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A scheduling approach for chemical vapour deposition processes in the production of semiconductors

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Abstract: The production of semiconductors for applications in microelectronics is operated through photo-lithographic and chemical processes whereof *Chemical Vapor Deposition* (*CVD*) technology is one of the most used. *CVD* processes need to operate in furnaces under controlled atmosphere and, every time the furnace is accessed from the external environment, a purging time is needed to restore the prescribed atmosphere. The optimisation of the utilisation of the furnaces depends on the sequencing of loading and unloading operations entailing the need to disturb the controlled atmosphere. We propose the use of a *disaggregated time formulation based on step variables* to model a scheduling problem aiming at identifying the optimal sequence of operations and supporting the definition of optimal dispatching policies.

Keywords: scheduling, semiconductors, human operators, RCPSP.

1. INTRODUCTION

The production of semiconductor components for microelectronics applications is operated through a multi-step sequence of photo-lithographic and chemical processes, one of these is the *Chemical Vapor Deposition* (*CVD*) technology. The *CVD* process involves the flowing of vaporised materials, both initiators and monomers, into a vacuum chamber containing heated wafers of semiconductor material (usually silicon) to be coated. In the chamber, under the right conditions in terms of temperature and pressure, the initiators helps to speed up the chemical process where the monomers link up in chains to form polymers on the hot surface of the wafer. This is accompanied by the production of chemical by-products that are exhausted out of the chamber along with unreacted gases (Creighton and Ho, 1994). The wafers are then cooled, to move from the $200^o - 1600^o C$ of the chemical reaction to the room temperature.

This process is operated by specific machines, called furnaces. Besides the vacuum chamber, where the process is operated, these machines also include a buffer for the wafers and an automatic handling system that moves the wafers from the buffer to the vacuum chamber and return. Due to the multiple constraints affecting the semiconductors production process, the impact of the scheduling is relevant in order to guarantee the timely execution of the process.

We consider a very common configuration where the *CVD* process is operated in a furnace containing two reactors and organized according the layout described in Figure 1. It consists of the following items.

- Two reactor units (Reactor 1 and 2) working in parallel, where the wafers undergo the deposition process.
- A buffer shared among the reactors, containing both raw and finished parts, organized as a carousel with different levels. It is named *WIP* station.
- A handling robot (in red in the figure) shared among the two reactors, named *Wafer Handling Robot* (*WHR*), whose role is to move the wafers from the *WIP* station to the reactors and back.

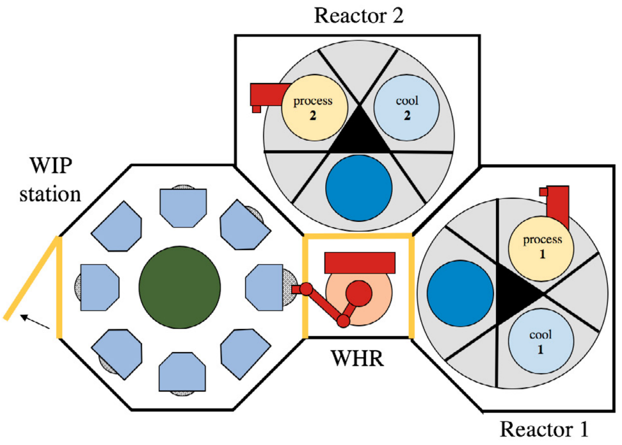

Fig. 1. Representation of the furnace used in the process.

The furnace has a single accessing point to load/unload wafers to/from the *WIP* station. This accessing point is a door (in yellow in the figure) that can be opened to allow a human operator to introduce or remove wafers that are handled through a *pick boat*, i.e., a fixture able to host several wafers of the same type. The *WHR* can operate

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by accessing the *WIP* and the reactor to load/unload the wafers.

To be processed inside the reactor, the wafers are positioned in a container (*boat*) acting as fixture. Each reactor contains three alternative positions for the *boats*: processing, cooling and load/unload. A carousel moves the *boats* from a position to another and, to avoid deadlock, only two boats are present.

