0002 — Report: components.py — Simulation Building Blocks

1. Purpose and role

The module `dtwinpy/components.py` defines the **discrete-event simulation building blocks** used by the Digital Twin. These components are assembled by `digital_model.py` from the graph JSON (nodes – machines, arcs → queues) and then run under SimPy to simulate the physical process and support services such as RCT (routing/optimization).

Main responsibilities:

- Represent **parts** (jobs) flowing through the system.
- Represent **machines** (activities) that take parts from input queues, process them, and send them to output queues (via **conveyors**).
- Represent **queues** (buffers between machines) and **conveyors** (transport with delay).
- Handle **branching** (one machine, multiple output paths) and allocation policies (first free, alternated, RCT, branching).
- Support **open/closed loop** via **Generator** (initial part placement) and **Terminator** (part completion and, in closed loop, part replacement).

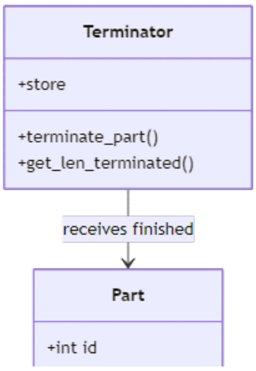
2. Module layout and dependencies

```
components.py
├── Part              # Entity: part/job
├── Machine           # Resource: processes parts (state machine)
├── Queue             # Buffer: simpy.Store between machines
├── Generator         # Initial WIP: places parts in queues
├── Terminator        # Sink: receives finished parts (and replaces in closed loop)
├── Conveyor          # Transport: delay between machine output and next queue
└── Branch            # Logic: which output path to use for a part at a branching machine
```

Imports:

- `simpy` — environment, timeouts, stores.
- `Helper` from `.helper` — logging/printing.
- `scipy.stats` (`norm`, `expon`, `lognorm`) — process-time distributions (used when `process_time` is a list like `["norm", μ, σ]`).

