

0001 — Report: Models Folder and JSON Structure of the Digital Twin

1. General context

This repository implements a **Digital Twin**: a digital model that represents a physical **machine-sequence processing** process. The twin allows simulating different scenarios and, in particular, a service uses the digital model to simulate and find the **most efficient path**, returning feedback to the physical world.

The **models** are the graph representation of the process: **nodes** (activities/machines) and **arcs** (connections/queues). The JSON files under Digital Twin/models define this topology and the initial state (parts in queues, times, etc.).

2. Structure of the models folder

The folder Digital Twin/models contains test scenarios and templates. Each subfolder or file represents a type of model (deterministic, stochastic, full queue, etc.).

```
Digital Twin/models/
├── 5s_stho/                # 5 stations, stochastic (stho)
│   └── 1681234301_62.json  # snapshot of model with state
├── 5s_determ/             # 5 stations, deterministic
│   └── initial.json
├── 5s_alternating/
├── 5s_capacity_error/
├── 5s_dist.json           # model with distributions
├── 5s_stho_template.json  # stochastic template
├── template_5s.json       # generic 5-station template
├── batch_rct/
├── CT/
├── debug_tracking/
├── debug_valid/
├── debug_rct/
├── debug_update/
├── queue_full/
└── ...
```

- **5s_***: models with 5 stations (5 nodes).
 - ***_stho**: stochastic times/parameters (e.g. normal distribution).
 - ***_determ**: deterministic times (fixed values).
 - **initial.json**: “clean” initial state of the model; other files (e.g. 1681234301_62.json) are snapshots with simulation state (WIP, worked_time, etc.).
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3. Model JSON structure

Every model is a JSON with three main blocks: **nodes**, **arcs**, and **initial**.

3.1 Overview

Key	Description
nodes	List of activities/machines (graph vertices).
arcs	List of connections between machines (edges + queues).
initial	Initial state: for each queue (index = order of arcs), list of parts (e.g. ["Part 26", "Part 27"]).

3.2 nodes — Activities / Machines

Each element in **nodes** is an object with the fields below. The **activity** field is the **activity ID** (used in predecessors/successors references and in arcs).

Field	Type	Description
activity	int	Activity (node) ID.
predecessors	[int]	IDs of activities that precede this one.
successors	[int]	IDs of activities that succeed this one.
frequency	number	Operation frequency (e.g. 999).
capacity	int	Machine capacity (e.g. 1).
contemp	number or ["norm", μ , σ]	Process time: fixed value or normal distribution (mean μ , std σ).
cluster	int	Logical grouping (cluster) of the machine.
worked_time	0 or [time, "Part N"]	0 = idle; [t, "Part N"] = processing "Part N" for t time units.
allocation_counter	int (optional)	Counter for allocation policy on branching machines.

Example (excerpt from 1681234301_62.json):

```
{
  "activity": 2,
  "predecessors": [1],
  "successors": [3, 4],
  "frequency": 999,
  "capacity": 1,
  "contemp": ["norm", 17, 2],
  "cluster": 2,
  "worked_time": [1, "Part 26"],
  "allocation_counter": 1
}
```

- Activity **2** is preceded by **1** and succeeded by **3** and **4** (branching).
- Process time: normal(17, 2).
- In this snapshot: processing "Part 26" for 1 time unit; allocation_counter used for alternating between successors.

3.3 arcs — Connections / Queues

Each arc links two activities and represents a **queue** between them (capacity, transport time, etc.).

Field	Type	Description
arc	[int, int]	Pair [source, target] (activity IDs).
capacity	int	Maximum queue capacity.
frequency	number	Arc frequency (e.g. 1000).
contemp	number	Transport time on the connection.

Example:

```
{"arc": [2, 3], "capacity": 10, "frequency": 1000, "contemp": 23}
```

I.e. queue from activity **2** to **3**, capacity 10, transport time 23.

3.4 initial — Initial state (WIP)

initial is an **array of arrays**. Index **i** corresponds to the **i-th queue** (order of arcs in the JSON). Each element is the list of parts in that queue at simulation start.

Example (excerpt from 1681234301_62.json):

```
"initial": [
  ["Part 27"],
  [],
  ["Part 19", "Part 21", "Part 23", "Part 25"],
  ["Part 20", "Part 22", "Part 24"],
  ["Part 16"]
]
```

- Queue 0: 1 part (Part 27).

- Queue 1: empty.
- Queues 2 and 3: several parts listed.
- Queue 4: Part 16.

The code extracts the **numeric ID** from the name (e.g. "Part 27" → 27) and creates Part objects assigned to the correct queues in the model. In general, the length of `initial` matches the number of **arcs** (one entry per queue); if there are fewer entries, the last queues have no initial parts.

4. Full example: 5s_stho/1681234301_62.json

This file models a system with **5 activities** and **6 arcs** (including the cycle closure).

