

# A CP-BASED OPTIMIZATION MODEL FOR CONSTRUCTION RESCHEDULING PROBLEMS

Shu-Shun Liu <sup>1</sup>, and Kuo-Chuan Shih <sup>2</sup>

<sup>1</sup> Assistant Professor, Department of Construction Engineering, National Yunlin University of Science and Technology, Touliu, Taiwan, 640, ROC

<sup>2</sup> Ph.D. Student, Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology, Touliu, Taiwan, 640, ROC  
Correspond to [liuss@yuntech.edu.tw](mailto:liuss@yuntech.edu.tw)

**ABSTRACT :** It is essential for project managers to make schedule adjustment based on their professional experience, in terms of rescheduling action discussed in this paper. This paper discusses the topics of resource-constrained construction rescheduling by modifying the concepts of manufacturing rescheduling. Moreover, the influence factors of construction rescheduling problems are investigated and identified in this paper. According to initial schedule plan and present progress, a new rescheduling mechanism based on Constraint Programming (CP) techniques is developed to reschedule projects with the objective of minimizing total project cost or duration, under three rescheduling policies. Through case study, the behavior of three different rescheduling policies is analyzed and discussed in this paper.

*Key words :* Construction scheduling, Resource-constrained project scheduling, Rescheduling, Constraint programming

## 1. INTRODUCTION

The rescheduling concept is first proposed and implemented in manufacturing industry, aiming at the purpose for executing quick response under diversified production environment. In general, any unexpected single accident such as machine failure will influence all the production line. The major topic of rescheduling issues is to discuss how to rearrange activities in order to adapt to the changing environment, and minimize the corresponding impact on initial schedule. Such rearrangement must respond immediately to diminish the impact on project progress. Contrary to manufacturing industry, the characteristics of construction scheduling environment contain more complicated factors such as environmental and productivity issues that make initial schedule difficult to maintain. However, though the needs for construction schedule updating and controlling are huge, very few research have been done in the domain of construction rescheduling problems. The paper tries to adapt the structure of rescheduling theory for the application in resource-constrained construction project scheduling problems. Several findings are presented and analyzed in this paper.

## 2. PRIOR RESEARCH RELATED TO CONSTRUCTION RESCHEDULING ISSUES

Hegazy [1] proposed a GA-based optimization model and critical chain concept in construction project control stage is involved. According to the concept of critical chain, some

unforeseen risks throughout the whole project are included in a project buffer. This buffer in terms of project duration extension is divided into three stages to distinguish the situation of project delay, and then evaluate the timing for corrective action based on stage status. The main goal of this research focuses on how to construct practical schedules prior to construction, and modify schedules during construction. However, the concept of project controlling mechanism in this prior research is conceptually different to the rescheduling concept illustrated in this paper.

In manufacturing industry, Wu[2] proposed a manufacturing rescheduling structure, including definition of types of rescheduling, rescheduling strategy, and rescheduling procedures. Moreover, Bo[3] tried to estimate the impact of machine failure on production lines, and propose a concept of the trigger value that is a critical value to evaluate the timing of rescheduling due to machine failure. Haldun[4] tried to re-define scheduling and rescheduling concept based on prior research.

Comparing other industries, construction scheduling environment constitutes more uncertainties, for example, relatively long duration, subcontracting behavior, etc. Therefore, how to control construction project schedules and maintain project progress with rescheduling concept becomes the objective of this paper.

### 2.1 Schedule updating and rescheduling

Schedule updating is not a new idea in construction, and usually performed for the purpose of project progress control

during construction phase. Moreover, Schedule updating is a key index for evaluating project performance. Several tasks of schedule updating during construction include: 1. Compare the initial schedule with current project progress. 2. Find out all activities that are delayed at present. 3. Identify responsibility of those delays. 4. Based on actual work progress, forecast and modify projected work progress.

In order to clearly define the scope of this study, the distinction between schedule updating and rescheduling is illustrated as shown in Figure 2.

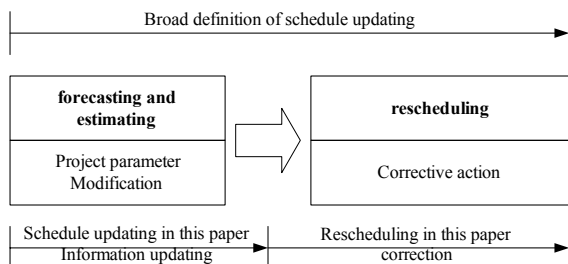


Figure 1. Distinction of schedule updating and rescheduling

### 2.2 Rescheduling environment

The definition of rescheduling concept can be illustrated as follows: based on an initial schedule that is feasible under original scheduling conditions, while any influence factor occurs and results in conflicts in the initial schedule, corrections are then executed to adjust initial schedule and diminish the impact on initial schedule due to those influences. In this paper, corrections are derived and suggested based on the optimized result.