The process operated by the furnace is composed by the following activities.

1. *Pick boat* loading: the *pick boats* are loaded into the *WIP* by the human operator outside the furnace.
2. Wafer loading: the carousel rotates the *boat* in the load/unload position, then, the wafers are loaded one-by-one by the *WHR* from a *pick boat* located in the *WIP* into the *boat* located in a reactor.
3. Deposition: the carousel rotates the *boat* in the processing position, then, the deposition process on the wafers inside the reactor is executed.
4. Cooling: the carousel rotates the *boat* in the cooling position, then, the *boat* is cooled.
5. Wafer unloading: the wafers are unloaded from the *boat* located in the reactor and positioned in the *pick boats* in the *WIP* using the *WHR*.
6. *Pick boat* unloading: the *pick boats* are unloaded from the *WIP*.

The deposition process is operated in a controlled atmosphere. Hence, every time the *WIP* area is accessed from the external environment, a purging time is needed to restore the prescribed atmosphere. During the purging time, the *WHR* cannot access the *WIP* and, hence, it can neither load nor unload the *boats* in the reactors.

In terms of planning and scheduling, the sequencing of the batches of wafers to be processed, as well as their assignment to a reactor, is decided by the production plan and cannot be modified. Hence, the only degree of freedom available is deciding if and when the *WIP* can be accessed from the external environment, to load and unload the *pick boats* containing the wafers, since this will cause a purging time constraining the processing of the wafers by the other elements in the system.

An example of sequencing the activities in the furnace is given in Figure 2a, where the processing of four different batches is considered. It is possible to see how the *pick boat loading* activities (in light green with the *PB LOAD* label) are scheduled at the beginning of the process. Then, the *WIP* enters the purging phase preventing the *WHR* to move wafers inside the furnace. After the purging time is expired, the wafers are loaded in the *boats* (*W LOAD*) by the *WHR*. Due to the presence of a single processor chamber in each reactor, the two *boats* present in each reactor are processed sequentially (*PROCESS #*). After the deposition and the cooling time (*COOL #*), the wafers are unloaded from the boats (*W UNLOAD*) to the *pick boats*. Hence, they can be unloaded from the *WIP* by a human operator (*PB UNL*).

An alternative sequence is depicted in Figure 2b, where the four *PB LOAD* operations are executed according to a different scheme. This entails two purging intervals and, in this case, a longer makespan for the same four batches. Grounding on this, the impact of the sequencing of the loading and unloading operations related to the *pick boats* can significantly impact on the performance of the process.

This article addresses a scheduling approach solution able to maximize the utilization of the two-reactor furnace by sequencing the load and unload of the *pick boats* in the *WIP* station.

Outline In Section 2, available scheduling formulations and their possible implementation are discussed, while in Section 3, problem description and formalization are provided. In Section 4, a use-case application is described and addressed, while Section 5 reports the conclusions and foresees evolution of the presented research work.

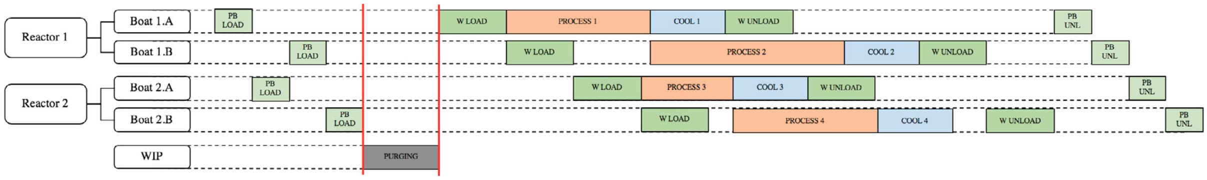
2. STATE OF ART

The scheduling problem under study has been firstly compared with the available deterministic scheduling models. Following the $\alpha \mid \beta \mid \gamma$ framework introduced by Graham et al. (1979), the furnace environment could be considered as the *Identical machines in parallel* environment in which each job can be processed on one or more of the available machines (Pinedo, 2008). The main aim of this class of models is the identification of optimal scheduling of the jobs and their association with available machines.