4.1 Activity graph (nodes)

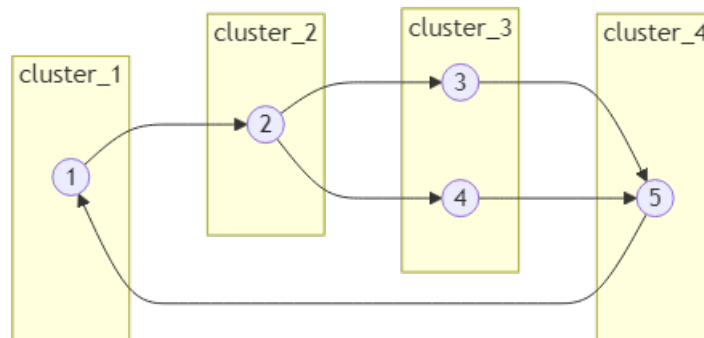


Diagram 1

- 1 → 2 (sequence).
- 2 → 3 and 2 → 4 (branching).
- 3 and 4 → 5 (convergence).
- 5 → 1 (closed loop).

4.2 Nodes table (summary)

activity	predecessors	successors	contemp	cluster
1	[5]	[2]	norm(11,2)	1
2	[1]	[3, 4]	norm(17,2)	2
3	[2]	[5]	norm(52.5,2)	3
4	[2]	[5]	norm(52.5,2)	3
5	[3, 4]	[1]	norm(10,2)	4

4.3 Arcs table (order = index in initial)

Index	arc	capacity	contemp
0	1→2	10	11
1	2→3	10	23
2	2→4	10	20
3	3→5	10	11
4	4→5	10	6
5	5→1	12	9

4.4 Simplified logic flow (code usage)

1. **Load JSON** → data = json.load(json_file).
2. **Create machines** → for each node in data['nodes'], instantiate Machine with activity, contemp, cluster, etc.
3. **Create queues** → for each arc in data['arcs'], instantiate Queue with arc, capacity, contemp.
4. **Link queues to machines** → queue_allocation(): for each queue, arc[0] → queue_out of source machine, arc[1] → queue_in of target machine.
5. **Initial state** → initial_allocation(): for each index i in data['initial'], place the listed parts in queues_vector[i].

Excerpt in digital_model.py (machine and queue creation):

```
# Create Machines
for node in data['nodes']:
    self.machines_vector.append(Machine(env=self.env, id=node['activity'],
    freq=node['frequency'], capacity=node['capacity'],
    process_time=node['contemp'], database=self.Database, cluster=node['cluster'],
    terminator=self.terminator, loop=self.loop_type, ...))

# Create Queues (arcs)
queue_id = 0
for arc in data['arcs']:
    queue_id += 1
    self.queues_vector.append(Queue(env=self.env, id=queue_id, arc_links=arc['arc'],
    capacity=arc['capacity'], freq=arc['frequency'], transp_time=arc['contemp']))
```

5. Relation to code (digital_model)

Concept in JSON	Usage in code
nodes	<code>Model.machines_vector</code> — each node becomes a Machine.
arcs	<code>Model.queues_vector</code> — each arc becomes a Queue.
initial	<code>initial_allocation()</code> fills queues with Part at simulation start.
contemp (node)	Machine process time (supports fixed value or ["norm", μ , σ]).
contemp (arc)	Queue transport time.
cluster	Grouping used in cluster logic and terminator.
worked_time	"In progress" state; used to sync with the physical world.
allocation_counter	Alternation policy on branches.

The **model_translator()** in `digital_model.py` is the central entry that reads the JSON and builds `machines_vector` and `queues_vector`, then calls `queue_allocation()`, `initial_allocation()`, `merge_queues()`, `discovery_working_parts()`, etc.

6. File naming and conventions

- **initial.json**: default initial state for the scenario (e.g. `5s_determ`, `batch_rct`).
- **{timestamp}_{id}.json** (e.g. `1681234301_62.json`): snapshot of a model at a given time (e.g. after sync with the physical system), possibly with updated `worked_time`, `allocation_counter`, and `initial`.
- ***_template.json**: reusable template (e.g. `5s_stho_template.json`), often with `worked_time: 0` and generic `initial`.

7. Summary

- The **Digital Twin/models** folder holds the graph (nodes + arcs) and initial state (WIP) of the Digital Twin.
- Each **node** = one machine/station; each **arc** = one queue between two machines.
- The **initial** array defines how many and which parts are in each queue at simulation start.
- **5s_stho/1681234301_62.json** is a full example: 5 stations, branching at 2→3 and 2→4, cycle 5→1, stochastic times, and filled WIP state.
- The **digital_model.py** module translates this JSON into Machine and Queue objects and uses this model to simulate and find the most efficient path, closing the feedback loop with the physical process.