The Scheduling Planning with Discrete Event Simulation Based on a Fuzzy Set Theory in a Semiconductor Fab Construction Engineering

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Abstract. In this paper, we propose a methodology integrating discrete event simulation based on the fuzzy set theory to solve the scheduling planning problem for construction operations in a new semiconductor building. Unlike traditional construction scheduling approaches that only cope with quantitative data, fuzzy set-based methods provide proper instruments for expressing planners' linguistic terms to determine the level of factors that affect the construction scheduling planning. A proposed scheduling planning procedure in modeling construction simulation system that applies the fuzzy logic and the fuzzy clustering algorithm is presented here. The objective aimed to achieve is to reduce the construction duration of a new fab on the uncertain and elaborate construction operations. An example is given to illustrate the proposed scheduling planning procedure and compares it with the scheduling planning results obtained by other existing approaches under evaluation criteria. It is our hope that the proposed discrete event simulation incorporated into fuzzy approaches from this study can assist semiconductor fab builders to deal with both quantitative and linguistic factors in improving the overall performance of their construction engineering.

Keywords: Construction scheduling, Simulation, Fuzzy set theory

1. INTRODUCTION

To retain the competition from the high-tech industries, the production cycle time becomes one of the key factors to succeed. The earlier a fab building completed, the faster the products operated in the manufacturing process to remain the advantage in markets. It is vital that how to plan a satisfactory scheduling for construction operations has been a substantial issue. The scheduling planning for construction is projected by each fixed activities to estimate the construction duration of a sub-structure, setup time of microelectromechanical systems (MEMS), move-in time of the machinery and equipment. However, a scheduling planning is affected easily by planner's subjective decisions and linguistic terms to evaluate the performance of the personnel, machines, and materials. As result, one may be difficult to justify which construction activity can be allocated precisely within the period of constructions.

In order to solve this problem, in this paper, a scheduling planning procedure in modeling construction simulation system that applies the fuzzy logic and the fuzzy clustering algorithm is proposed. Unlike traditional construction scheduling approaches that only cope with quantitative data, fuzzy set-based methods provide proper instruments for expressing planners' linguistic terms to determine the level of factors that affect the construction scheduling planning. An intelligent scheduling heuristic algorithm with a mathematical programming model is also developed. The simulation technique makes high-tech industrial fab construction plan more efficient and precise in the supervision of cost, resources, and construction duration to minimize the risk of resource leveling fluctuation. The objective aimed to achieve is to reduce the construction duration of a new fab on the uncertain and elaborate construction operations. Figure 1 shows the layout of a semiconductor fab which contains a precast and cast-in-place construction area.

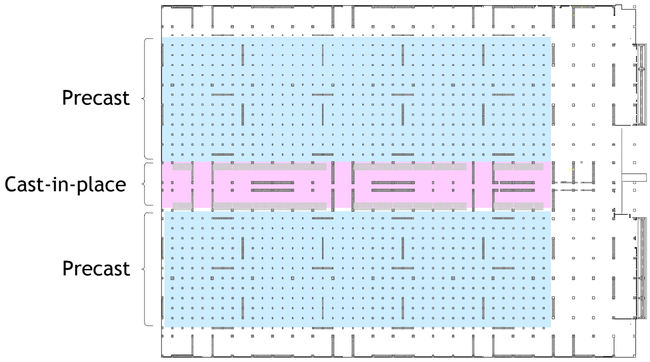

Figure 1: The layout of a precast and cast-in-place construction for a semiconductor fab.

The remainder of this paper is organized as follows. In section 2, a review of the literature pertinent to this design problem is conducted. In section 3, the design methodology we proposed is explained. An example is given in section 4 to illustrate the proposed design method. Finally, section 5 concludes and summarizes the results of this study.