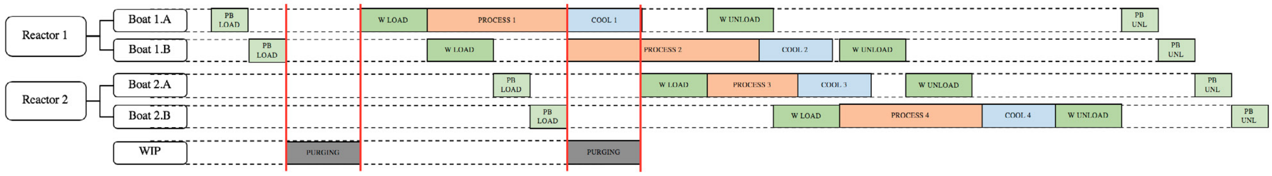
In the case under study, the *CVD* process is significantly constrained by the furnace model used and the association between batches and reactors is provided by the process plan. It is needed to consider the *WHR* as a shared resource and the *WIP* station as a buffer with limited capacity. Grounding on this, the scheduling of each singular activity has to be addressed, with a particular attention at the ones related to the load and unload of *pick boats* and the respect of purging times.

For these reasons, the scheduling problem under study has been modelled as a *Resource Constrained Project Scheduling Problem* (*RCPSP*). As mentioned in (Klein, 2000) there is a plethora of applications of the *RCSPS* that have stimulated the development of many mathematical formulations.

The group of *disaggregated time-indexed formulation* has been considered, in which the precedence constraints are relaxed using pulse variables (Christofides et al., 1987). One of the first formulations has been proposed in (Pritsker et al., 1969), in which authors introduced binary variables $x_{j,t}$ that equal 1 if activity j is completed at the end of period t, and 0 otherwise. This formulation allows to minimize a completion time by using *finish-to-start* and resource consumption constraints. Instead, the formulations proposed in (Kaplan, 1988) and (Klein, 2000) introduce binary variables $x_{j,t}$ that equal to 1 if activity j is in progress at time t, 0 otherwise. The advancement in Kaplan (1988) and Klein (2000) lies on the total number of constraints that decreases from $O(n^2 + m \cdot T)$ to $O(n^2 \cdot T)$, with T the time horizon, n the number of activities and m is the precedence constraints between activities. The formulation proposed in (Alvarez-Valdés and Tamarit, 1993) adds the integer variables f_j denoting the time



(a) Example of optimal sequencing.



(b) Example of non-optimal sequencing.

Fig. 2. Two examples of operation sequencing and the impact of the purging time on the makespan.

period at the end of which an activity j is completed. The completion time minimization leads this formulation to $O(n^3)$ constraints.

These pulse formulations do not allow i) to model the purging time as a lag between groups of activities, and ii) to model the *WIP* station capacity constraint, to be considered during the processing of batch inside the furnace.

For addressing these problems, we take advantage of the *disaggregated time formulation based on step variables* introduced in (Bianco and Caramia, 2013) and then discussed and refined in (Artigues, 2013). The authors use variables $s_{i,t}$ (and $f_{i,t}$) assuming value 1 if activity has started (completed) in a time period $\tau \leq t$, 0 otherwise. Authors use these variables for addressing precedence relations between activities and resource consumption constraints.

We exploit these step variables for representing the purging time constraints as a combination of resource consumption constraints and *finish-to-start* relations with lags, and to model the *WIP* station capacity constraint.

