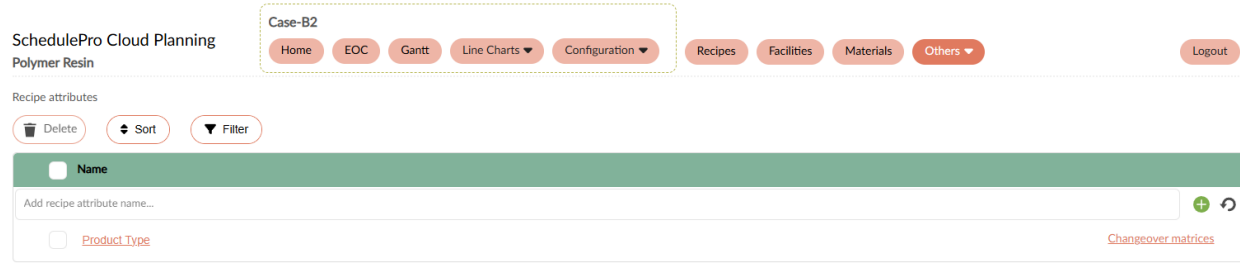



*Figure 21: View of the Recipe Attributes table.*

Next, activate the "Product Type" recipe attribute side-panel by clicking on the Product Type link. In the **Values** tab of the side-panel, define the three recipe attribute values (A, B and C) by typing their names in the "Add recipe attribute value…" filed and clicking on the add button, ⊕, as shown in Figure 22 below.

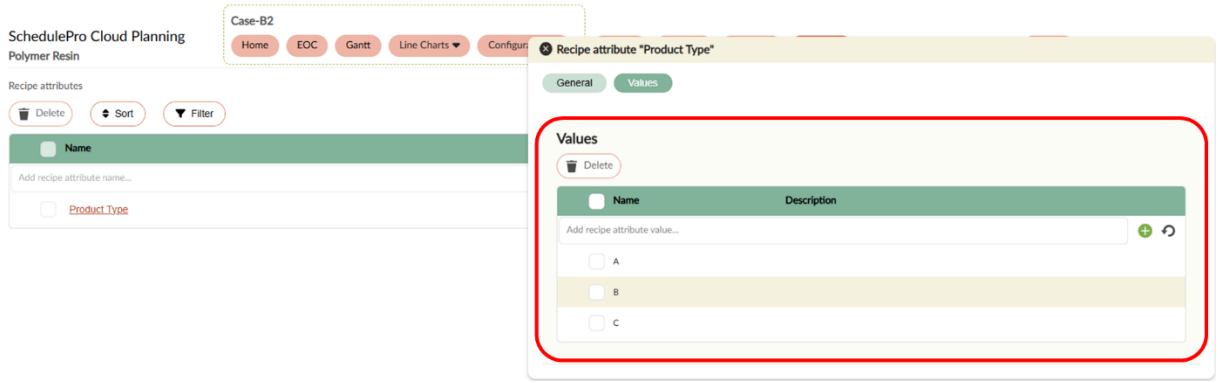



*Figure 22: View of the "Product Type" recipe attribute side-panel*

After the "Product Type" recipe attribute is created, the related changeover matrixes can be created too. In this example a changeover matrix named "Reactor Cleaning" was created. To create the "Reactor Cleaning" changeover matrix, click on the Changeover matrices link on the right-hand side of the "Product Type" row, in the **Recipe attributes** table. Next, type the changeover matrix name in the "Enter changeover matrix name…" field. Finally, click on the add button, ⊕, to create it. Next, click on the

"Reactor Cleaning" link to activate its side-panel. Navigate to the **Values** tab and click on the **Edit** button to expand the available specification options. To construct the changeover matrix, simply specify transitions by selecting the "From attribute value" and the "To attribute value" using the corresponding combo boxes, and specifying the changeover time, as shown in Figure 23 below. Finally, by clicking on the Add button the transition is saved as a new table row. Follow the same steps to create all the transitions of Table 5. The row labels in this matrix represent the "from" side of the batch transition, whereas the column headings represent the "to" side. In other words, when transitioning from an Idle state to production of Recipe Type A, 6 hours of cleaning/changeover time is required. Similarly, when transitioning from an Idle state to Recipe Types B and C, 6 hours of cleaning/changeover time is required. Furthermore, when transitioning from a batch of Recipe Type A to another batch of Recipe Type A, only 4 hours is needed. In contrast, when transitioning from a batch of Recipe Type A to a batch of Recipe Type B, 6 hours is required. If a matrix is declared "symmetrical" (by enabling the corresponding checkbox), only one half of the matrix should be specified (upper or lower).

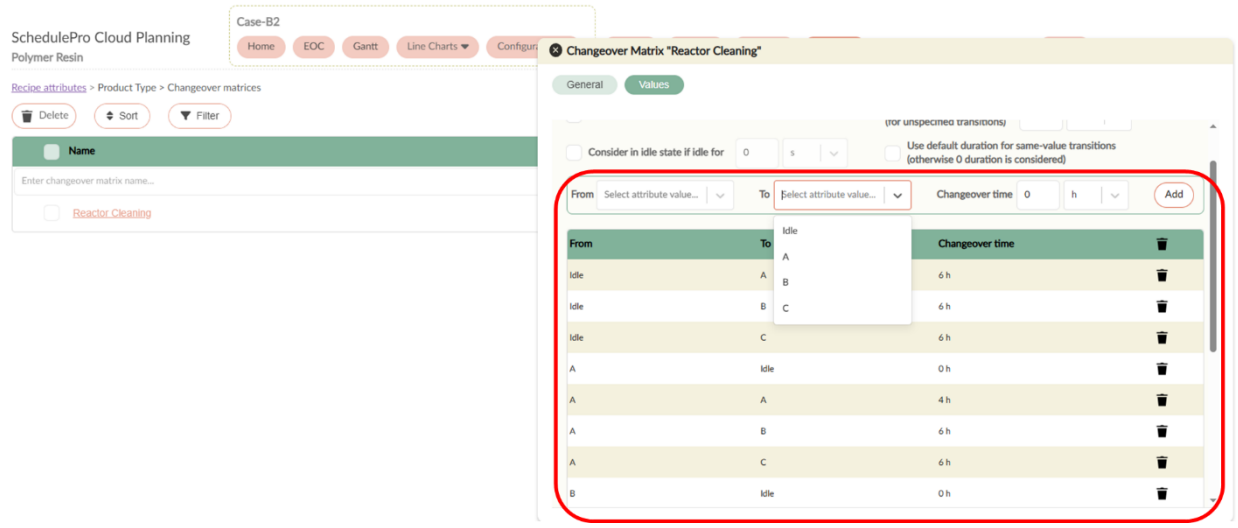



*Figure 23: View of the "Reactor Cleaning" Changeover Matrix side-panel.*

*Table 5: The Changeover matrix for Reactor Cleaning*

| Duration (h) | Idle | A | B | C |
|---|---|---|---|---|
| **Idle** | 0.00 | 6.00 | 6.00 | 6.00 |
| **A** | 0.00 | 4.00 | 6.00 | 6.00 |
| **B** | 0.00 | 6.00 | 4.00 | 6.00 |
| **C** | 0.00 | 6.00 | 6.00 | 4.00 |

After the "Reactor Cleaning" changeover matrix is defined, the "Product Type" recipe attribute values must be assigned to their respective recipes. Click on the **Recipes** button in the main menu of the application, to redirect to the recipes page. Then, click on the **Product-A-Changeover Matrix** recipe to

activate its side-panel. Edit the **Recipe attributes group** and use the **Attributes** combo box to select the "Product Type: A" value. Click on the **SAVE** button to close the side-panel. Repeat these steps to assign the "Product Type: B" value to the **Product-B-Changeover Matrix** recipe and the "Product Type: C" value to the **Product-C-Changeover Matrix** recipe.