2. LITERATURE REVIEW

Martinez and Ioannou (1999) examined the characteristics of construction discrete-event simulation system on CYCLONE and STROBOSCOPE, in terms of the application breadth, modeling paradigm, and flexibility. They illustrated that an effective general-purpose simulation tool for construction is essential for modeling many simple or complex construction operations based on the forms of activity cycle diagrams and the activity scanning modeling paradigm. Lu and Chan (2004) introduced an enhanced version of the Simplified Discrete Event Simulation Approach (SDESA) by incorporating a concurrent interruptions model. The authors intended to make construction simulations more realistic without compromising the simplicity of the original SDESA. A construction model is validated by the well-established CYCLONE method to check the check the results given by SDESA. Chan and Lu (2008) presented a university-industry joint endeavor for improving the effectiveness of the materials handling system on a precast viaduct construction project in Hong Kong by implementing the simplified discrete-event simulation approach (SDESA). The results showed that knowledge derived from simulation can add to experiences of site managers in materials handling system design. With the aid of simulation, even junior engineers would be capable to draw up an actionable construction plan that leads to enhancement of cost effectiveness and productivity. Zhang et al. (2008) proposed a simulation-based methodology to handle the time constraints including the cyclical break, preemption, and overtime use. An algorithm to determine the execution of the time-constrained activities and the concepts of time cycle and time window are also introduced by them. Some examples illustrate and validate the algorithm, and highlight the effectiveness of the developed construction simulation. Song and Eldin (2012) proposed an adaptive real-time tracking and simulation of heavy construction operations for look-ahead scheduling during construction field operations. They used tacking sensors to capture construction operation data and the data is then fed into a simulation model for automatic model updating. Compared to the traditional offline simulation, the capability of the proposed real-time simulation can improve the accuracy of project look-ahead scheduling. Cheng et al. (2013) presented the information constraint net (ICN) to represent the complex information constraint relations among design activities involved in the building design process. They developed an algorithm to transform the information constraints throughout the ICN which simulates and optimizes resource allocation into a Petri net model. The experiment demonstrates that approach can shorten the development cycles and optimal allocation of resources. Akhavian and Behzadan (2014) described a methodology for collecting and mining of spatio-temporal data corresponding to the interactions of queue entities in a construction simulation. They argued that there are many situations in which formation of waiting lines or queues is inevitable, the queuing systems simulation for analysis of queuing systems is employed to identify the best operational strategies to reduce the time wasted in queues.

For presenting the linguistic expression of knowledge in construction projects, fuzzy set theory has been widely incorporated into discrete-even simulation. Zhang et al. (2005) presented a combination of the fuzzy set theory and a fuzzy ranking measure with discrete-event simulation to model uncertain activity duration in simulating a real-world system. The uses of the fuzzy activity duration and the probability distribution-modeled duration are compared through a series of simulation experiments in authors' study. The results showed that the fuzzy simulation outputs are arrived at through only one cycle of fuzzy discrete-event simulation. Corona-Suárez et al. (2014) developed a simulation-based fuzzy logic approach for estimating the effect of project quality management (PQM) on construction performance. They adopted fuzzy sets and fuzzy logic to incorporate the subjectivity and uncertainty implicit in the performance assessment of these PQM factors to discrete-event simulation models. The results showed that simulation approach allows experimenting with different performance levels of the PQM practices implemented in a construction project and obtaining the corresponding productivity estimates of the construction operations. Sadeghi et al. (2015) provided a methodology to consider subjective uncertainty in analyzing the fuzzy queues in construction fuzzy discrete event simulation (FDES) models. They argued that FDES provides a framework to consider subjective uncertainty in construction simulation models, and the project complete time is only considered. To enhance the applicability of FDES in construction projects, they further incorporate the fuzzy queuing theory with FDES to illustrate practical aspects of proposed methodology.