3. SOLUTION APPROACH

3.1 Process description

The entire process grounds on the use of *pick boats* for handling the wafers during the loading and unloading activities. In particular, the wafers are processed in batches whose dimension is n-times the capacity of a *pick boat*. When a batch of wafers is moved from the *WIP* station to one or more *boats* to be processed, the associated *pick boats* remain reserved although empty in the *WIP* station. Indeed, these *pick boats* wait for wafers returning at the end of the process. This fact avoid the blocking in the furnace but limits the number of batches inside the furnace and significantly constraints the management of the *pick boats*.

The formal model of the sequencing problem under study lies on the following hypothesis and considerations.

- The sequence of batches to be processed in the furnace and their assignment to reactors and *boats* are given and defined *a-priori*.
- The processing times are deterministic and given.
- The *WIP* station has a limited capacity and is totally empty at the start of the process.
- The wafers to be loaded in the furnace are always available, hence, no delay in the loading of *pick boats* is experienced.
- The load and unload of the *WIP* has no external constraint (i.e., the human operator is always available).
- The *WHR* can not be preempted.
- After being processed in the reactor, a *boat* must be immediately moved in the cooling position.

3.2 Process formulation

The scheduling problem is modelled through the sets, variables and parameters listed in Table 1. We consider a set of batches I to be produced, each one according to the template process described in Section 1.

Table 1. Notation for data and variables.

Sets	
T	time horizon
I	set of batches
A	set of activities
R	set of shared resources
Variables	
$s_{j,t}$	assumes 1 if activity j starts in $\tau \leq t$ assumes 0 otherwise
$f_{j,t}$	assumes 1 if activity j is completed in $\tau \leq t$ assumes 0 otherwise
$x_{j,t}$	the percentage of j executed till time period t
Parameters	
PBL_i	*pick boat* loading of batch $i \in I$
WL_i	wafer loading of batch $i \in I$
D_i	deposition of batch $i \in I$
C_i	cooling of batch $i \in I$
WU_i	wafer unloading of batch $i \in I$
PBU_i	*pick boat* unloading of batch $i \in I$
$P1_i$	first purging time of batch $i \in I$
$P2_i$	second purging time of batch $i \in I$
$b_{j,k}$	the request of resource $k \in R$ by activity $j \in A$
B_k	the availability of resource $k \in R$
N	*WIP* station capacity
d_j	duration of activity $j \in A$

The respect of the purging time has to be guaranteed before the two activities using the *WHR* (the wafer loading and unloading). For this reason, we define activities $P1_i$ and $P2_i$, for each batch $i \in I$, representing the purging time to be respected before the wafer loading and the wafer unloading, respectively. The execution of these activities simulates the time interval to be respected and forces the *WHR* to wait until their completion. In addition to this, the time needed to rotate the carousel in the reactors is considered negligible.

We consider A as the set of activities to be executed, and T as the time horizon of the schedule. The starting time of an activity $j \in A$ is modelled with the binary variable $s_{j,t}$ assuming value 1 if activity j starts in $\tau \leq t$. In the same way, variable $f_{j,t}$ represents the completion time of activity $j \in A$. R represents the set of renewable resources to be shared among the activities, while $b_{j,k}$ and B_k model the amount of resource type $k \in R$ requested during execution of activity $j \in A$ and the associated availability, respectively.

The utilization of the furnace has to be maximized under the following constraints.

1. The sequence of operations and batches, as declared in Section 3.1.
2. The resource availability, under the hypothesis of a single human operator, a single *WHR* and two *boats* for each reactor.
3. The capacity of the *WIP*.
4. The need of a purging phase every time the *WIP* is accessed from outside the furnace.