Next the changeover matrix must be assigned to relevant operations within the recipes. Edit the contents of the **Product-A-Changeover Matrix** recipe and move the **Clean Reactor** operation to the beginning of the Polymerization procedure. Next, click on the **Clean Reactor** operation to activate its side-panel and navigate to the Scheduling tab. Schedule the **Clean Reactor** operation backwards with respect to the **Charge Materials** operation, as shown in Figure 24. The latter operation should start with batch start.

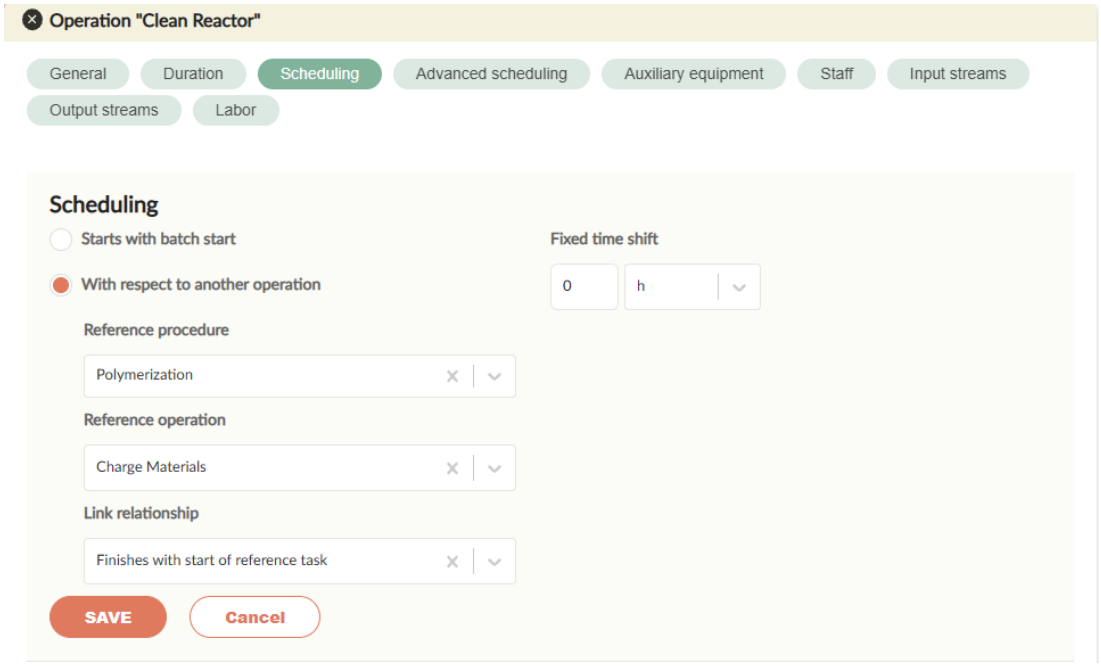



*Figure 24: View of the Scheduling tab in the Clean Reactor operation properties side-panel of procedure Polymerization.*

Then, navigate to the Duration tab (also see Figure 25). Click on the **Edit** button and set its "Duration" attribute to "Based on changeover matrix". Next, choose the **Reactor Cleaning** changeover matrix in the drop-down list. In this example, the changeover duration will be calculated based on the product that was produced previously within that equipment. To set this state transition mode, simply set the "State transition with respect to" attribute to "Task before".

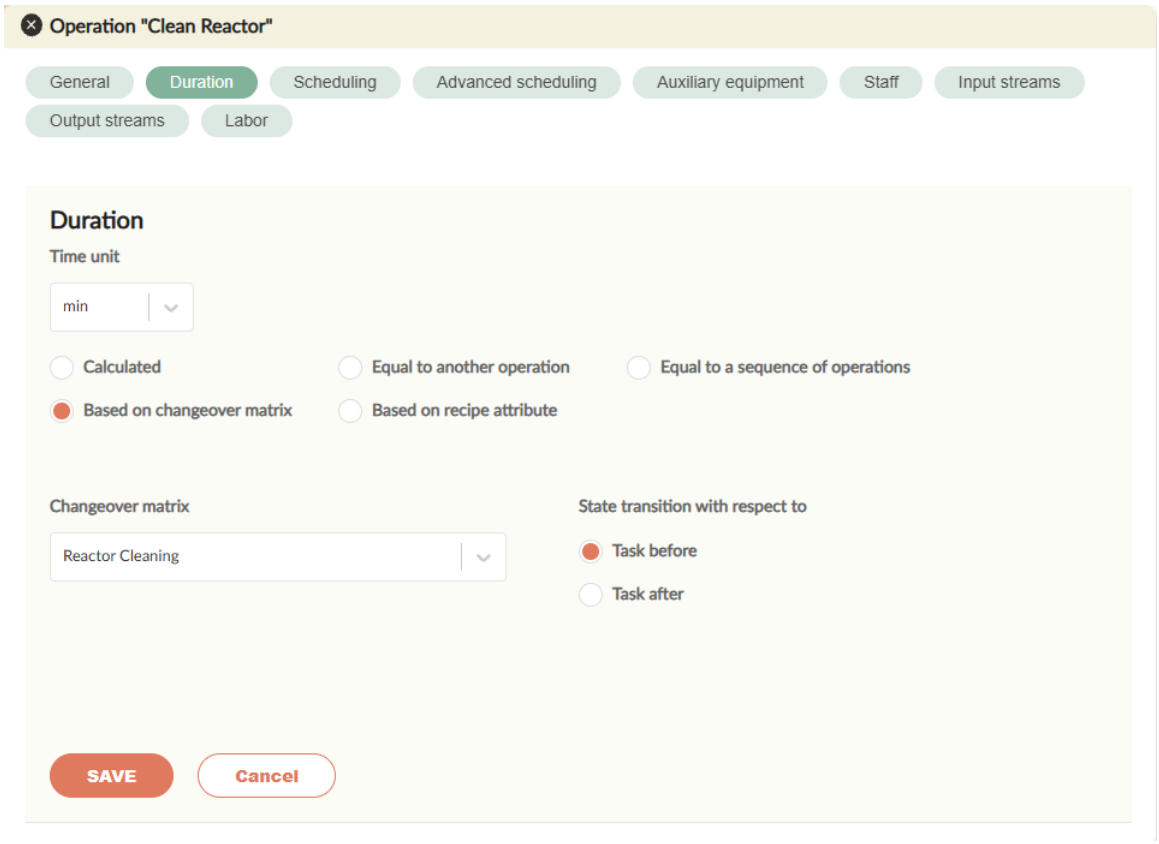



*Figure 25: View of the Duration tab in the Clean Reactor operation properties side-panel of procedure Polymerization.*