3. THE PROPOSED METHODOLOGY

The aim of this study is to propose a methodology that the construction scheduling integrating simulation and optimization of the precast and cast-in-place construction of a sub-structure for a high-tech industrial fab construction was implemented under various routes and criteria. Due to the various aspects of activities between the precast and cast-in-place construction, lots of space conflict will highly take place during the real construction period. Given the reason to avoid the efficiency reduction from the construction conflict, a well-prepared plan becomes more substantial. Figure 2 gives an overview of the proposed construction method.

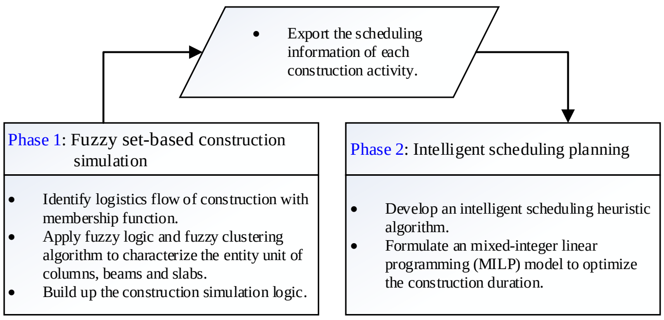

Figure 2: The flow chart of the proposed construction method.

As shown in Figure 2, the proposed construction method has two phases – fuzzy set-based construction simulation and intelligent scheduling planning. The purpose of the construction simulation is to provide a model that can simulate appropriate construction logic of the precast and cast-in-place activities to reflect conditions in a real construction project. To achieve this purpose, the project engineer is required to identify various logistics flow in the in-&out transportation of vehicles, materials, labors in precast and cast-in-place construction. Then a construction model can be developed and programmed by a process simulation computing software, Arena® (Rockwell Automation 2004, Kelton *et al.* 2003). However, these variables may not be described precisely due to uncertainty on them. It is important to determine these variables as factors, define the membership function, and rate the linguistic values for these variables via a fuzzification module in the fuzzy decision-making system (FDMS) shown in Figure 3.

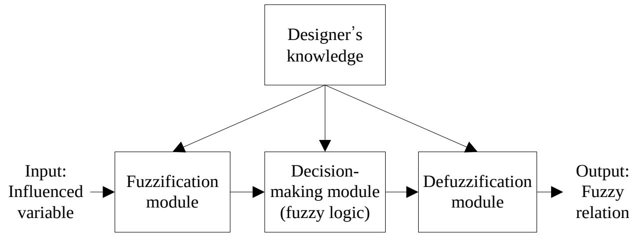

Figure 3: A fuzzy decision-making system (FDMS) configuration.

After conducting the simulation experiment, each time slot of the construction activity can be recorded as the schedule information that will be an input to intelligent scheduling planning. The purpose of the intelligent scheduling planning is to develop an intelligent scheduling heuristic algorithm. A mathematical programming constrained by resource allocation, construction sequence, and spatial planning equations is formulate to optimize the construction duration and even correct the mistakes of the scheduling logic over the construction duration accurately. We will explain each of them as follows.

3.1 The study scope of the fab construction

A semiconductor fab construction of the high-tech industry can be categorized into three projects – sub-structure, super-structure, and cleanroom. The study scope in this paper will focus on the sub-structure that accounts for the majority of the construction duration.

3.2 The fuzzy set-based construction simulation

Given various parameters in terms of construction items, resources, sequences, and priorities, two models of the construction process simulation are proposed to stand for the precast and cast-in-place activities respectively. If the construction activities at the operations specifically present the visualization of objects, attributes, and the logic over the construction duration, the potential problems are easily identified in the processes simulated by the process simulation method. Therefore, we convert some construction objects into entity units used for driving the construction process, assign each entity its attribute that presents meaningful criteria for construction, and implement the simulation to record the experiment result as the schedule information.