The scheduling problem is modeled according to the following mathematical formulation.

$$minimize \qquad T - \sum_{t \in T} f_{PBU_{I,t}} + 1 \tag{1}$$

$$subject \quad to$$

$$s_{WL_{i,t}} \leq f_{PBL_{i,t-1}} \quad \forall i \in I, \forall t \in T \tag{2}$$

$$s_{D_{i,t}} \leq f_{WL_{i,t-1}} \quad \forall i \in I, \forall t \in T \tag{3}$$

$$s_{C_{i,t}} \leq f_{D_{i,t-1}} \quad \forall i \in I, \forall t \in T \tag{4}$$

$$s_{WU_{i,t}} \leq f_{C_{i,t-1}} \quad \forall i \in I, \forall t \in T \tag{5}$$

$$s_{PBU_{i,t}} \leq f_{WU_{i,t-1}} \quad \forall i \in I, \forall t \in T \tag{6}$$

$$s_{C_{i,t}} = 1 \quad \forall i \in I, t \mid \left[f_{D_{i,t-1}} = 1 \wedge f_{D_{i,t-2}} = 0\right] \tag{7}$$

$$x_{j,t+1} - x_{j,t} = (1/d_j)(s_{j,t} - f_{j,t}) \quad \forall j \in A, \forall t \in T \tag{8}$$

The completion time of an activity $j \in A$ can be expressed as $T - \sum_{t \in T} f_{PBU_{I,t}} + 1$, hence, the objective function (1) represents the minimization of the time when the last unloading activity is executed, i.e., the makespan.

Equations (2)-(6) model *finish-to-start* precedence constraints between activities belonging to the same batch. As an example, consider Equation (3), if the wafer loading operation (WL_i) is not completed till slot $t-1$, the right hand side is less than 1, then the deposition (D_i) can not start. The cooling operation (C_i) has to start as soon as the deposition (D_i) is completed, as constrained by Equation (7). Equation (8) regulates the duration of the activities $\forall j \in A$.

$$s_{j,t} \leq s_{j,t+1} \quad \forall j \in A, \forall t \in T \tag{9}$$

$$f_{j,t} \leq f_{j,t+1} \quad \forall j \in A, \forall t \in T \tag{10}$$

Equation (9) states that if an activity $j \in A$ is started at time t, then variable $s_{j,\tau} = 1$ $\forall \tau \geq t$, and, on the contrary, if activity j is not started at time t, $s_{j,\tau} = 0$ $\forall \tau \leq t$. Equation (10) provides an analogous constraint for completion times.

$$s_{PBL_{i,t}} \leq f_{PBL_{i-1,t}} \quad \forall i \in I, \forall t \in T \tag{11}$$

$$s_{WL_{i,t}} \leq f_{WL_{i-1,t}} \quad \forall i \in I, \forall t \in T \tag{12}$$

The sequencing of the batches according to the production plan is enforced through Equations (11)-(12) in which the processing of batch $i-1$ precedes the processing of batch i, $\forall i \in I$.

$$\sum_{j \in A} b_{j,k}(s_{j,t} - f_{j,t}) \leq B_k \quad \forall k \in R, \forall t \in T \tag{13}$$

The execution of the activities is constrained by the availability of the resources in set R through Equation (13). We consider the resource request $b_{j,k}$ associated to an activity $j \in A$ during its execution, i.e. while $s_{j,t} - f_{j,t} = 1$.

$$\sum_{i \in I} (s_{PBL_{i,t}} - f_{PBU_{i,t}}) \leq N \quad \forall t \in T \tag{14}$$

The constraint on the capacity of the *WIP* station can not be represented with a simple resource allocation, because a *pick boat* associated to a given batch occupies a position in the *WIP* station from the moment when it enters the furnace, that is $t \mid \left[s_{PBL_{i,t}} = 1 \wedge s_{PBL_{i,t-1}} = 0\right]$, to the moment when it exits, that is $t \mid \left[f_{PBU_{i,t}} = 1 \wedge f_{PBU_{i,t-1}} = 0\right]$.