> *Modeling Tip: Note that it is generally best to apply the changeovers at the start of each batch (rather than at the end of each batch.) This is because when determining changeover durations, better solutions will be generated by SchedulePro Cloud if the changeover activities are treated as pre-processing (rather than post-processing) activities. This is because SchedulePro Cloud always knows which product was scheduled previously within a given piece of equipment, but it may now know which product will be scheduled next within that piece of equipment. As a result, if the changeover matrix is assigned to an operation at the end of a batch, SchedulePro Cloud's solution algorithm will have to guess which product will be produced next in that equipment (and therefore guess which changeover duration to use). Then it will schedule additional batches and check whether or not the changeover durations were correct. If the changeover durations were incorrect (because the guesses regarding the product sequence were incorrect), SchedulePro will update the durations of the affected operations but will not reschedule to resolve conflicts creates.*

Next, click on the **SAVE** button to save the settings and close the **Clean Reactor** operation properties side-panel. Repeat these steps to apply the **Reactor Cleaning** changeover matrix to the Polymerization procedures of recipes **Product-B-Changeover Matrix** and **Product-C-Changeover Matrix**.

Lastly, visit the Home tab and enter and schedule the nine campaigns shown in Figure 18, according to the instructions in the *3.2 Case B1: Adding and Scheduling the New* Campaigns sub-section. The results of the production schedule with the Reactor Cleaning changeover matrix are shown are shown in the EOC of Figure 26 below.

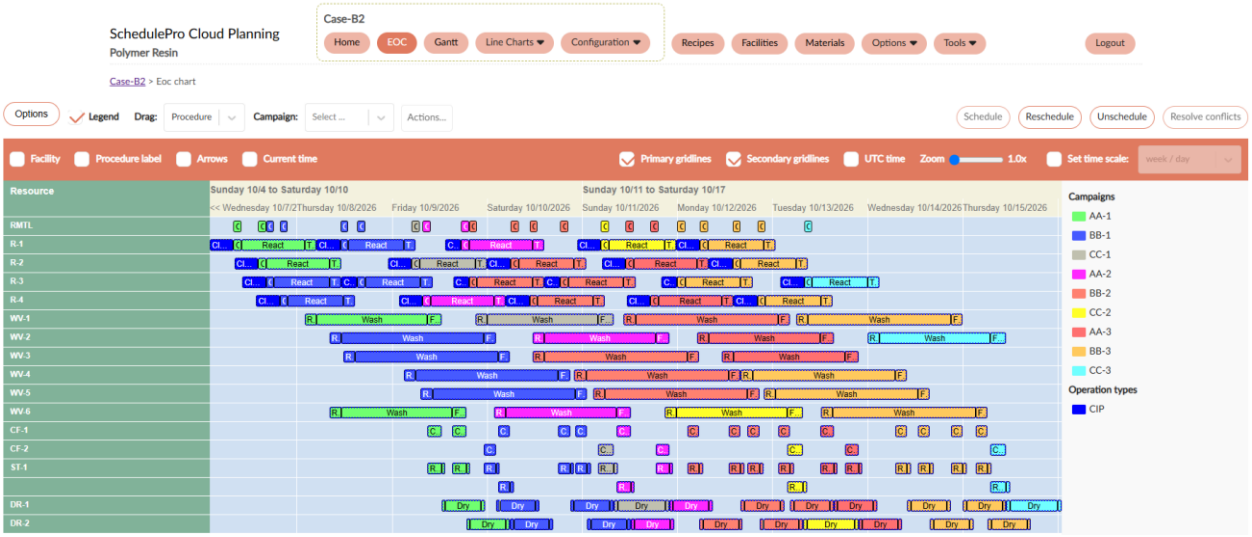



*Figure 26: View of the Equipment Occupancy Chart (EOC) of Case B2.*

The changeover times for the four reactors at the end of each campaign are represented by dark blue bars (labeled as "CIP" in the legend on the right side of the EOC). Notice that the changeovers are not all the same length. For instance, the changeover during the transition from batch BB-2-0 to batch BB-2-3 in R-3 is shorter (4 h) than the changeover during the transition from batch BB-3-0 to batch CC-3-0 in the same reactor (6 h)

Also, note that the makespan for the production schedule has been increased to 8 d and 23 hours (in Case B1, the makespan for the production schedule is equal to 8 d, 13 h and 30 min). This is because many of the changeover times between batches are longer than the original duration assigned to reactor cleaning operations in the previous case (Case B1), and those reactors were occasionally the production bottleneck.

Finally, notice that all cleaning (CIP) operations in Figure 26 are the same color (dark blue) regardless of which campaign an individual cleaning operation belongs to. This can be specified by assigning Operation Types to specific operations. In this example, an operation type named "CIP" was created and assigned to the Clean Reactor operations across the three product recipes.

To create a new operation type, select **Options / Operation Types** from the main menu. Next, type the recipe attribute name in the “Add operation type name…” field. Finally, click on the add button, , to create it. The operation types table, containing the “CIP” type is shown in Figure 27.

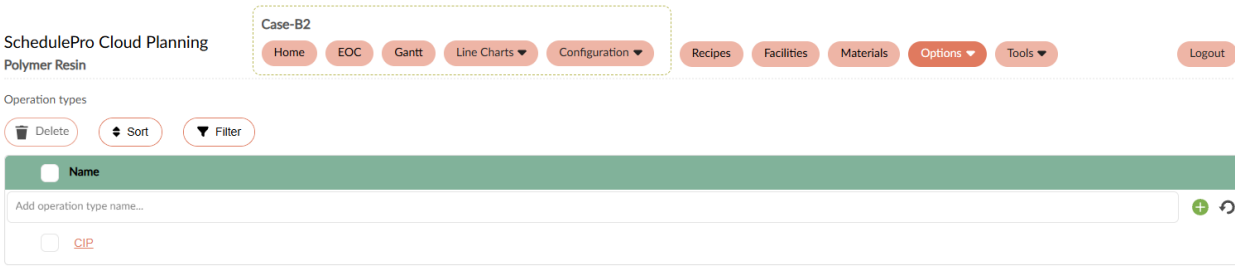



*Figure 27: View of the Operation Types table.*

After the “CIP” operation type has been created, it can be assigned to the respective operations. Click on the **Recipes** button in the main menu of the application, to redirect to the recipes page. Then, edit the contents of the **Product-A-Changeover Matrix** recipe and click on the **Clean Reactor** operation to activate its side-panel. In the **General** tab use the **Edit** button to expand the **Identification** section and select the “CIP” operation type from the “Type” dropdown list. Repeat the same steps for the Clean Reactor operations of recipes **Product-B-Changeover Matrix** and **Product-B-Changeover Matrix**.

To color-code the “CIP”-tagged operations in the EOC, simply switch to the EOC view and expand the **Options** menu. Then, enable the “Use activity color for selected operation types” checkbox and select the “CIP” operation type from the corresponding combo box.

# 4 Case C: Use of Suites

Similarly to Case B, Case C represents a multiproduct facility which produces three different polymer resins. However, this time the equipment is separated into Suite 1 and Suite 2, as shown in Figure 28. This is a useful case for understanding how to use SchedulePro Cloud to model equipment trains (sometimes referred to as "production lines"). Note that for the sake of simplicity, Cases C and D do not include equipment changeovers.