3. Class overview (Mermaid)



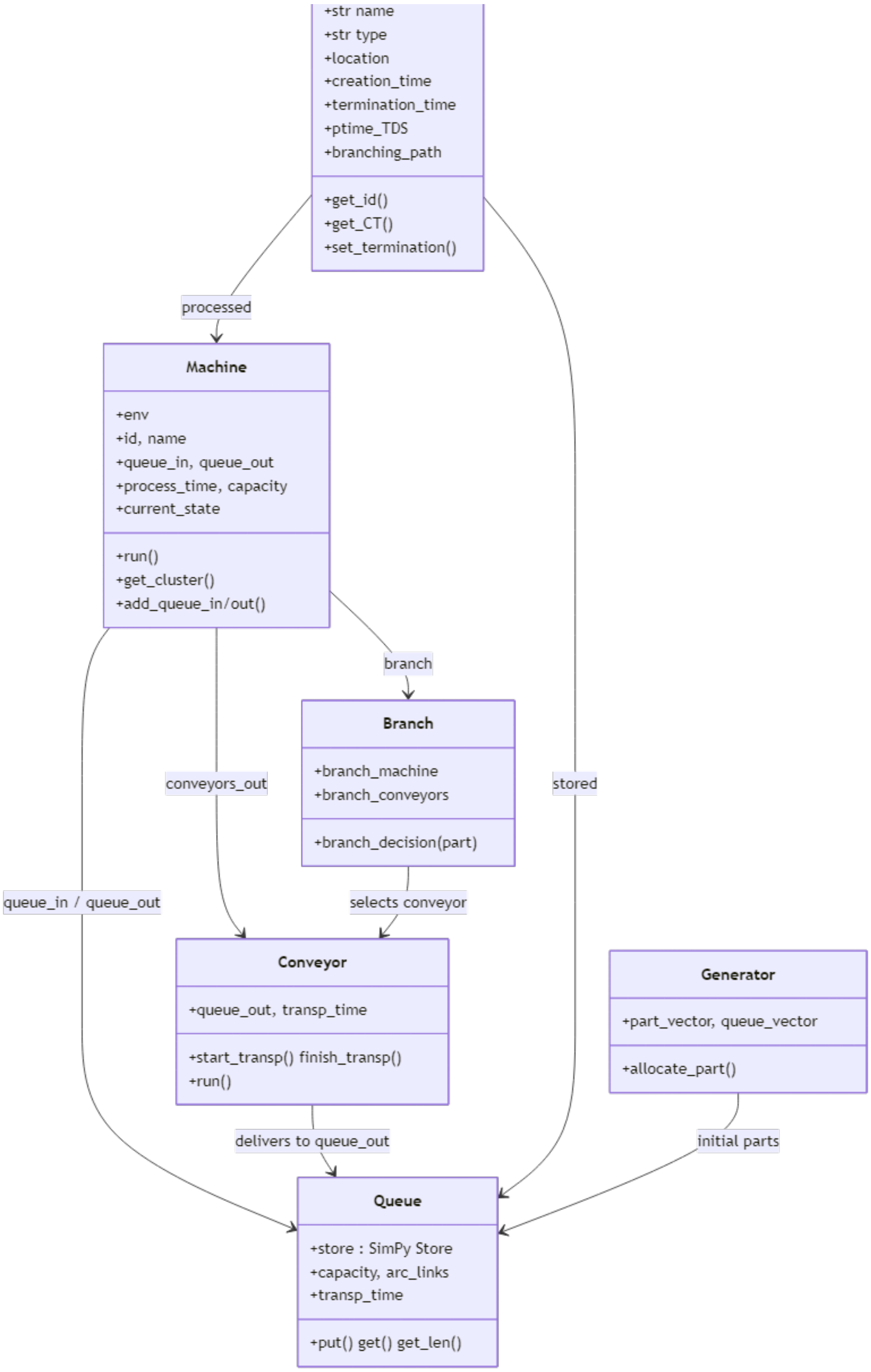


Diagram 1

4. Part

Represents a **part** (job) in the system.

4.1 Main attributes

Attribute	Type	Description
`id`	int	Unique part ID.
`name`	str	`"Part " + str(id)`.
`type`	str	Part type (e.g. `"A"`).
`location`	—	Queue index (used by Generator for initial placement).
`creation_time`	number	SimPy time when part entered the system.
`termination_time`	number	SimPy time when part left (set by Terminator).
`ptime_TDS`	list	Trace-Driven Simulation: process times per cluster.
`finished_clusters`	int	Number of clusters already completed (TDS).
`convey_entering_time`	number	When part entered current conveyor.
`branching_path`	list	Conveyors (or path) chosen for branching; used by Branch.

4.2 Main methods

- **Getters:** `get_id()`, `get_name()`, `get_type()`, `get_location()`, `get_creation()`, `get_termination()`, `get_CT()`, `get_ptime_TDS(cluster)`, `get_branching_path()`, etc.
- **Setters:** `set_termination()`, `set_finished_clusters()`, `set_ptime_TDS()`, `set_convey_entering_time()`, `set_branching_path()`, etc.
- **`calculate_CT()`** — Cycle time: `termination_time - creation_time`.
- **`quick_TDS_fix(current_cluster)`** — Adjusts `ptime_TDS` for parts that join mid-flow (pads with zeros for finished clusters).

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5. Machine

Represents a **machine** (activity/node). It runs as a SimPy process with a**state machine**: **Idle** → **Processing** → **Allocating** → **Idle**.