This constraint is modelled through a step function defined in T, whose value identifies the number of batches in the *WIP*. Its value at instant t increases by 1 unit if the *pick boats* of a batch i have been loaded at a time $\tau <= t$ ($f_{PBL_{i,t}}$) and decreases by 1 if it has been unloaded at $\tau \leq t$ ($f_{PBU_{i,t}}$). The value of this function is constrained by the capacity N of the *WIP*, according to Equation (14).

$$s_{WL_{i,t}} \leq f_{P1_{i,t}} \quad \forall i \in I, \forall t \in T \tag{15}$$

$$s_{WU_{i,t}} \leq f_{P2_{i,t}} \quad \forall i \in I, \forall t \in T \tag{16}$$

$$s_{P1_{i,t}} \leq f_{PBL_{i,t}} \quad \forall i \in I, \forall t \in T \tag{17}$$

$$s_{P2_{i,t}} \leq f_{WL_{i,t}} \quad \forall i \in I, \forall t \in T \tag{18}$$

The purging time has to be guaranteed every time the *WHR* has to move wafers, that is in correspondence to activities WL_i and WU_i, $\forall i \in I$. To this aim, we introduce activities $P1_i$ and $P2_i$ representing the *purging times* that have to be operated to let the batch i enter and exit the furnace. These activities have to respect precedence relations with WL_i and WU_i according to Equations (15) and (16).

In addition to this, we constrain the start of the first purging time ($P1_i$) after the completion of the *pick boat* loading executed by the human operator (PBL_i) with Equation (17).

Regarding the second purging activity ($P2_i$), we constrain its starting time after the completion of the wafer loading activity (WL_i) with Equation (18), in order to avoid the contemporary execution with the first purging. Indeed, by considering only the precedence constraint in Equation (16), the solver managing the mathematical model and looking at the minimization of the makespan, could fix the execution of both the purging activities at the same time.

$$s_{P1_{i,t}} - f_{P1_{i,t}} + \sum_{h \in I} \left(s_{PBL_{h,t}} - f_{PBL_{h,t}}\right) \leq 1 \tag{19}$$

$$s_{P1_{i,t}} - f_{P1_{i,t}} + \sum_{h \in I} \left(s_{PBU_{h,t}} - f_{PBU_{h,t}} \right) \leq 1 \tag{20}$$

$$s_{P1_{i,t}} - f_{P1_{i,t}} + \sum_{h \in I} \left(s_{WL_{h,t}} - f_{WL_{h,t}} \right) \leq 1 \tag{21}$$

$$s_{P1_{i,t}} - f_{P1_{i,t}} + \sum_{h \in I} \left(s_{WU_{h,t}} - f_{WU_{h,t}} \right) \leq 1 \tag{22}$$

$$s_{P2_{i,t}} - f_{P2_{i,t}} + \sum_{h \in I} \left(s_{PBL_{h,t}} - f_{PBL_{h,t}} \right) \leq 1 \tag{23}$$

$$s_{P2_{i,t}} - f_{P2_{i,t}} + \sum_{h \in I} \left(s_{PBU_{h,t}} - f_{PBU_{h,t}} \right) \leq 1 \tag{24}$$

$$s_{P2_{i,t}} - f_{P2_{i,t}} + \sum_{h \in I} \left(s_{WL_{h,t}} - f_{WL_{h,t}} \right) \leq 1 \tag{25}$$

$$s_{P2_{i,t}} - f_{P2_{i,t}} + \sum_{h \in I} \left(s_{WU_{h,t}} - f_{WU_{ht}} \right) \leq 1 \tag{26}$$

$$\forall t \in T, \forall i \in I \tag{27}$$

The last set of constraints avoids the simultaneous execution of the purging time activities for a given batch i and the utilization of the *WHR* related to a general batch $h \in I$. A different approach has to be used with respect to activities belonging to different batches.

A first option could be to consider that the purging activities need the *WHR* for their execution, but in this way also the contemporary execution of more purging activities would be avoided. This option should not be avoided, but rather facilitated.