Since the modeling of suites involves edits at the recipe level, a new scheduling board was created to host Case C. Moreover, the three original product recipes (Product-A, Product-B and Product-C) were duplicated and renamed to **Product-A-Two Production Lines**, **Product-B-Two Production Lines** and **Product-C- Cases-Two Production Lines**. The scheduling board of this case exclusively uses the above recipes.

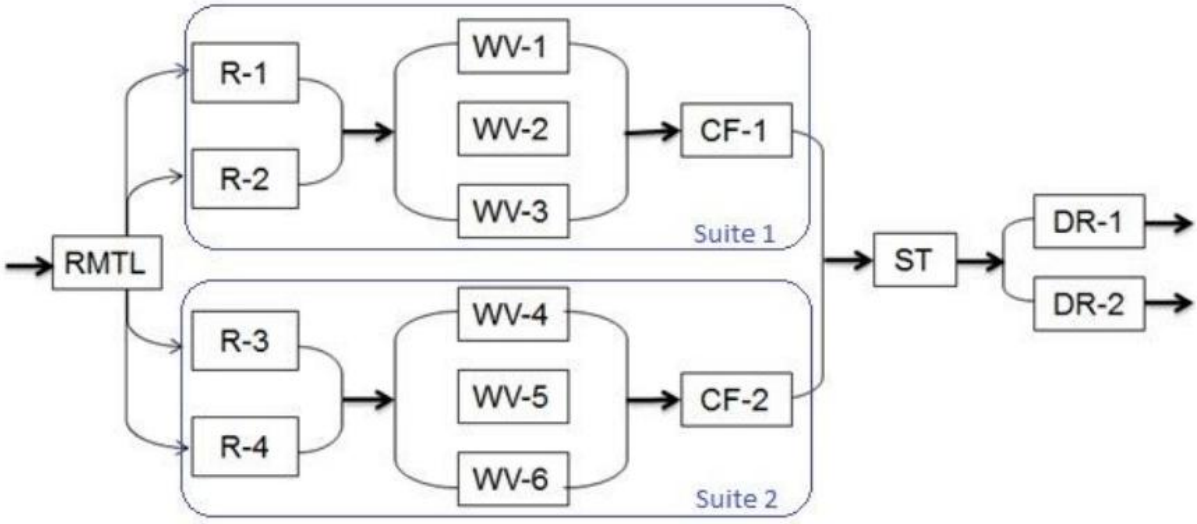



*Figure 28: Equipment diagram for 2-suite polymer production facility.*

As with Cases A and B, in Case C the raw materials are fed by a single transfer line (RMTL) into one of the four reactors, and only one reactor can be charged at a time. Unlike Cases A and B, the reactors, wash vessels and centrifuges are split into two production suites. Suite 1 includes two reactors (R-1 and R-2), three wash vessels (WV-1, WV-2, and WV-3), and one centrifuge (CF-1). Suite 2 also includes two reactors (R-3 and R-4), three wash vessels (WV-4, WV-5, and WV-6) and one centrifuge (CF-2). A batch that is started in a certain suite must remain in that suite until it goes through centrifugation. The centrifuged solids (coming out of CF-1 and CF-2) are then stored in mobile totes (ST). These totes are specified as

multi-tasking with unlimited parallel activities. This specification was made on the Parallel Execution group of the in the General tab of the properties side-panel “ST” equipment item in the Resin Plant facility. As can be seen in Figure 29, the Storage tote can execute unlimited parallel tasks. The specification of unlimited parallel activities is equivalent to having an unlimited number of totes. This ensures they will not become a scheduling bottleneck. The two dryers (DR-1 and DR-2) are in another part of the building and are not linked to the production suites. Therefore, any batch can go to either dryer.

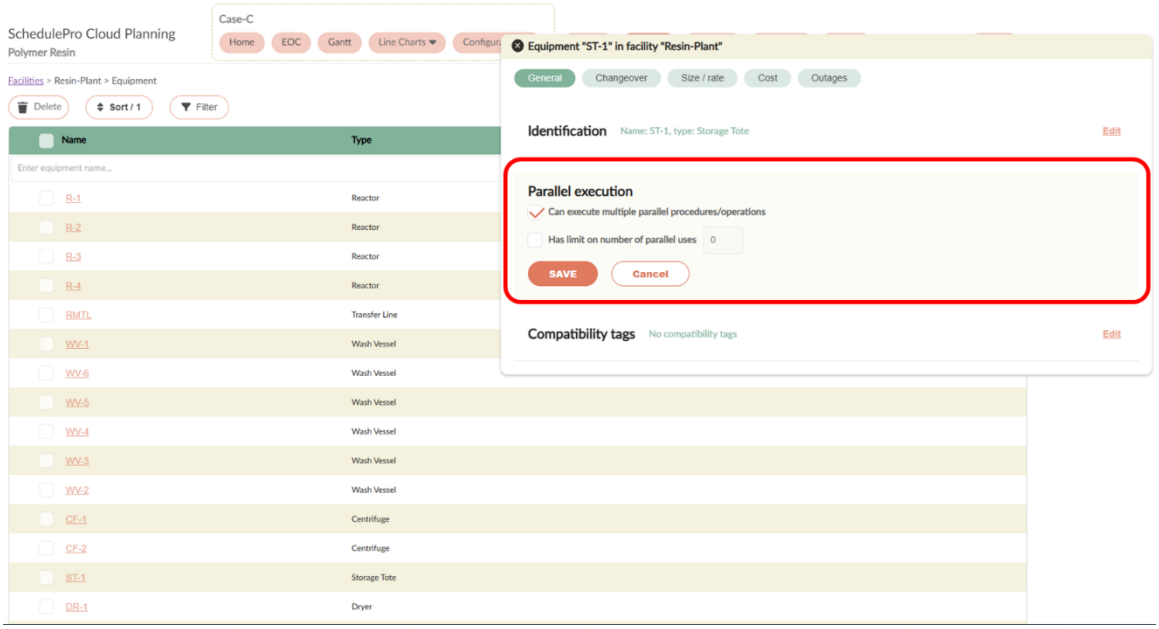



*Figure 29: View of the General tab in the **ST-1** equipment properties side-panel.*

## 4.1 Modeling Suites using Compatibility Tags

The key feature in SchedulePro Cloud that enables suite-level modeling is the use of compatibility tags. These tags allow equipment units to be grouped based on shared attributes, such as belonging to the same manufacturing suite. Once all equipment units associated with a given suite have been appropriately tagged, compatibility constraints can be enforced at the recipe level, specifically within individual procedures.

The modeling process consists of the following steps:

1. Create two compatibility tags representing Suite 1 and Suite 2.
2. Assign each equipment unit to the appropriate suite by applying the corresponding tag.

3. In the Washing and Centrifugation procedures, enforce compatibility with the Polymerization procedure.

With this configuration, when SchedulePro selects a reactor (e.g., R-1) for a batch in the Polymerization procedure, it will automatically restrict the selection of the corresponding Washing Vessel (WV) and Centrifuge (CF) to equipment units that share the same compatibility tag. This ensures that all operations for a given batch are carried out within the same suite.

