3.2 Problem Formulation

The case study deals with a pharmaceutical batch plant with multiple products, either 30 in the small case study or 60 in the large case study, and it has six stages with a total of 17 machines as resources. The machine environment is a flexible flow shop with additional features: some orders skip a stage and some operations are only allowed on certain machines. This machine environment is also known as a hybrid flow shop. Following the roadmap in [21] the features of the problem can be described as follows:

- Multiproduct plant layout
- Variable equipmet assignment
- Unlimited intermediate storage (UIS)
- Instantaneous material transfer
- Fixed batch size
- Machine dependent processing times
- Sequence-dependent changeovers
- Operational and changeover costs
- Due dates

This problem is highly complex due to its size, the plant layout, and the many constraints. The plant layout itself is presented in the next figure.

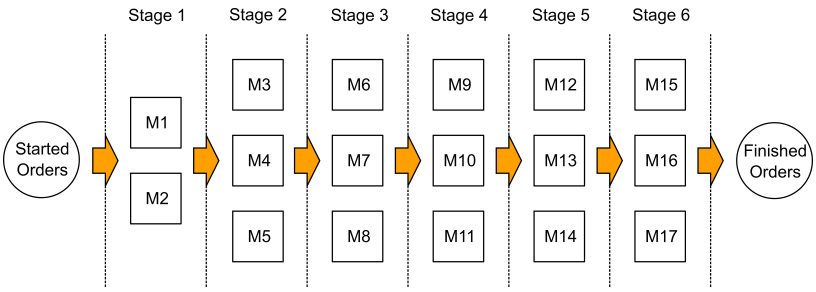

Figure 3.1: Pharmaceutical batch plant layout with six stages and 17 machines. The orders start at the first stage and are processed successively stage by stage. The machine eligibility depends on the recipe. The storage policy between the stages considered in this work is UIS (see 2.2.1).

An order is processed on one machine in every stage and cannot be interrupted. Between two stages, different storage policies are possible, which are UIS and Zero Wait (ZW), however, only the UIS policy is considered in this work (see 2.2.1 for more details on storage policy). Every order follows a recipe that determines the route and machine eligibility. In total, there are ten recipes, which are presented in Table B.1.

The scheduling problem has three types of decision variables, which are the allocation, sequencing, and timing. Three different objectives are optimized independently from each other:

the makespan (Definition 3.2.1), the weighted lateness (Definition 3.2.2), and the overall and changeover cost (Definition 3.2.3).

Definition 3.2.1 *The makespan*

$$C_{max} = max(C_i) \quad [h] \tag{3.1}$$

C_i := *completion time of i*

Definition 3.2.2 *The weighted lateness*

$$W.L. = \sum_i \alpha \cdot E_i + \beta \cdot T_i \quad [-] \tag{3.2}$$

$E_i = max(0, \delta_i - C_{compl,i})$ *and* $T_i = max(0, C_{compl,i} - \delta_i)$

Definition 3.2.3 *The overall and changeovercost*

$$O.\&C.C. = \Omega \cdot C_{max} + \sum_i cc_i \quad [10^3\$] \tag{3.3}$$

Ω := *operating cost and* cc_i := *sum of changeover cost of i*

Using the Graham Notation [17], the scheduling problem can be expressed as:

$$FF_6|UIS^*|C_{max} \text{ or } W.L. \text{ or } O.\&C.C. \tag{3.4}$$

With the two problem sizes, this leads to a total of 6 problem instances, which are considered in this work (see Table 3.1). The weightes for the W.L. objective are set to $\alpha = 0.9$ and $\beta = 4$, as in [4]. The process parameters are listed in Table X.

Problem Instance	N_i	Machine Environment	Storage Policy	Objective
PI01	30	FF_6	UIS	C_{max}
PI02	30	FF_6	UIS	$W.L.$
PI03	30	FF_6	UIS	$O.\&C.C.$
PI04	60	FF_6	UIS	C_{max}
PI05	60	FF_6	UIS	$W.L.$
PI06	60	FF_6	UIS	$O.\&C.C.$

Table 3.1: The six problem instances considered problem instances for the short-term scheduling problem with UIS.

All instances have additional constraints: machine-dependent processing time, sequence dependent changeover time, machine eligiblity, the due dates.

* The other constraints are omitted in this convention due to them beeing constant for all instances