The formalization does not consider the use of the *WHR* during the purging time activities but limits their contemporary execution with other activities using the *WHR* by taking advantage of the step variables $s_{j,t}$ and $f_{j,t}$. Eight step functions defined in T have been modelled, whose values depend on the starting and completion time of the purging activities related to batch i and the starting and completion time of activities related to a batch $h \in I$ that use *WHR*. The constraints related to $P1_i$ and $P2_i$ are represented with Equations (19)-(22) and (23)-(26).

Consider Equation (19) that models the simultaneous execution of the first purging activity for batch i ($P1_i$) and the *pick boat* loading activity for batch h (PBL_h). Its value increases by 1 if the first purging activity or the *pick boat* loading start in $\tau \leq t$ ($s_{P1_{i,t}}$ and $s_{PBL_{h,t}}$). Its value decreases by 1 if the first purging activity or the *pick boat* loading is completed in $\tau \leq t$ ($f_{P1_{i,t}}$ and $f_{PBL_{h,t}}$). The value of this function has to be always lower or equal to 1, in order to have only one of these two activities in execution at the same time. In the same way, Equations (20)-(26) model additional step functions with the same aim but considering different *WHR* activities and the second purging activity. These constraints are applied $\forall t \in T, \forall i \in I$ as stated in Equation (27).

4. APPLICATION

The formulation presented in Section 3.2 is applied to a real semiconductor production process. We consider a set I containing 24 batches labelled with letters from A to X. In Table 2, the list of operations for each batch and their durations are reported. The only duration that differs from a batch to another is the deposition time, included in Table 3 together with the reactor and the *boat* associated to each batch. The *WIP* station has 4 available positions. The *MIP* has been implemented in *IBM ILOG CPLEX Optimization Studio* and solved with*Constraint Programming* approach due to its non-linearity.

Table 2. List of operations for each batch.

Operation	Duration
Pick boat loading	2 *min* for the complete load of a batch
Purging	30 *min*
Wafer loading	20 *min* for the complete load of a *boat*
Deposition	variable, see Table 3
Boat rotation	0 *min*
Cooling	25 *min*
Wafer unloading	20 *min* for the complete unload of a *boat*
Pick boat unloading	2 *min* for the complete unload of a batch

Table 3. Deposition information for each batch.

Batch	Reactor	Boat	Depo. duration
A	2	B	180 *min*
B	2	A	175 *min*
C	2	B	131 *min*
D	1	B	128 *min*
E	1	B	128 *min*
F	1	A	128 *min*
G	1	A	128 *min*
H	1	B	128 *min*
I	1	A	128 *min*
J	1	A	128 *min*
K	1	A	124 *min*
L	1	B	124 *min*
M	1	A	124 *min*
N	1	A	124 *min*
O	2	A	122 *min*
P	1	A	124 *min*
Q	2	A	120 *min*
R	2	B	120 *min*
S	2	B	120 *min*
T	2	A	120 *min*
U	2	A	120 *min*
V	2	B	120 *min*
W	2	A	120 *min*
X	2	B	119 *min*

The model identifies the sequence of operations that minimizes the completion time that is represented in the Gantt chart in Figure 3. In this graph, we reported the starting and execution time of every activity with different colours; we also indicated the first purging time in gray. It is possible to see how every time the *WHR* loads or unloads wafers in or from a *boat* (activities *PBL* and *PBU* in light and dark green, respectively), the *WIP* is not used for 30 minutes or more. The sequence identified guarantees a makespan of 52.17 hours. We compared this value against the data coming from the log of a two-reactor furnace in the real system. The makespan experienced during the real process is 54.88 hours, 5% longer that the optimal sequence one.