Navigate to the **Compatibility Tags** page by selecting **Options / Compatibility tags** from the main menu. A new compatibility tag can be created by typing its name followed by clicking on the add button, ⊕, or by pressing the enter key on the keyboard. Create two tags named Suite 1 and Suite 2 as shown in Figure 30.

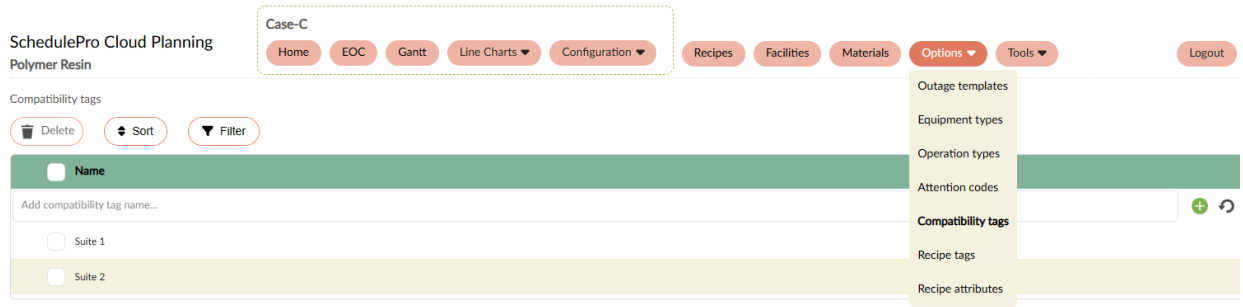



*Figure 30: View of the Compatibility Tags page of Case C.*

Subsequently, navigate to the Equipment page by selecting **Facilities / Equipment** from the main menu. Activate the properties side-panel of Reactor R-1 and click on the **Edit** button in the **Compatibility tags** group in the **General** tab. Use the combo box to assign the "Suite 1" tag to R-1 and click on the **SAVE** button to save this new setting. Repeat the same process for the rest of the equipment units that belong to Suite 1 or Suite 2, according to Figure 28.

After specifying which equipment is associated with each suite, it is necessary to revisit the product recipes in order to enforce suite allocation. Open the contents of the **Product-A-Two Production Lines** recipe by selecting **Recipes / Product-A-Two Production Lines** from the main menu. Enable the side-panel of the **Washing** procedure and navigate to the **Main Equipment Pool** tab. Use the **Edit** button to expand the Main Equipment Pool options and activate the "Enforce equipment compatibility with procedure" option. Then, use the dropdown list to select the **Polymerization** procedure. This setting ensures that SchedulePro Cloud will assign a wash vessel that exists in the same suite as the reactor that was assigned to the polymerization step. The same setting should be applied to the Centrifugation procedure. This

process should be repeated for recipes **Product-B-Two Production Lines** and **Product-C-Two Production Lines**. Also note that the Storage and Drying procedures of the three recipes do NOT need to be updated, since the storage and drying equipment are not separated into specific suites.

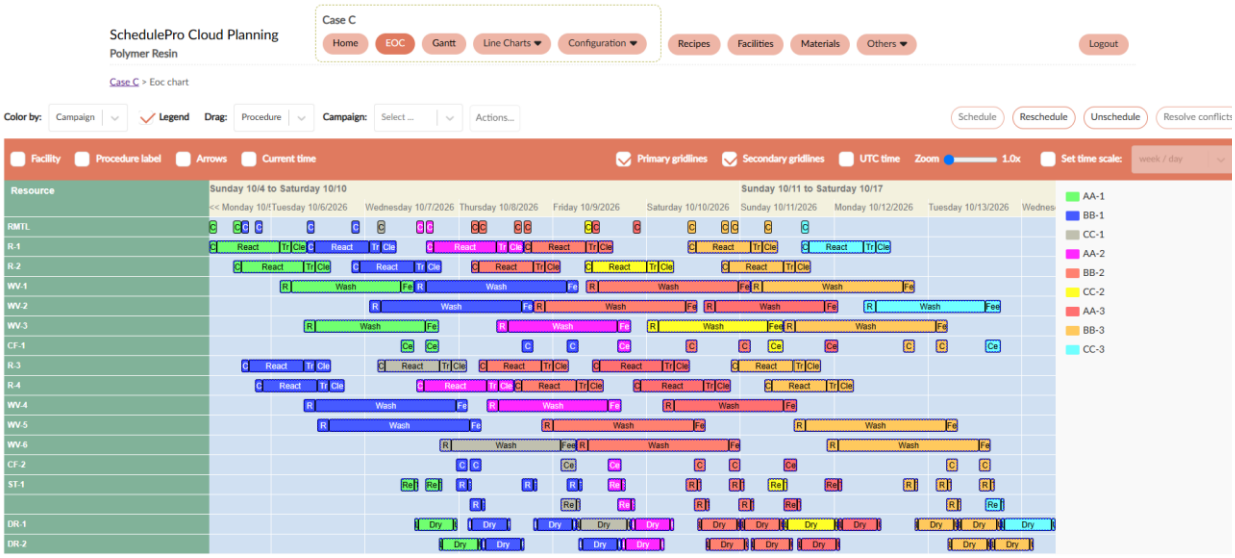



*Figure 31: View of the Equipment Occupancy Chart (EOC) of Case C*

After completing the suite definition and allocation, it is possible to generate a new EOC (see Figure 31). Comparing Figure 31 to Figure 19, it is apparent that some procedures have been automatically reassigned to different equipment[2]. This re-assignment was necessary to ensure that related procedures of a given recipe stayed within the same suite. For instance, in Figure 19, Batch BB-1-1 starts in reactor R-2 and then it is processed in wash vessel WV-4. Once suites are specified, this material flow is not allowable. As a result, in Figure 31, batch BB-11-1 correctly stays within Suite 1 for all operations in the Polymerization, Washing and Centrifugation steps of this recipe, as it is now processed in wash vessel WV-2 instead of wash vessel WV-4. In this particular example, enforcing suite allocation doesn't have a significant impact on the overall makespan of the production schedule (the makespan increase is equal to 11 h). However, in other situations the makespan may increase substantially.

[2] Also note that the ordering of the equipment in Figure 19 is different from the ordering of the equipment in Figure 31; the EOC in Figure 31 has been re-arranged to group equipment within the same suite together.

# 5 Case D: Production Tracking and Conflict Resolution

This case explains how to track production activities and resolve conflicts on an on-going basis. It expands upon Case C in order to incorporate production delays and required preventive maintenance activities. This case is useful for schedulers who will be working with SchedulePro Cloud on a daily basis to monitor and update plant schedules and to plan new campaigns. This case features two dedicated scheduling boards named **Case-D1** and **Case-D2** respectively. The two scheduling boards of this case exclusively use the **Product-A--Two Production Lines** , **Product-B-Two Production Lines** and **Product-C-Two Production Lines** recipes.

## 5.1 Production Tracking

Tracking the status of production schedules in SchedulePro is facilitated by the concept of current time, which corresponds to the user's local system time. The current time is represented on the EOC chart of case D1 by a red vertical line, which can be toggled on and off using the corresponding checkbox (see Figure 32). This current-time line can be used as a reference point to separate past and future activities.