5.1 State diagram

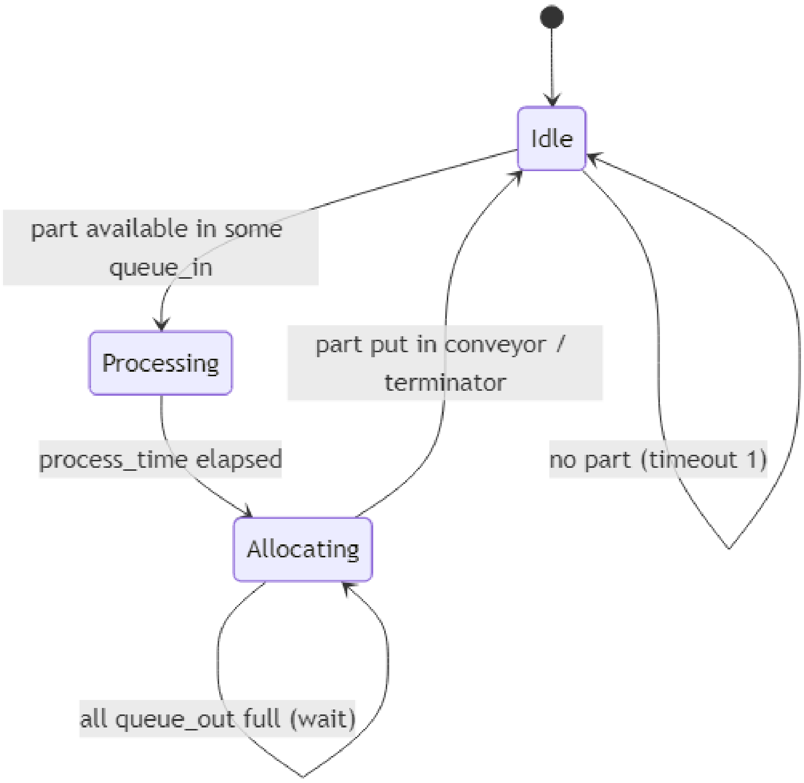
Idle
part available in some queue_in
Processing
part put in conveyor / terminator
process_time elapsed
no part (timeout 1)
Allocating
all queue_out full (wait)

Diagram 2

- **Idle:** Check `queue_in`; if any queue has a part, choose one (e.g. first non-empty), set `queue_to_get`, move to **Processing**.
- **Processing:** Get part (from queue or `initial_part` if `worked_time != 0`). Compute process time (normal/TDS/qTDS), then `yield env.timeout(process_time)`. Then move to **Allocating**.
- **Allocating:** Choose output (queue/conveyor) by policy; if chosen queue is full, wait and retry; otherwise put part in conveyor (or send to terminator for final machine). Then move back to **Idle** (or trigger exit for open-loop / targeted part / maxparts).

5.2 Main attributes (selection)

Attribute	Description
`env`	SimPy environment.
`id`, `name`	Machine ID and `"Machine " + id`.
`queue_in`, `queue_out`	Lists of Queue objects (input/output).
`process_time`	Fixed number or `["norm", μ, σ]` (and similar).
`capacity`	Machine capacity (e.g. 1).
`current_state`	`"Idle"` | `"Processing"` | `"Allocating"`.
`queue_to_get`, `queue_to_put`	Selected queue for current part.
`part_in_machine`	Part currently being processed or allocated.
`conveyors_out`	List of Conveyor objects (one per output queue).
`branch`	Branch object if this machine is a branching point.
`allocation_policy`	`"first"` | `"alternated"` | `"branching"` | `"rct"`.
`allocation_counter`	Index for alternated policy.
`parts_branch_queue`	RCT: list of (part_name, queue_name) for routing.
`final_machine`	True for the last machine in the loop.
`loop`	`"closed"` or `"open"`.
`terminator`	Terminator that receives finished parts.
`worked_time`, `initial_part`	For sync: part already in machine at start.
`simtype`	`None` | `"TDS"` | `"qTDS"` for process time source.

5.3 Allocation policies (Allocating state)

- **first** — First output queue that is not full.
- **alternated** — Round-robin over `queue_out` via `allocation_counter`; if all full, wait and retry.
- **branching** — Use `branch.branch_decision(part)` to pick conveyor (and thus queue) from part's `branching_path`.
- **rct** — Use `parts_branch_queue` to get queue name for current part and select that queue.