In general, there are two types of rescheduling environment in relation to rescheduling issues, depending on the predictability of task requirement, defined as follows: 1. static scheduling environment, which contains finite jobs, for example, construction projects or any project-based environment; 2. dynamic scheduling environment, where job quantity is assumingly unlimited, depending on customer orders, like manufacturing and service businesses.

Regarding rescheduling environment, rescheduling decisions are less complicated in construction projects than those in manufacturing production. Consequently, rescheduling concept should be easier to be implemented in construction. Besides, referring to the management goal in planning issues, rather than forecasting order quantity in manufacturing, risk assessment for construction projects during construction is relatively important in construction. Therefore, periodic rescheduling based on updated progress information should be applicable in construction.

### 2.3 Rescheduling factors

Comparing manufacturing production, there are several differences of rescheduling factors in construction, shown as follows: 1. Resource uniqueness. Manufacturing production mainly depends on machine operation. As a consequence, the shortage of machine resources such as machine failure will lead to unbalanced schedule. In construction, the supply sources of critical resources are

usually diversified, and outsourcing options are available at most times, 2. Operational environment. Comparing the fact where manufacturing operations proceed in factories, construction operations are significantly influenced by many external factors such as weather, resource productivity, and change order. Therefore, it implies that the influence of rescheduling factors in construction that is not elaborated in this paper requires more attention, comparing those in manufacturing.

### 2.4 Rescheduling procedure

According to the research by Wu [2], three stages are involved in the execution of rescheduling actions, shown as Figure 1, and illustrated as follows:

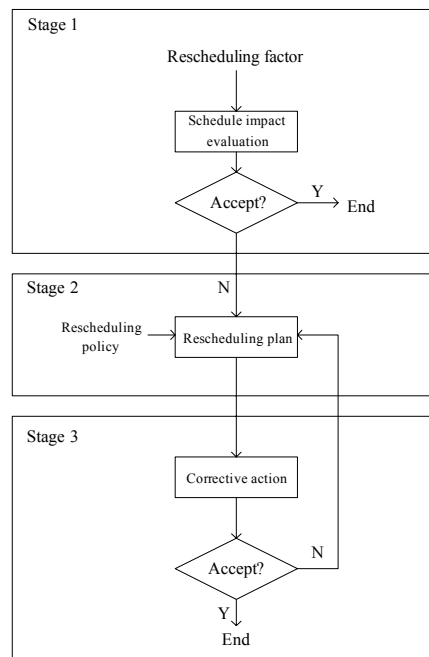


Figure 2. Rescheduling procedure [2]

#### (1) Stage 1: Schedule impact evaluation

While an unexpected event occurs, the impact on initial schedule should be immediately evaluated. Two situations are needed to be considered as follows: 1. If the impact judged by planners' experience is too great in an unacceptable shape, the procedure should go to stage 2 for rescheduling action. 2. The impact can be ignored if it is acceptable.

#### (2) Stage 2: Rescheduling plan

A feasible rescheduling plan for removing the impact from rescheduling factors is constructed in this stage. It is the most difficult part in resolving rescheduling issues.

The rescheduling strategies are divided into two categories as follows: dynamic scheduling and forecast-respond strategies. The dynamic scheduling strategy assigns tasks by assignment heuristics and pull mechanism, depending on the information obtained in a real-time environment. The forecast-respond strategy is the most common strategy that produces an initial schedule and

modifies it periodically or depending on an event-triggered basis.

In general, three types of rescheduling policies are involved in solving rescheduling problems, shown as follows: 1. Right shifting. Postponing all tasks that can be postponed to release time for remedying the accidents, until all issues are resolved. 2. Partial scheduling. Rescheduling only the tasks that are impacted and maintaining the least overall project fluctuation, compared with initial schedule plan. It is also the main rescheduling policy in this study. 3. Full rescheduling. Producing a new schedule with the optimal solutions with respect to different objectives, regardless of the fluctuation of each activity. Though the objectives for these three policies are different, all of them aim for modifying the original schedule based on the real-time information.

### (3) Stage 3: Corrective action

This stage focuses on the realization of optimized rescheduling plan that is generated in stage 2. When a new schedule can be accepted, the mission of rescheduling procedure is ended. Otherwise, recursively generate new rescheduling plans to modify schedule till a feasible plan is acceptable.