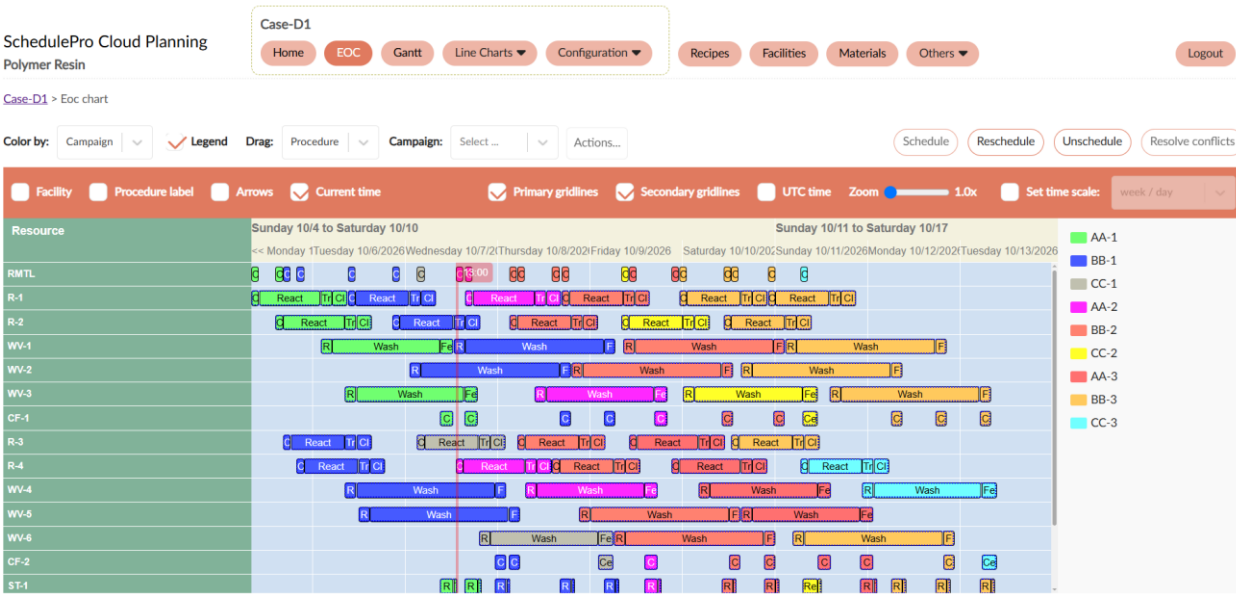



*Figure 32: Partial view of the Equipment Occupancy Chart (EOC) of Case D-1.*

## 5.2 Case D1: Identification and Resolution of Conflicts

The completion of certain tasks is often delayed due to variability in raw materials, operator skills, performance of process controllers, equipment failures, etc. Such delays may lead to scheduling conflicts with future activities. SchedulePro Cloud enables users to follow the schedule in real time and modify activities to account for process delays and other deviations from the original production schedule. Scheduled activities can be modified through the Gantt and Equipment Occupancy charts. Let's assume that the polymerization reaction in batch BB-1-3 (the third batch of the first BB campaign) takes 2 hours longer than planned. Such a delay can be specified by right-clicking on the bar of the corresponding operation and selecting **Operation / Properties** in order to bring up the side-panel shown in Figure 33. Timing information can be accessed / modified by editing the **Timing** group in the **Scheduling** tab. The 2-hour delay can be specified by either increasing the duration of the operation from 14 to 16 hours or by adjusting its End date and time.

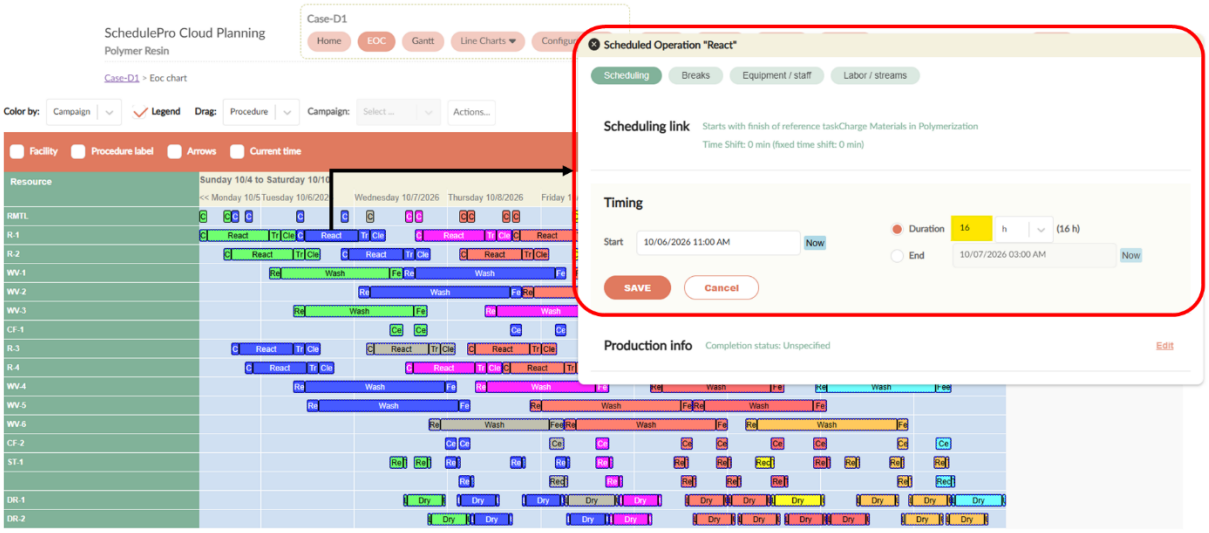



*Figure 33: View of the EOC chart of Case D1, featuring the "Scheduled Operation" side-panel.*

The EOC in Figure 34 represents the impact of the 2-h delay in the reaction step of BB-1-3. This delay propagates to the wash vessel WV-2, which leads to a conflict with the washing of BB-2-1 (the first batch of the second BB campaign that was scheduled to utilize the same wash vessel). Furthermore, the delayed drying of BB-1-3 leads to a conflict with the drying of CC-1-1 (both scheduled to utilize DR-1). These conflicts are highlighted automatically in SchedulePro by the addition of extra equipment lines in the EOC (labeled with exclamation points), and by changing the outline of each conflicting activity from black to red (see the red rectangle lines in Figure 34).