After choosing `queue_to_put`, the machine puts the part into the corresponding **conveyor** (`conveyor_to_put.start_transp(part)`), not directly into the queue.

5.4 Process time modes (Processing state)

- **Normal (`simtype == None`):**
  - If `process_time` is a list (e.g. `["norm", 17, 2]`), sample from that distribution.
  - If numeric, use it.
  - Subtract `worked_time` when resuming from a synced "in progress" part.
- **TDS:** Use `part.get_ptime_TDS(machine_cluster - 1)` for the current cluster.
- **qTDS:** Use `ptime_qTDS[finished_parts]` and increment `finished_parts`; when exhausted, switch back to normal.

5.5 Code snippet (state transitions and conveyor handoff)

```
# Idle → Processing: first queue with a part
for queue in self.queue_in:
    if queue.get_len() != 0:
        flag_new_part = True
        self.queue_to_get = queue
        break
if flag_new_part:
    self.current_state = "Processing"

# Allocating: put part in conveyor (after policy chose queue_to_put)
conveyor_to_put.start_transp(self.part_in_machine)
# ...
if flag_allocated_part:
    self.current_state = "Idle"
```

6. Queue

Thin wrapper around a **SimPy Store** for parts between machines (and between conveyor and machine input).

6.1 Main attributes and methods

Attribute	Description
`store`	`simpy.Store(env, capacity=capacity)`.
`capacity`	Max number of parts.
`arc_links`	`[source_activity_id, target_activity_id]` from model JSON.
`transp_time`, `freq`	From JSON (transport time used by Conveyor).

Methods: `put(resource)`, `get()` (delegate to `store`), `get_len()`, `get_arc_links()`, `get_name()`, `get_capacity()`, `get_id()`.

`digital_model.py` builds one Queue per arc and links them to machines via `queue_allocation()`.

7. Generator

Places **initial WIP** parts into queues at simulation start.

- **`allocate_part()`** — For each part in `part_vector`, puts it in `queue_vector[part.get_location()]`. Returns `queue_vector`.
- **`create_part(...)`** — Factory: creates a `Part` with `creation_time=env.now`.

Used by the model when `initial == True` and after building the initial list of parts (e.g. from JSON `initial`).

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8. Terminator

Represents the **sink** of the process: receives parts that have completed all operations.

- **`terminate_part(part)`** — Sets `part.set_termination(env.now)` and puts the part in an internal store.
- **`get_len_terminated()`** — Number of parts in the store (for stop conditions: max parts, targeted part, etc.).
- **`get_all_items()`** — Access to terminated parts (e.g. for analytics).

In **closed loop**, when the **final machine** finishes a part, it calls `terminator.terminate_part(part)` and then creates a **new part** and puts it into the conveyor that feeds the first machine, so the total number of parts in the system stays constant. In **open loop**, the final machine only terminates (no replacement).

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9. Conveyor

Models **transport delay** between a machine output and the next queue. Parts are not put directly into the next queue; they are put into a conveyor that, after `transp_time`, places them in `queue_out`.

9.1 Behaviour

- **`start_transp(part)`** — Sets `part.convey_entering_time = env.now` and puts the part into an internal store (`convey_store`).
- **`run()`** (SimPy process) — In a loop: take the **first** part in the conveyor (FIFO); if `env.now - convey_entering_time >= transp_time`, remove it and `queue_out.put(part)`; then `yield env.timeout(wait)` and repeat.

So each conveyor is a delay line: parts leave the machine at event time, and arrive at the queue at event time + `transp_time`.

9.2 Main attributes

Attribute	Description
`id`	Same as `queue_out.get_id()` (links conveyor to queue).
`name`	`"Conveyor towards " + queue_out.get_name()`.
`transp_time`	Transport delay (from arc in JSON).
`queue_out`	Target queue.
`convey_store`	SimPy Store holding parts in transit.