## 3. SCHEDULE UPDATING

### 3.1 Initial schedule

This paper does not focus on how to build and optimize the initial schedule, since this topic is not in the scope of this study, as long as the initial schedule is feasible under resource-constrained scheduling environment. However, the effort for finding initial construction project schedule may refer to Shih's work [6], which developed a scheduling optimization model for solving resource-constrained construction project scheduling problems, based on CP techniques. Therefore, given a known initial schedule, the project information including start time, duration, resource requirement, and direct cost for each activity are recognized.

### 3.2 Schedule updating

Considering rescheduling demand, schedule updating should focus on information updating mechanism that truly reflects real situation of project progress. All updating and rescheduling actions are executed in four types of activities shown as follows:

#### (1) Finished activity:

For finished activities, they are removed from rescheduling activity list, and the information regarding actual work progress and expense are retained for schedule impact evaluation. In other words, the observation of examining the finished activities performed as of the initial schedule or not, needs to be conducted. If the inconsistency is discovered, the causes that might be due to environmental factors or incorrect productivity assessment need to be investigated. The corresponding impacts on the succeeding activities or projected work progress can then be

evaluated, and rescheduling plan can be established.

#### (2) In-progress activity

It is more complex than other types of activity for dealing with in-progress activities. Because they may be the key reason of why rescheduling is needed. In general, the in-progress activities can be grouped into two categories: splitting and non-splitting activities. Planners can determine if an in-progress activity can be split based on their knowledge of activity characteristic and projected work progress. When splitting is not allowed once in-progress activities start, the resources already assigned to them cannot be released, and such condition is described as shown in Eqn 1. On the contrary, when splitting is allowed, in-progress activities may be split but not required at the rescheduling examination time, and the assigned resources can be released for other higher priority activities that may have not started yet but "being critical", according to rescheduling mechanism. Eqn 2 represents such condition.

$$AS_i = T \quad (1)$$

$$AS_i \geq T \quad (2)$$

Where

T is rescheduling examination time,  $AS_i$  is the start time for the portion of in-progress activity  $i$  not been completed at time T, and  $i$  belongs to in-progress activity set I

#### (3) Activity being scheduled

As for rescheduling issues, the most important task is the rearrangement for the activities being scheduled, complying with different objectives. However, such rearrangement will produce a new schedule that may cause great influence on all remaining activities and participators in the project. Thus, how to minimize overall project fluctuation, compared with initial schedule plan, is crucial for ensuring a feasible and practical scheduling plan. Therefore, the concept of partial scheduling is adopted for achieving the goal mentioned above in the proposed model. Moreover, partial scheduling also satisfies the needs for construction project scheduling involving lots of subcontractors. The following equations illustrate the constraints for representing start times for activities being scheduling.

$$AS_i = OAS_i \quad (3)$$

$$D_i = OD_i \quad (4)$$

Where

$OAS_i$  is the start time for activity  $i$  in initial schedule,  $D_i$  is the start time for activity  $i$ ,  $OD_i$  is the duration for activity  $i$  in initial schedule, and  $i$  belongs to set I of activity being scheduled.

(4) New activity

New activities may be added to scheduling plan due to change orders during construction. Therefore, the flexibility of the proposed rescheduling model is honored for providing planners the capability of considering activity addition impact on initial schedule.

**3.3 Productivity modification and activity duration adjustment**

By examining the reasons for causing activity delays, productivity modification is needed for correction, if incorrect assessment of productivity for specific resources is identified for the cause. Therefore, productivity modification and activity duration adjustment can be conducted through Eqn 5. However, if the delay reason is due to learning curve behavior in construction operations, only activity duration adjustment needs to be done through Eqn 6.

$$D_i = \text{ceil} [OD_i \times (1 - PA_i) \times (AD_i \div OD_i) \div PA_i] \quad (5)$$

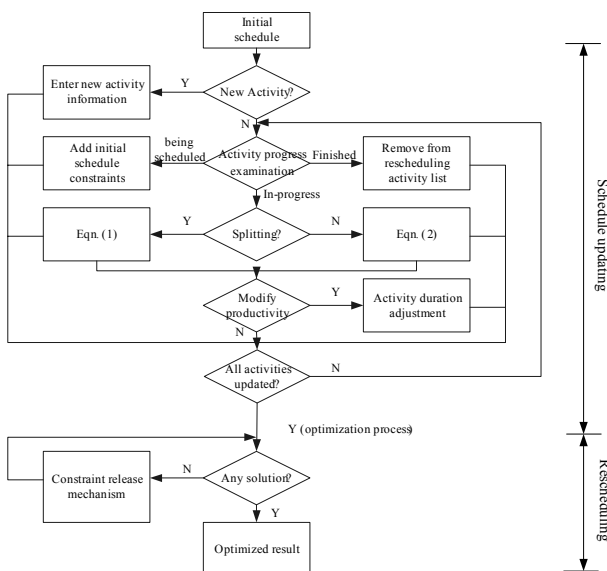
$$D_i = OD_i - AD_i \quad (6)$$

Where

$PA_i$  is the completion percentage of activity  $i$ ,  $AD_i$  is actual proceeding days for activity  $i$ .