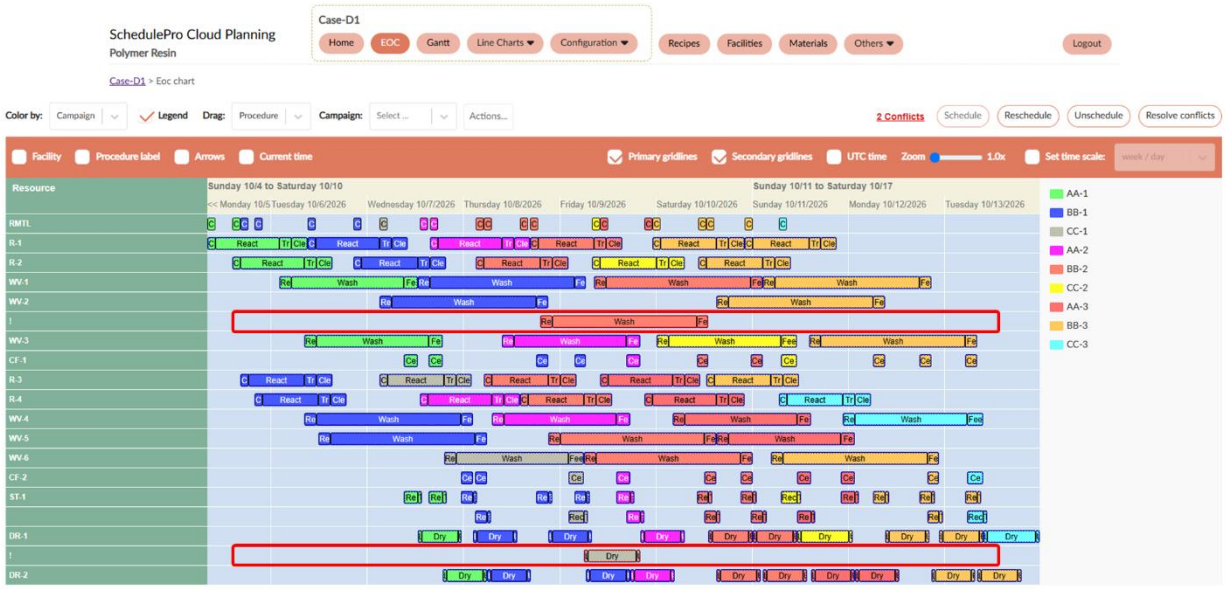



*Figure 34: View of the EOC chart of Case D1, featuring conflicts resulting from delay in BB-1-3 reaction step.*

At this point, the next logical step is to resolve the conflicts created by the initial delay. These conflicts can be resolved manually using the drag-and-drop capabilities of SchedulePro Cloud. In other words, the items that have scheduling conflicts can be shifted by clicking and dragging them to new locations on the EOC. The choice of which type of scheduled item to shift is made by clicking the **Drag** menu item near the upper left corner of the EOC (next to the Legend checkbox). There you can specify that you wish to drag individual operations, or procedures, or batches, or even entire campaigns. Then you simply click on one of the scheduled items on the EOC and drag the cursor to the right or left in order to change the start time of that item. Be aware that resolving one conflict using the drag-and-drop method may generate new conflicts in other locations. Another option is to resolve conflicts automatically by using SchedulePro Cloud's conflict resolution algorithms. To do the latter, right-click on the conflicting entity and use the context menu options (e.g., Procedure / Resolve Conflicts) or use the Conflict Resolution button on the chart toolbar. Note that when there is a conflict between two batches, it is the latter batch that the conflict is assigned to. Also note that conflict resolution can be performed in a stepwise fashion with the user controlling the extent to which SchedulePro Cloud will resolve the scheduling conflicts. Thus, if you right-click on a conflicting entity, the menu that pops-up shows options to resolve conflicts for the corresponding operation, procedure, batch, campaign or for the entire schedule. For better control of the schedule and to avoid big changes, it is generally better to resolve conflicts at a local level (e.g. a single batch or campaign) and proceed gradually until all conflicts are resolved. In this case, incremental resolution of the conflicts results in delays in the execution of various batches. This is because the original

schedule had very little idle time between batches. In general, adding a small amount of idle time to the schedule is desirable in manufacturing because the idle time provides flexibility for absorbing delays.

## 5.3 Case D2: Modeling Equipment Outages

After all conflicts have been resolved automatically, by clicking on the **Resolve Conflicts** button, and the EOC has been updated, let's add a preventive maintenance activity to reactor R-1. This activity can me modelled as an equipment outage. Navigate to the **Facilities** page and click on the **Equipment** button in the Resin Plant Facility. Then, click on the R-1 reactor and visit the Outages tab of its properties side-panel. In this view, the facility outages are shown in a calendar view (Outage calendar).

Click the **Add Outage** button to add a new equipment outage. In this example case, the start of the outage was set on 10/14/2026 at 12:00 PM and its duration was assumed to be equal to 48 hours (as shown in Figure 35). After setting this downtime and saving the Calendar Entry, you will see the downtimes displayed graphically on the calendar window by grey bars, as shown in Figure 36. Alternatively, users can define **Outage Templates** that can be used in any entity (equipment/staff/labor) of the workspace. For more information on Outage Templates users are encouraged to study the SCP Could Tutorial which is accessible via the home page of SCP Cloud.

