

The XML Files

There are three different types of XML files, the configuration file, the initial file, and the solution file. The configuration file contains all the fixed information about the workshop, such as machines and variants of products which can be produced in the workshop. The initial file on the other hand contains information which changes over time, such as the positions of the products in the workshop, which workers are present. The solution file contains a solution schedule to the problem given by the configuration and initial file. In the following we give an overview of these three different file types.

Configuration

The configuration file contains all the information about the setup of the workshop which does not change (easily) over time. The configuration file contains the workstations and buffers, their location in the workshop, the distances between the stations (as walking times), as well as the possible variants of products that can be produced in the workshop.

```
<FlowShopConfiguration name="BoschExample">
  <WalkingTimes>
  <Variants>
  <ProcessingUnits>
```

The root element of the XML file is the FlowShopConfiguration and has as an attribute name, which uniquely identifies the configuration and is referenced to in the initial and solution files. The FlowShopConfiguration has three subelements, WalkingTimes, Variants and ProcessingUnits.

```
<ProcessingUnits>
  <ProcessingUnit type="STATION" id="STATION-1" lane="1" position="1" />
  <ProcessingUnit type="BUFFER" id="BUFFER-1" lane="1" position="1" capacity="1" />
  <ProcessingUnit type="STATION" id="STATION-2" lane="1" position="2" />
  <ProcessingUnit type="BUFFER" id="BUFFER-2" lane="1" position="2" capacity="1" />
```

The ProcessingUnits elements contains as subelements a list of ProcessingUnit elements. Each ProcessingUnit is of type either BUFFER or STATION, no other types are allowed. If a ProcessingUnit is of type STATION, then it has four attributes: type, id, lane and position. The id assigns a unique identification string to the station. The lane and position specifies the location of the station in the workshop. If all stations are arranged in one line, then the lane value of each station is equal to 1. On the other hand, if the stations are arranged as two lines, then some stations is in lane 1 and others in lane 2. The position attribute gives the position of the station in its lane. If a ProcessingUnit is of type BUFFER, then it has five attributes: type, id, lane, position and capacity. The id assigns a unique identification string to the buffer. The lane and position specifies the location of the buffer in the workshop similarly to the stations. Note that if the position of a buffer is equal to i , then it is located directly after the station with position i .

```
<WalkingTimes>
  <WalkingTime start="STATION-1" end="STATION-1" traveltime="0" />
  <WalkingTime start="STATION-2" end="STATION-1" traveltime="10" />
  <WalkingTime start="STATION-3" end="STATION-1" traveltime="20" />
  <WalkingTime start="STATION-4" end="STATION-1" traveltime="30" />
  <WalkingTime start="STATION-5" end="STATION-1" traveltime="40" />
  <WalkingTime start="STATION-6" end="STATION-1" traveltime="50" />
  <WalkingTime start="STATION-7" end="STATION-1" traveltime="60" />
```

The WalkingTime Element has a list of subelements all of type WalkingTime, which specify the time it takes for a worker to walk from one station to another. Each WalkingTime has attributes start, end and traveltime. The traveltime is a positive integer and specifies the time it takes for a worker to walk from the station specified under start to the station specified under end. Note that the start and end attributes are equal to station IDs like they are specified in the ProcessingUnits element. If not all WalkingTimes between any two stations are given, we assume that they are symmetric (so the traveltime for start=X and end=Y is the same as the traveltime for start=Y and end=X) and that the traveltime from one station to itself is equal to 0.



The final subelement of FlowShopConfiguration is the Variants element which has a list of all available variants as subelements. Each Variant has as an attribute an id, which is a unique string. As subelements, each Variant has a list of all the worksteps which must be processed for products of this type. Each Workstep has three attributes: id, location and automatic. The id attribute gives a unique identifier to the workstep. The location attribute gives the id of the station on which the workstep must be processed and automatic is a Boolean which is True if an automatic workstep is being processed at the station. For all worksteps with automatic = "False", the workstep has exactly one subelement Duration, which gives the time it takes for a worker to complete the workstep. If the workstep has automatic = "True", then it has three subelements: Duration, SetupTime and TakedownTime, where the duration gives the time it takes for the automatic workstep to complete, the SetupTime gives the duration it takes a worker to prepare the product for the automatic step at the station and similarly the TakedownTime is the time it takes a worker to take the product down after the automatic step.