Before the simulation logic, the problem we deal with is to assign *n* construction material types to *c* entity units (i.e. clusters) in which vehicles or labors operated. In tradition, one needs to define a finite data set X, $X=\{x_1, x_2, \ldots, x_n\}$, and let $x_k=\{x_{k1}, x_{k2}, \ldots, x_{kq}\}$, where x_k is a vector represented by q features of characteristics such as part type q operating with the machine x_k. For gathering vehicles, materials, labors, one aim to determine the similarity rating between these construction objects. In our study, we replace the characteristics with how similar x_k to others is.

In order to form the similarity rating matrix, five variables determined by designers between construction objects in a construction fab are: in-vehicle transfer flow (IVF), out-vehicle transfer flow (OVF), material flow (MF), labor flow (LF), and similarity rating (SR). The set of membership functions used for them can be illustrated in Figure 4. An example of the fuzzy logic between a pair of objects is reasoned as follows:

IF (IVF) is (very high) AND (OVF) is (very high) AND (MF) is (very high) AND (LF) is (very high) THEN (SR) is (A)

All the input variables are considered as trapezoidal membership functions while output variable is considered as triangular membership function. The number of rules in decision-making module can be calculated by Equation (1):

$$N = \sum_{j=1}^{m} \left(\prod_{i=1}^{n} L_i \right) \qquad (1)$$

where

N = the total number of rules,

L_i = the number of membership function in ith input variable,

m = the number of the sets of rules, and

n = the number of input variables used in a set of rules.

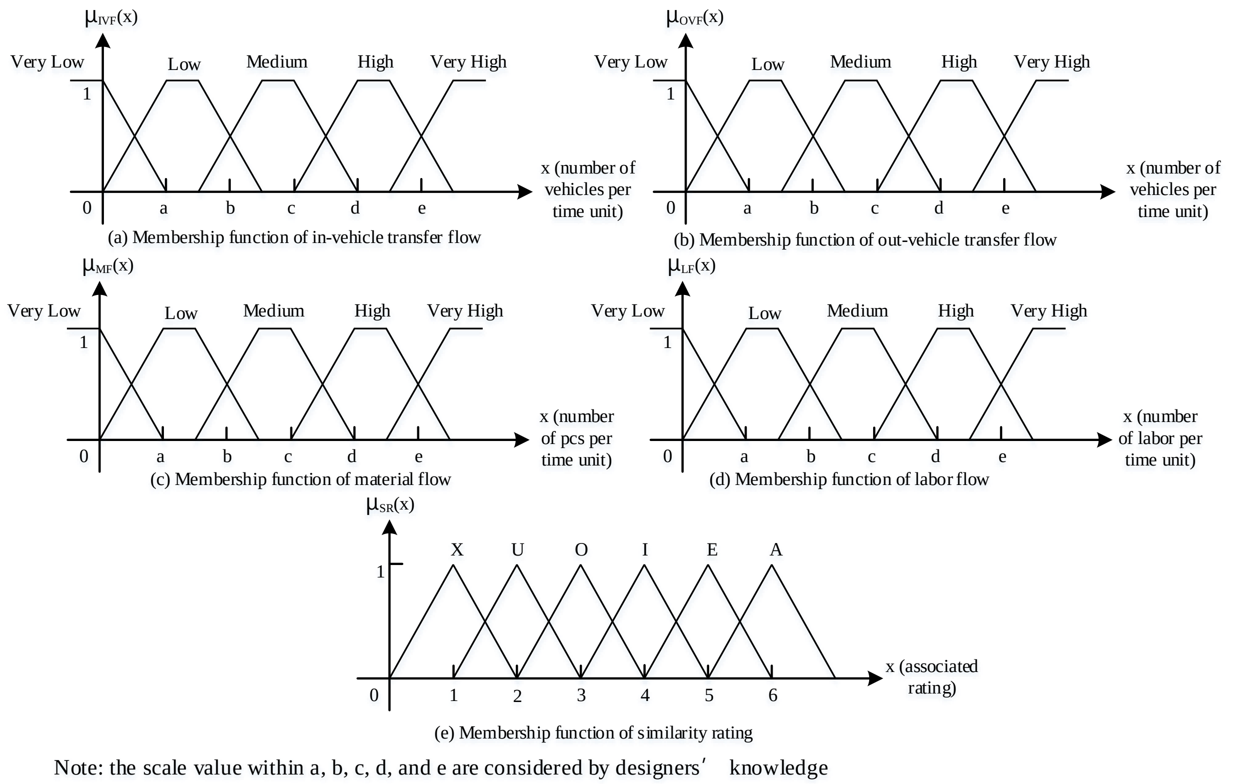

Figure 4: The membership functions of variables.