**4. NETWORK-LEVEL RESCHEDULING OPTIMIZATION PROCESS**

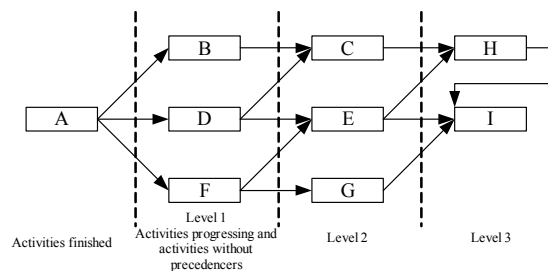
Figure 3 shows the schedule updating and rescheduling optimization process in proposed model.



**Figure 3.** Schedule updating and rescheduling optimization process

After schedule updating finishes, all of activities in-progress and being scheduled are included in a rescheduling activity list. First, rescheduling process begins with the

optimization of total cost minimization by constraining all rescheduling activities to initial schedule. If an optimal solution is achieved, the whole process ends and generates solution output. However, along with the great possibility of no single solution found, the process takes the activities in-process and any activity being scheduled without preceding activities as first-level activities, and their successors as second level, and so on. Then the optimization operations execute recursively level by level for finding feasible solutions (Figure 4), by releasing rescheduling activity constraints bounded to initial schedule, until all constraints of all levels of rescheduling activities are released. Therefore, once the constraints for the activities in the last level are released, an optimal solution is guaranteed. Through the rescheduling optimization process described above, the multi-objective goal of minimizing project total cost and maintaining the least overall project fluctuation can be achieved.



**Figure 4.** Constraint release mechanism through recursive optimization operations

**5. CASE STUDY**

The example project from Leu[5] is adopted and modified in the proposed model for rescheduling illustration, and the information is shown as in Table 1 and Table 2:

**Table 1.** Example project information

Act.	Dur.	Demand of resource 1	Demand of resource 2	Demand of resource 3	
A	50	5	4	5	
B	60	3	4	5	
C	90	4	5	2	
D	120	4	6	6	
E	130	3	6	5	
F	150	5	2	4	
G	120	1	5	6	
H	130	1	5	4	
I	140	1	5	2	
	F	160	6	4	4
	F	170	5	3	3
	F	180	4	2	2
	F	190	3	1	1
G	130	3	3	6	
H	140	3	2	5	
I	70	6	4	3	
	H	80	6	3	2
	I	90	5	5	5

**Table 2.** Cost and resource limit information

Indirect cost	2000 (\$ / day)		
Unit cost of resource 1	500 (\$ / unit)	Daily limit	10
Unit cost of resource 2	400 (\$ / unit)	Daily limit	10
Unit cost of resource 3	300 (\$ / unit)	Daily limit	10

The initial schedule with resource constraints is generated through the total cost optimization model developed by Shih[6], where the optimized total cost is \$5640000 and the associated project duration is 630 days, as shown in Table 3, and the detailed optimization operation is not elaborated here.

**Table 3.** Initial schedule plan

Act.	Dur.	Start time	Act.	Dur.	Start time
A	50	0	F	190	140
B	90	50	G	140	330
C	130	200	H	70	470
D	150	50	I	90	540
E	140	330			

Assuming the project proceeds to the 120th day, and the total expense to this day is \$700,000. Activity A is already finished. Activity B is in-progress, which has completed 90 percents of work and is ahead of schedule, so duration adjustment is not required. Activity D is in-process, which has only completed 42 percent of work and is behind schedule, needs productivity modification and duration adjustment. According to Eqn 5, the remaining duration for activity D is adjusted to 97 days. All other activities are not started yet.

As mentioned before, the detailed comparison of three rescheduling policies in proposed model are listed in Table 4, respectfully.