Initial State

The initial file contains all the information which changes over time, such as which workers are present to produce products and which products are currently waiting to be processed.

```

<FlowShopInitialState name="BoschExample-1">
  <ConfigurationFile name="BoschExample" />
  <Workers>
  <Products>

```

The root element of the initial file is FlowShopInitialState with one name attribute which uniquely identifies the initial setup and is referenced in the solution file. It contains three subelements: ConfigurationFile, Workers and Products. The ConfigurationFile has as attribute the name of the corresponding configuration file. This makes it easy to know which configuration file is associated with the initial file.

```

<Workers>
  <Worker id="WORKER-1" skill="100" location="STATION-1" releasetime="0" />
  <Worker id="WORKER-2" skill="100" location="STATION-2" releasetime="0" />
  <Worker id="WORKER-3" skill="100" location="STATION-4" releasetime="10" />

```

The Workers subelement contains a list of Worker elements which represent all the workers currently in the workshop. Each worker element has four attributes: id, skill, location and releasetime. The id attribute gives a unique string identifier to the worker, the skill is an integer between 0 and 100 and gives the skill level of the worker. The skill level determines the speed at which a worker can process worksteps. The best skill level a worker can have is 100 and any worker with skill level 100 can process worksteps in the duration specified in the configuration file. If a worker has skill x , then the time it takes for this worker to produce a workstep with duration t is equal to $(100/x)*t$. The location attribute gives the id of the station where the worker is currently standing or will have arrived at after the releasetime. The releasetime attribute is an integer which specifies the time at which the worker is free to start walking or producing.

```

<Products>
  <Product id="PRODUCT-1" variant="VARIANT-3" location="BUFFER-9" />
  <Product id="PRODUCT-2" variant="VARIANT-4" location="BUFFER-5" />
  <Product id="PRODUCT-3" variant="VARIANT-1" location="STATION-4" step="manual" releasetime="10" />
  <Product id="PRODUCT-4" variant="VARIANT-2" />
  <Product id="PRODUCT-5" variant="VARIANT-1" />
  <Product id="PRODUCT-6" variant="VARIANT-4" />

```

The Products subelement contains a list of Product element which are currently being produced or in the queue waiting to be produced. Each Product element has between two and five attributes. Every product must have an id attribute, which is a string element uniquely identifying the product, and a variant attribute which specifies, as id of a variant, of which variant the product is. If production on a product has not started yet, then the product only has these two attributes. If production on a product has already been started, then the product also has a location attribute. The location attribute is the id of the station or buffer on which the product is lying on at the initial time. If the location is that of a buffer, then the product element has no further attributes and is waiting to be processed at the next station. If the location attribute is that of a station on the other hand, then the product has two further attributes: step and releasetime. The step attribute identifies the production step which is currently carried out on the product. If the product is on a manual station, then the step is equal to "manual". If the product is currently at an automatic station however, then the step can be any of "setup", "automatic" or "takedown" depending on whether the product is currently being prepared for the automatic step, being processed in the automatic step or taken down after the automatic step. No other step types are possible. The releasetime attribute specifies the time until the current workstep is completed.

Solution

The solution file contains a single solution schedule for the problem specified by a configuration and an initial setup.

```
<FlowShopSolution configuration="BoschExample" initialState="BoschExample-1">
  <Events>
  <Schedule gap="0" objective="3290.0" solver="OR-Tools" solvingTime="54.538715499999995" status="OPTIMAL">
```

The root element of the solution file is FlowShopSolution, which has two attributes and two elements. The attributes are configuration and initialState which give the name of the corresponding configuration and the name of the corresponding initialState respectively. Its two subelements are Events and Schedule.