As indicated in Lee (1990), the three commonly used strategies may be described as the max criteria, the mean of maximum, and the center of area (COA). In addition, Braae and Rutherford (1978) concluded that COA strategy yields superior results. In this study, we adopt COA as the defuzzification strategy to calculate the final crisp value of each similarity rating. Among objects, the FDMS is repeated with the number of combination of each pair of objects. After all crisp values of similarity rating obtained, the similarity rating matrix can be formed as a kind of characteristics to follow up a clustering algorithms.

3.2.1 The model in the precast construction area

The object in the precast activities is comprised of columns, beams and slabs. The beams can be divided into big and small ones. The hoisting logic for the object is formulated in accordance with the of construction convenience which takes into account the space factor in the hoisting activity. Figure 5 demonstrates an entity unit in the precast construction field. Seven entity units grouped together by dotted line is formed from amount of columns, beams and slabs based on fuzzy logic applied previously. The process completion time of each entity is calculated on the total number of the columns, beams and slabs the hoisting crane operated expressed by Equation (2). Figure 6 shows the simulation model of a precast construction process in which an entity stands for precast units to be created and disposed throughout the construction duration.

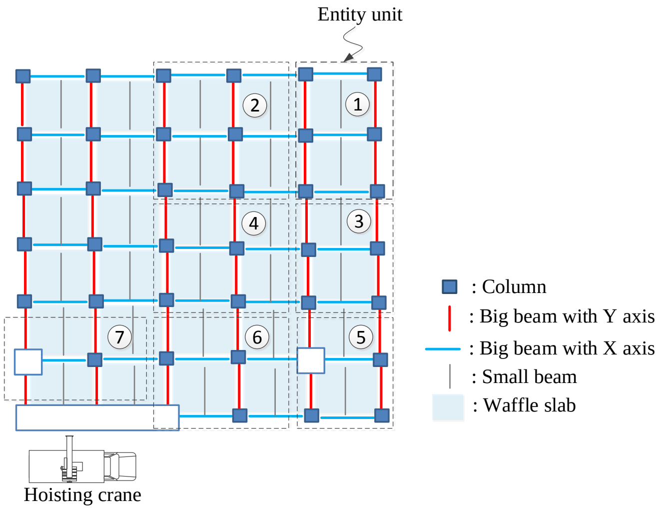

Figure 5: The demonstration of an entity unit in the precast construction field.

$$PT = \sum_{i=1}^{m} \left(P_i + W_{ij}\right) \quad \forall j \neq i \tag{2}$$

where

PT = the total completion time of an entity in the precast,

P_i = the process time of the ith object,

W_{ij} = the waiting time of the ith object for the jth object the hoisting crane been operating, and

m = the number of the sets of objects

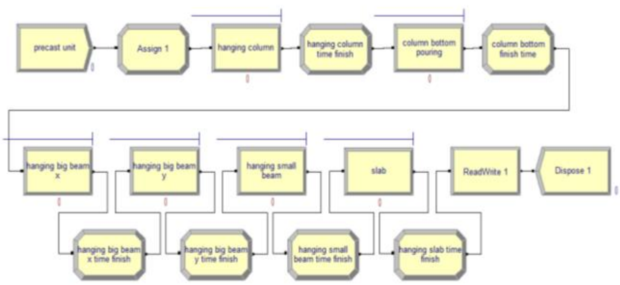

Figure 6: The simulation model of a precast construction process.

