# Problem 1: Electronics Assembly Scheduling with Machine Routing Constraint (MILP vs Heuristic)

## Context – Electronics Assembly Line

In a production facility for electronic devices, 5 specialized machines (M1 to M5) are used to assemble components. Each component (job) must be processed by 3 operations, which can be done on any of the machines.

However, one specific component, **Job J5**, must always be processed by **both Machine 1 and Machine 2** (in any order) during its processing cycle.

There is a setup time (transfer time) required when moving a component between two machines.

## Objective

Determine a schedule that:

- Assigns 3 operations to each job,

- Includes machines M1 and M2 for J5,

- Avoids machine overlaps,

- Minimizes the makespan,

- Includes transfer times between machines.

## Processing Times (in minutes)

| Job | M1 | M2 | M3 | M4 | M5 |
|-----|----|----|----|----|----|
| J1 | 10 | 11 | 9 | 12 | 8 |
| J2 | 11 | 9 | 10 | 11 | 9 |
| J3 | 12 | 13 | 11 | 10 | 11 |
| J4 | 9 | 10 | 12 | 11 | 10 |
| J5 | 10 | 11 | 8 | 9 | 7 |

## Transfer Times Between Machines (in minutes)

| From\To | M1 | M2 | M3 | M4 | M5 |
|---------|----|----|----|----|----|
| M1 | – | 1 | 2 | 3 | 2 |
| M2 | 1 | – | 2 | 2 | 2 |
| M3 | 2 | 2 | – | 2 | 1 |
| M4 | 3 | 2 | 2 | – | 1 |
| M5 | 2 | 2 | 1 | 1 | – |

## Tasks

(a) Formulate a MILP model to solve the problem with the routing constraint on J5 and considering transfer times.

(b) Propose a heuristic method (e.g., greedy or local search) and implement it.

(c) Compare the performance (makespan and computation time) between the MILP and the heuristic approach.