The Events Element has two subelements, Workers and Products. The Workers element stores all events of workers while the Products element stores all the events of products.

```
<FlowShopSolution configuration="BoschExample" initialState="BoschExample-1">
  <Events>
    <Workers>
    <Products>
  <Schedule gap="0" objective="3290.0" solver="OR-Tools" solvingTime="54.538715499999995" status="OPTIMAL">
```

This means, that the Worker element has several Event subelements, each with start, end, station, and worker attributes. The event specifies that the worker with worker id as in the attribute worker is at the station with station id as specified in the attribute station between the times specified under start and end. In the example below, WORKER-1 is at STATION-1 from time 0 up to time 600.

```
<Events>
  <Workers>
    <Event end="600" start="0" station="STATION-1" worker="WORKER-1" />
    <Event end="540" start="40" station="STATION-10" worker="WORKER-2" />
    <Event end="60" start="50" station="STATION-6" worker="WORKER-3" />
    <Event end="700" start="100" station="STATION-2" worker="WORKER-3" />
```

The subelements of Products are similarly Event elements each with start, end, location, and product attributes. Each Event specifies that a certain product, as specified in the product attribute by its id, is at a certain location, which can be a station or buffer and is specified under location by its id, between the times specified under start and end. In the example below, PRODUCT-4 is at STATION-1 from time 0 until time 100.

```
<Events>
  <Workers>
  <Products>
    <event end="100" location="STATION-1" product="PRODUCT-4" start="0" />
    <Event end="540" location="STATION-10" product="PRODUCT-1" start="40" />
    <event end="850" location="STATION-6" product="PRODUCT-2" start="50" />
    <event end="600" location="STATION-2" product="PRODUCT-4" start="100" />
    <event end="200" location="STATION-1" product="PRODUCT-5" start="100" />
    <event end="600" location="BUFFER-1" product="PRODUCT-5" start="200" />
```

The other subelement of FlowShopSolution is the Schedule element. Schedule has a subelement corresponding to each worker and five attributes: gap, objective, solver, solvingTime and status. The objective gives the time until the final workstep is completed in this solution, so the makespan of the

proposed schedule. The status gives the status of the solution, whether it is a proven optimal solution or is only a suboptimal solution. The gap specifies in percent the gap to the estimated optimal solution, so when the gap is equal to zero then an optimal solution has been found. The solvingTime gives the solving time it took to find this solution in seconds. The solver specifies which solver or solution approach has been used to generate this solution.

The subelements of Schedule are of type Worker and have an attribute id, which uniquely identifies them as one of the workers given in the initial file. Each Worker Element has a subelement AssignedWorkSteps, which has a list of worksteps as subelements. Each Workstep subelement has five attributes, start, end, product, station, and workstep. Each of product, station and workstep are specified by their id. This element specifies that the given worker is producing the given workstep of the given product at the given station between the times specified under start and end. This means that in the example below WORKER-1 is producing WORKSTEP-V2-S1 on PRODUCT-4 at STATION-1 between time 0 and time 100.

```
<Schedule gap="0" objective="3290.0" solver="OR-Tools" solvingTime="54.538715499999995" status="OPTIMAL">
  <Worker id="WORKER-1">
    <AssignedWorkSteps>
      <Workstep end="100" product="PRODUCT-4" start="0" station="STATION-1" workstep="WORKSTEP-V2-S1" />
      <Workstep end="200" product="PRODUCT-5" start="100" station="STATION-1" workstep="WORKSTEP-V1-S1" />
      <Workstep end="600" product="PRODUCT-6" start="500" station="STATION-1" workstep="WORKSTEP-V4-S1" />
      <Workstep end="1200" product="PRODUCT-6" start="700" station="STATION-2" workstep="WORKSTEP-V4-S2" />
    </AssignedWorkSteps>
  </Worker>
</Schedule>
```