Note: `Conveyor.get_id()` returns `self.id` (an int); the code in the file is `return self.id()` which would be incorrect if `id` is not callable — the rest of the code uses `conveyor.id` directly.

10. Branch

Encapsulates **branching logic** for a machine that has multiple output queues/conveyors. Used when the model has one node with several successors (e.g. machine 2 → queues to machines 3 and 4).

10.1 Attributes

- **`branch_machine`** — The Machine that performs the branching.
- **`branch_conveyors`** — List of Conveyor objects (one per output path).
- **`branch_queue_in`** — Input queue(s) for the branch (for reference).

10.2 branch_decision(part_to_put)

Finds the conveyor that matches the part's **pre-assigned path**:

- For each conveyor in `branch_machine.get_conveyors_out()`,
- Check if it appears in `part_to_put.get_branching_path()` (by conveyor `id`).
- Return the matching conveyor; the machine then uses it as `conveyor_to_put` and puts the part there.

So the part's `branching_path` is set elsewhere (e.g. by the RCT service or by the digital model), and Branch only selects which conveyor (and thus which queue) to use for that part.

11. Data flow (high level)

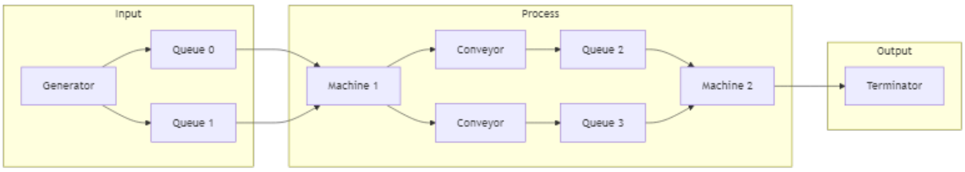

Diagram 3

1. **Generator** places initial parts in queues (by `location`).
2. **Machines** get parts from `queue_in`, process (state machine), then choose output via allocation policy and **Conveyor**.
3. **Conveyors** delay parts by `transp_time` then put them in the next **Queue**.
4. **Terminator** receives finished parts; in closed loop, a new part is created and fed back into the first conveyor(s).

12. Relation to digital_model and JSON

JSON / concept	components.py
`nodes`	Each node → one **Machine** (process_time from `contemp`, cluster, etc.).
`arcs`	Each arc → one **Queue** (capacity, transport time) and one **Conveyor** (transp_time, queue_out).
`initial`	**Generator** + Part list → `allocate_part()` into queues.
Branching node	**Branch** object created and set on the **Machine**; machine uses `allocation_policy = "branching"` and `branch.branch_decision(part)`.
RCT routing	**Machine.parts_branch_queue** set from service; machine uses `allocation_policy = "rct"`.

`digital_model.Model.model_translator()` builds `machines_vector` and `queues_vector` from the JSON, ther calls `queue_allocation()`, `create_conveyors()`, `branch_discovery()`, `initial_allocation()`, etc., so that the graph is fully implemented with these components.

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13. Summary

- **Part:** Entity flowing through the system; holds TDS data and branching path.
- **Machine:** SimPy process with Idle → Processing → Allocating; process time from distribution or TDS/qTDS; allocation by first / alternated / branching / rct; handoff via Conveyor.
- **Queue:** SimPy Store for parts between stages; capacity and arc_links from JSON.
- **Generator / Terminator:** Initial WIP placement and part completion (and replacement in closed loop).
- **Conveyor:** Transport delay between machine output and next queue; FIFO, delay `transp_time`.
- **Branch:** Selects which conveyor (and thus queue) to use for a part at a branching machine, based on `part.branching_path`.

Together, these classes form the executable simulation used by the Digital Twin to evaluate scenarios and support the RCT (routing) service.