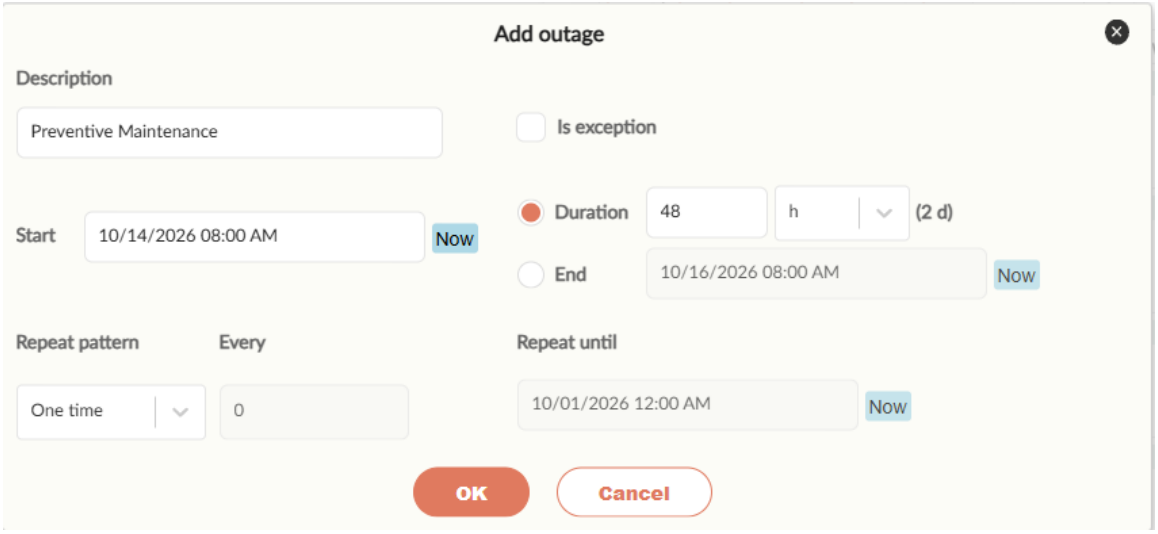



*Figure 35: Equipment Outage panel.*

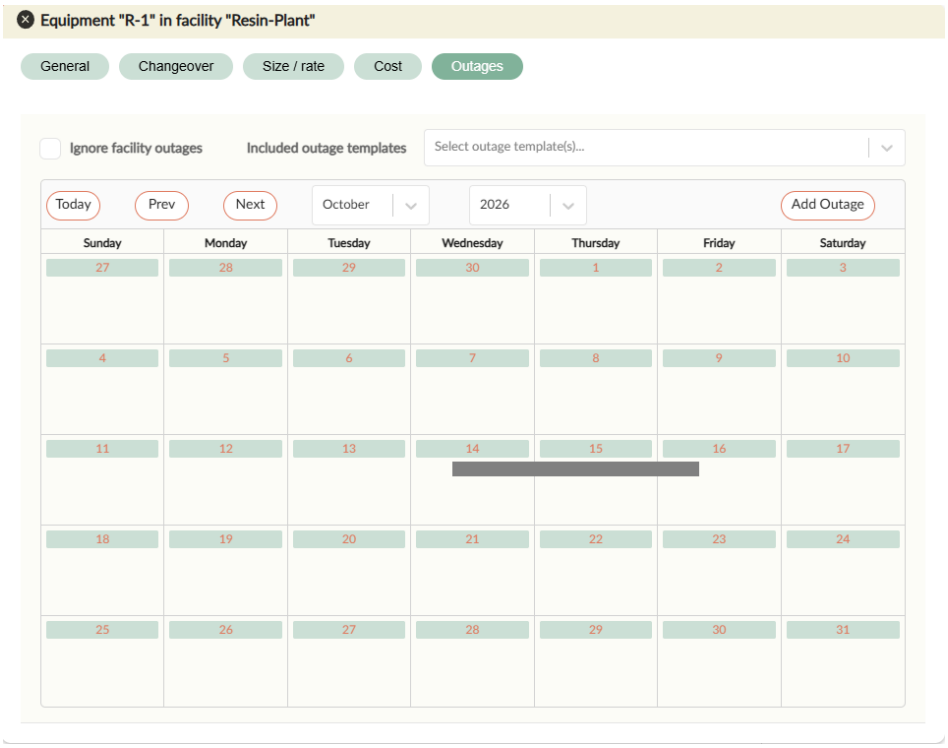



*Figure 36: View of the Outage calendar panel of reactor R-1*

The reactor R-1 downtime, due to scheduled preventive maintenance, will be represented by a grey bar in the Equipment Occupancy chart too, as shown in Figure 37.

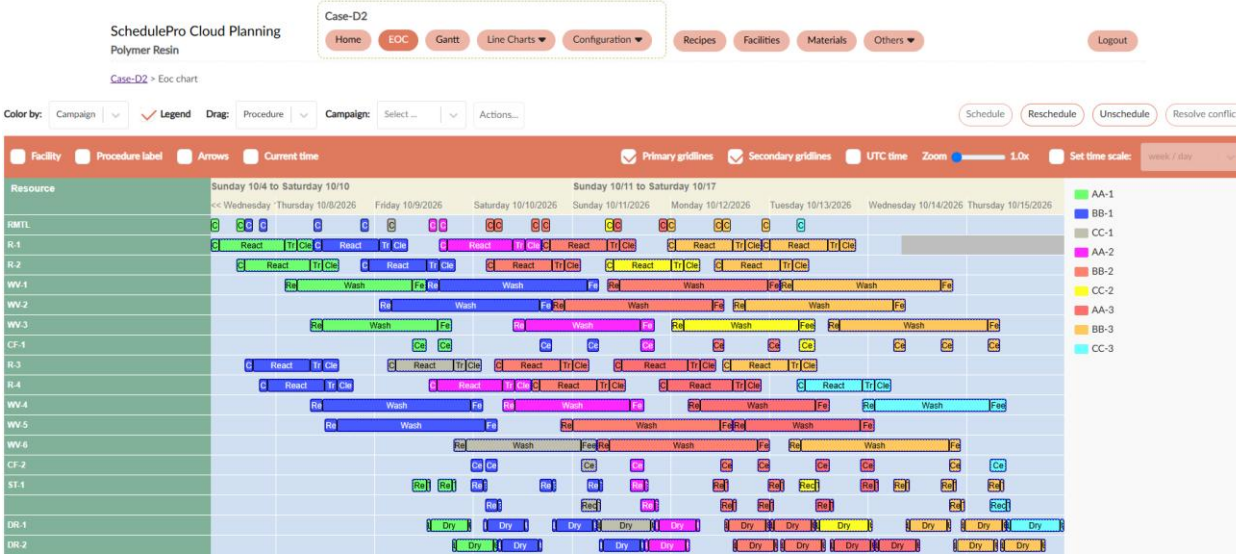



*Figure 37: View of the EOC chart of Case D2, featuring the reactor R-1 outage due to preventive maintenance*

Let's now add a new set of campaigns, including a 2-batch campaign of recipe Product-A, a 4-batch campaign of recipe Product-B, and a 1-batch campaign of recipe Product-C. The resulting EOC (Figure 38) shows that the next batch to use reactor R-1 (batch AA-5-1 on campaign AA-5) starts after the preventive maintenance activity that we added previously.

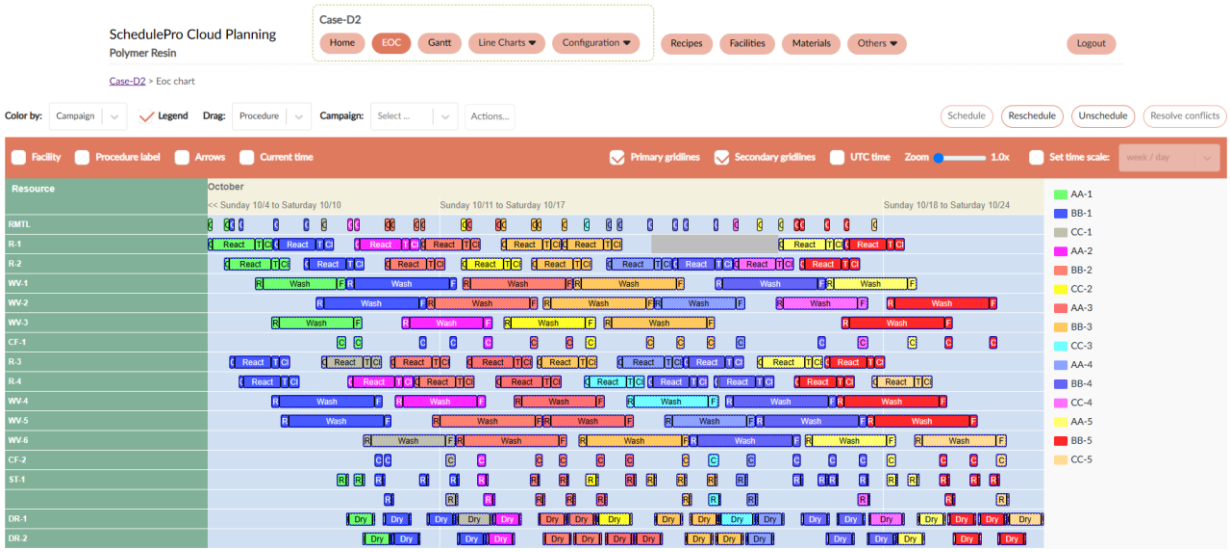



*Figure 38: Partial view of the EOC chart of Case D-2, including two additional sets of Product A, Product B and Product C campaigns.*

This concludes the polymer production example. For additional details on how to create models in SchedulePro Cloud, and for information on additional capabilities of SchedulePro Cloud please refer to the SchedulePro Cloud's tutorials and their associated workspaces, which can be accessed via the home screen of the web application.