3.2.2 The model in the cast-in-place construction area

Unlike the construction logic in the precast activities, the object in the cast-in-place only contains columns and shear walls. The logic for the object is formulated associated with the construction size of area divided into distinct types. The construction activities relied on an enormous and skilled labour supply at the operations abide by a process in a fixed sequence by loft, prolong, scaffolding, stirrups, template, pouring, remove template, remove scaffold, heavy bracket, slab template, slab stirrups, and slab pouring. Figure 7 demonstrates an entity unit for dissimilar types in the cast-in-place construction field. An entity unit grouped together by dotted line is formed based on fuzzy logic from amount of columns and shear walls and characterized by three types in the both top and bottom half of the cast-in-place area. The process completion time of each entity is calculated on the total number of the columns and shear walls the labour operated expressed by Equation (3).

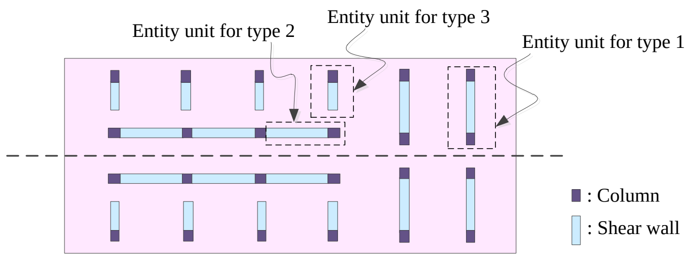

Figure 7: The demonstration of an entity unit in the cast-in-place construction field.

$$CT = \sum_{i=1}^{m} \left(P_i + W_{ij}\right) \quad \forall j \neq i \tag{3}$$

where

CT = the total completion time of an entity in the cast-in-place,

P_i = the process time of the ith object,

W_{ij} = the waiting time of the ith object for the jth object the labour been operating, and

m = the number of the sets of objects

3.3 The intelligent scheduling planning

After conducting the simulation experiment, each time slot of the construction activity of precast and cast-in-place is recorded as the schedule information used for integrating into an intelligent scheduling planning model. Two steps are performed in the scheduling planning model. Firstly, an intelligent scheduling heuristic algorithm based on Simulated Annealing (SA) is developed. Figure 8 shows the SA algorithm adopted by us. The proposed algorithm that vehicle transportation route and material stocking yard on the space axis combine with construction sequence and elapsed time of resources on the time axis can find a satisfactory combination solution of construction methods for the precast and cast-in-place.

1. Start with an initial feasible solution $X^{(0)}$, an initial temperature t, and an iteration limit $I_{\max}$. Initialize $X^* = X^{(0)}$ and $I = 1$.
2. While $I << I_{\max}$ do
   2.1. Until a feasible move ΔX is accepted do
      2.1.1. Randomly select a feasible move ΔX
      2.1.2 Calculate the change of value ΔV incurred by ΔX
      2.1.3. If $\Delta V \geq 0$, accept, else accept ΔX with a probability of $\exp^{\Delta V/T}$.
   2.2 Update the current solution $X_T = X_{T-1} + \Delta X$.
   2.3 If the value of X_T is better than that of X^*, than update.
   2.4 Decrease the temperature if appropriate.
3. Stop and report the best solution found.

Figure 8: The SA algorithm adapted from Rardin (1998).

In the second step, to improve the initial solution in the first step, a construction planning taking account for construction duration, vehicles and labors requirements simultaneously on the precast and cast-in-place areas is formulated as an optimized mathematical programming model. Constrained by resource allocation, construction sequence, and spatial planning equations, the shortest duration and the optimal resource allocation can be derived intelligently from solving a multiple objective planning problem to fulfill construction industry's need in the practical on-site construction environment. An objective function of mixed-integer linear programming (MILP) model is formulated for both construction areas expressed by Equation (4).