**Table 4.** Comparison of three rescheduling policies

Rescheduling policy	Full rescheduling	Rescheduling under project budget limitation	Partial rescheduling
<b>Characteristic</b>	Total cost control	Total time control	Aiming for diminishing overall schedule variation
<b>Objective</b>	Minimize total cost	Minimize project duration	Minimize total cost
<b>Special constraint</b>	None	Budget limitation	Constraint release mechanism

Case analysis for different rescheduling policies is

conducted based on the optimized results, and illustrated as follows:

**Case 1**

Full rescheduling regardless of the fluctuation of each activity. Table 5 shows the optimized schedule with total cost \$5482900 and the associated project duration 647 days. Compared with initial schedule shown in Table 3, the new schedule of this case is totally changed for all rescheduling activities. This result implies that the goal of total cost minimization without schedule variation consideration generally results in the disorder for initial schedule adjustment.

**Table 5.** Rescheduling result of case 1

Act.	Dur.	Start time	Act.	Dur.	Start time
B	9	120	F	190	129
C	130	217	G	140	319
D	97	120	H	70	487
E	130	347	I	90	557

**Case 2:**

Rescheduling subject to project budget limitation. Table 6 shows the optimized schedule with project duration 627 days and the associated total cost \$5531900. Compared with the project duration of case 1, the overall project duration of this case is 20 days shorter than that in case 1. Moreover, the same behavior as that in case 1 regarding schedule variation issue can be observed.

**Table 6.** Rescheduling result of case 2

Act.	Dur.	Start time	Act.	Dur.	Start time
B	9	120	F	190	129
C	120	217	G	140	337
D	97	120	H	70	467
E	130	337	I	90	537

**Case 3:**

Partial schedule. Table 7 shows the optimized schedule with total cost \$5537900 and the associated project duration 630 days. The optimization process is described as follows: according to constraint release mechanism in proposed model (Figure 4), rescheduling activities can be grouped into three levels. The first level contains activity B, D, and F; second level C, E, and G; final level H and I. After two levels of recursive optimization processes, an optimal solution is found. It means that the initial schedule constraints for activity H and I are retained. Compared with initial schedule shown in Table 3, overall project duration and the schedule for activity H and I in this case are insured. However, in order to diminish the schedule variation for each rescheduling activity, a trade-off may be compromised for such goal. It can be observed from the comparison of case 1, 2, and 3, where the total cost in this case is more than that in case 1; the project duration is longer than that in case 2.

**Table 7.** Rescheduling result of case 3

Act.	Dur.	Start time	Act.	Dur.	Start time
B	9	120	F	190	129
C	120	217	G	140	477
D	97	120	H	70	470
E	130	467	I	90	540

## 6. CONCLUSION

This paper proposes a rescheduling optimization model for construction projects, including schedule updating, productivity modification, and a recursive optimization process. Schedule updating procedures considering the scheduling behavior of four types of activities are discussed in this paper. In order to diminish overall project variation, a network-level rescheduling optimization process is established in the proposed model. Moreover, considering different perspectives of rescheduling issues, three rescheduling policies are conducted and analyzed as follows: (1) full rescheduling, (2) rescheduling subject to project budget limitation, (3) partial rescheduling.

Based on the results from case study, the complexity of construction rescheduling issues is then identified. Depending on different management goals of rescheduling policies, the realization of new schedules through the proposed rescheduling optimization process requires a trade-off. Such trade-off in time or cost can exchange for a “steady” schedule, and more research efforts should be done for the clarification of this trade-off problem in the future, from the perspective of dynamic project control.

## ACKNOWLEDGEMENTS

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## REFERENCE

- [1] Hegazy, T., M.ASCE and Petzold, K., 2003, “Genetic Optimization for Dynamic Project Control,” *Journal of Construction Engineering and Management*, Vol. 129, No. 4, pp. 396-404, July/August.
- [2] Wu H. H., Li R. K., 1997, “Lecture review and analysis for rescheduling decision problem in production schedule”, *Journal of the Chinese Institute of Industrial Engineers*, Vol. 14, No. 2, pp. 147-158.
- [3] Haldun A., Mark A. L., Kenneth M., Shantha M., Reha U., 2005, “Executing production schedules in the face of uncertainties: A review and some future directions,” *European Journal of Operational Research*, Vol. 161, pp. 86-110.

[4] Bo, G., Yasuo, N., 1999, “Rescheduling and optimization of schedules considering machine failures,” *Int. J. Production Economics*, Vol. 60-61, pp. 503-513.

[5] Leu, S. S., Yang, C. H., 1999, “GA-Based Multi-criteria Optimal Model for Construction Scheduling,” *Journal of Construction Engineering and Management*, Vol. 125, No. 6, pp. 420-427, November/December.

[6] Shih K. C., *Resource-constrained Construction Project Scheduling and Rescheduling Model Using Constraint Programming Techniques*, Master Thesis, Department of Construction Engineering, National Yunlin University of Science and Technology, Taiwan, 2004.