This result demonstrates how the use of an optimization approach could be beneficial for the makespan minimization in such a context. The proposed approach, besides providing an optimal schedule for a given set of jobs, could help in the definition of dispatching policies. An example

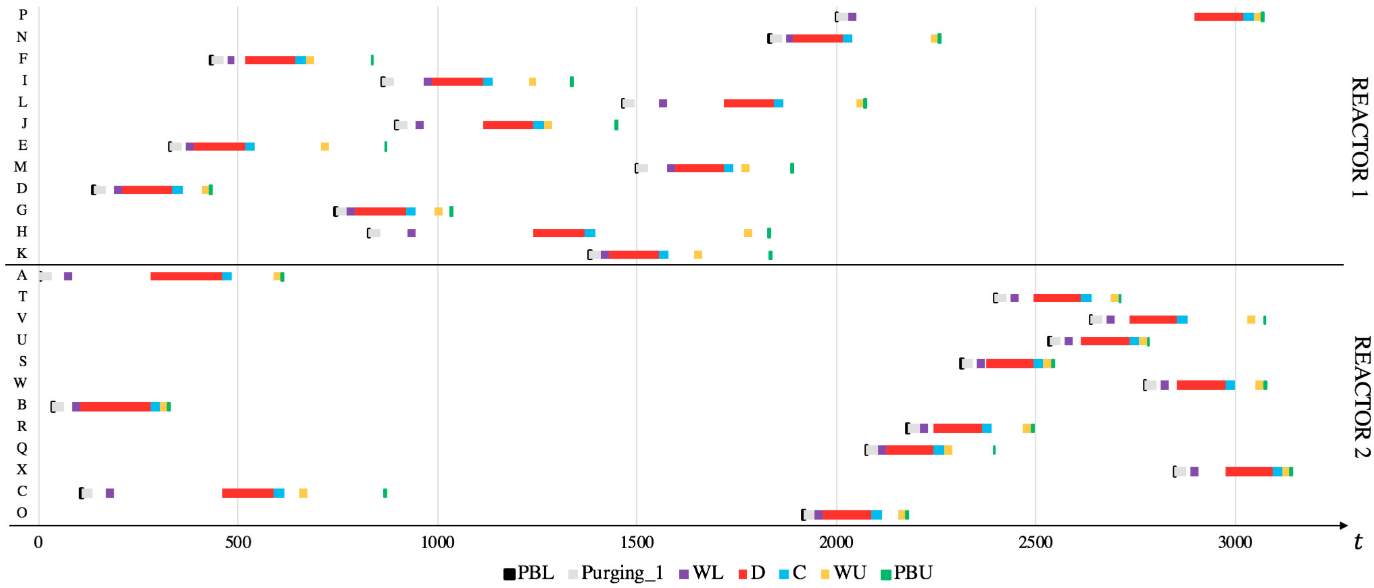


Fig. 3. Gantt chart of the optimal solution.

of policy could be to group the PBL_i and PBU_i activities for different batches, in order to limit the number of times the *WIP* station is accessed from the outside, as suggested in the Gantt chart (Figure 3) for the batches A, B, C and D. An extension of this policy could be to fix a minimum number of activities requesting the human operator before let them start, as suggested for batches F, I, J, E and H for their PBL_i and PBU_i activities. An additional analysis has been done by reducing the batches to be processed, thus mimicking the adoption of a different, i.e. shorter, rescheduling horizon. In fact, if we consider a smaller subset of batches the result improves. By considering only the first 17 batches listed in Table 3, the optimal makespan is 8% shorter than the original one in the log (35.88 against 39 hours). Furthermore, if we consider only the first 10 batches listed in Table 3, the optimal makespan is 18% shorter than the one in the log (20.42 against 25 hours). Nevertheless, further analysis has to be provided to demonstrate the real impact of this option on a longer time horizon.

5. CONCLUSIONS

In this paper, we presented an adaptation of the *disaggregated time formulation based on step variables* to model the scheduling of a *CVD* process in a two-reactor furnace, with the aim to help in the definition of optimal or near-optimal dispatching policies. In particular, we formalized the problem and identified the constraints due to the purging time in taking the decision of load or unload the *WIP* station as the most important issue. Future activities will be devoted to i) the identification of optimal policies exploiting the presented formulation and ii) the extension of the problem formulation to uncertain contexts, e.g., when the duration of operations could be uncertain.

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