Minimize

$$\begin{aligned}&\sum_o\sum_m\sum_n\sum_a\sum_i\sum_t (SC_{maoit}S_{maoit})\times D_{omnait}\\&+\sum_o\sum_m\sum_n\sum_a\sum_i\sum_t (GC_{naoit}G_{naoit})\times D_{omnait}\\&+\sum_o\sum_p\sum_n\sum_a\sum_i\sum_t \left|ATG_{at}-(HR_{paoit}H_{paoit})\right|\times D_{opnait}\\&+\sum_o\sum_m\sum_n\sum_a\sum_i\sum_t RT_{omait}PR_{omait}(S_{maoit}+G_{naoit})\times D_{omnait}\end{aligned} \quad (4)$$

where decision variables are defined as follows.

D_{omnait} = 1, if construction object o of material type n being hoisted by hoisting crane m in construction area a for construction activity i during period t., 0, otherwise.

D_{opnait} = 1, if construction object o of material type n being operated by labor p in construction area a for construction activity i during period t., 0, otherwise.

S_{maoit} = amount by which the total space of the hoisting crane m hoists construction object o in construction area a for construction activity i during period t.

G_{naoit} = amount by which the total space of construction object o of material type n occupies in construction area a for construction activity i during period t.

H_{paoit} = Number of labor p which operates construction object o of material type n in construction area a for construction activity i during period t.

RT_{omait}, PR_{omait}, HR_{paoit}, SC_{maoit}, and GC_{naoit} are all objective function coefficients to define construction efficiency, priority, completion region, rental cost of machine, and storage cost of material respectively. As shown in Equation (4), the objective function of the mathematical programming model is the minimization of total costs across the entire construction process for entire planning horizon.

Constraints

Con.1: Precast hoisting activities predecessors. For example, the predecessor of beam hoisting is column hoisting, and the predecessor of slab hoisting is beam hoisting.

Con.2: Concurrent activities for precast and cast-in-place construction.

Con.3: Minimal safety distance between the hoisting crane of precast and the labor in cast-in-place construction.

4. EXPERIMENTAL RESULT

According to the construction activities of the cast-in-place in fixed sequence, the completion time for each of them can be obtained on a daily basis. Table 1 lists the results of the construction simulation experiment for the twelve activities in the both top and bottom half of the cast-in-place area as well as solutions determined by SA and MILP. Table 1 also lists the improvement rate over the planning period. From Table 1, one can see the construction duration has been reduced among one to two days after scaffolding activity.

5. CONCLUSION

In this paper, a simulation method applying the fuzzy logic and the fuzzy clustering algorithm and an intelligent scheduling planning that takes all resources of the personnel, machines, and materials into consideration to make high-tech industrial fab construction plan more efficient and precise to minimize the supervision cost, resources, and construction duration is proposed. The proposed method is capable of justifying construction engineering more objectively which construction project is satisfactory in the early planning phase.

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Table 1: Results of the construction experiment.

Activity	Fuzzy-set simulation		SA-MILP		Improvement rate (days)
	Completion time of bottom half	Completion time of top half	Completion time of bottom half	Completion time of top half	
Loft	15th, July	15th, July	15th, July	15th, July	0
Prolong	15th, July	16th, July	15th, July	16th, July	0
Scaffolding	17th, July	19th, July	17th, July	18th, July	1
Stirrups	20th, July	23th, July	19th, July	22th, July	1
Template	24th, July	28th, July	23th, July	27th, July	1
Pouring	25th, July	29th, July	24th, July	28th, July	1
Remove template	27th, July	31th, July	25th, July	29th, July	2
Remove scaffold	31th, July	4th, August	29th, July	2rd, August	2
Heavy bracket	4th, August	8th, August	2rd, August	6th, August	2
Slab template	7th, August	11th, August	4th, August	9th, August	2
Slab stirrups	8th, August	12th, August	5th, August	10th, August	2
Slab pouring	10th, August	14th, August	7th, August	12th, August	2

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