A QUANTITATIVE APPROACH TO CONSTRUCTION POLLUTION CONTROL BASED ON RESOURCE LEVELING

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ABSTRACT: A quantitative approach for construction pollution control that is based on construction resource leveling is presented. The parameters of construction pollution index (*CPI*), hazard magnitude (h_i) are treated as a pseudo resource and integrated with a project's construction schedule. When the level of pollution for site operations exceeds the permissible limit identified by a regulatory body, a Genetic Algorithm (GA) enhanced leveling technique is used to re-schedule project activities so that the level of pollution can be re-distributed and thus reduced. The GA enhanced resource leveling technique is demonstrated using 20 on-site construction activities in a project. Experimental results indicate that proposed GA enhanced resource leveling method performs better than the traditional resource leveling method used in MS Project©. The proposed method is an effective tool that can be used by project managers to reduce the level of pollution at a particular period of time; when other control methods fail.

INTRODUCTION

Pollution and hazards generated from construction sites include noise, solid and liquid wastes, dust, and harmful gases. In many cases, especially if the construction sites are in the densely polluted areas, the level of pollution emission can not exceed a limit specified. For example, the Noise Pollution Protection Act in China (NPPA 1993) specifies that the level of noise cannot exceed 75 dB (A), above which site operations will be stopped by legal actions. In a construction site, the level of pollution emission from individual operations may not exceed the legal limits specified under the regulations however the aggregated level of pollution from multiple sources may exceed the limit. To prevent this and ensure that the level of pollution emission will not exceed the legal limits during the duration of a construction project, this paper describes a two-step quantitative method that can be used to control construction pollution. First, the method can predict the distribution of pollution emission levels throughout a project's duration. Second, if it detects that the level of

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pollution exceeds the limit at a certain point of time, then on site activities are re-scheduled so that the level of pollution can be re-distributed.

This paper presents a quantitative approach for construction pollution control based on resource leveling. Our experimental results indicate that the use of construction pollution index (*CPI*) and its interrelated hazard magnitude (h_i), as kind of pseudo resources, and its integration with a project's construction scheduling can practically combine construction pollution control with scheduling. The quantitative approach can ensure that the level of construction pollution is within the a legal range throughout the entire project duration. The limitation of the quantitative approach presented here is that it has not been endowed with a capability towards adjusting pollution level of a construction procedure when the pollution level is hard to be relayed down.

CONSTRUCTION POLLUTION MEASUREMENT

Pollution Control in Construction Projects

The pollution control in construction projects is defined here as the control of all human activities that have an either significant or small negative impact on the environment during the whole construction process (Griffith, *et al*. 2000). Construction pollution has received much attention in the industry over the past 30 years. At the same time, there have been many studies related to pollution control in construction. For example, a study on noise pollution, air pollution and solid waste pollution from construction sites was conducted in early 1970s (U.S. EPA, 1971, Jones, 1973, Skoyles and Hussey 1974; Spivey, 1974). The conception of environmental management during construction is put forward in late 1970s, and a role of environmental inspector is introduced in the design and construction phases of projects. The environmental inspector is a specialist whose academic background or experience results in considerable understanding of environmental impacts and applicable control measures. The environmental inspector, a specialist with professional knowledge in environmental impacts and applicable control measures, is an advisor to construction engineers on all matters of environmental management on (Henningson, 1978).

There have also been some studies engaged to the quantitative measurement and effective control of construction pollution, using methods such as life-cycle costing; efficient energy consumption; reduction, reuse, and recycle of construction and demolition material/debris; degradation and abatement of construction noise and dust; and environmental impact assessment, etc. However, there was little enthusiasm for establishing an environmental management system in a commercial construction company until two main important standards, BS 7750 (1992) and ISO 14000 series

(1996), are promulgated. As the environmental management system is a formal structure of a construction organization that implements environmental management (Griffith, *et al*. 2000), quantitative approaches to construction pollution control are therefore more useful and effective in construction projects managed by such a construction organization.

Construction Pollution Index

A method for quantifying construction pollution, known as the Construction Pollution Index (*CPI*) has been proposed by Chen *et al*. (2000) and has been adopted in this paper. The CPI is shown in Formula 1:

$$CPI = \sum_{i=1}^{n} CPI_i = \sum_{i=1}^{n} h_i \bullet D_i \qquad \ldots(1)$$

Where CPI is the *C*onstruction *P*ollution *I*ndex of an urban construction project, CPI_i is the CPI of a specific construction operation i, h_i is the *H*azard magnitude per unit of time generated by a specific construction operation i, D_i is the *D*uration of the construction operation i that generates pollution and/or hazard h_i, n is the number of construction operations that generate pollution and hazards.

In Formula 1, parameter h_i is a relative value indicating the magnitude of hazard generated by a particular construction operation in a unit of time. Its value is limited in the range of [0,1]. If h_i = 1, it means that the hazard may cause fatal damage or generate a catastrophe to people and/or properties nearby. For example, if a construction operation can generate some noise and the sound level at the receiving end exceeds the 'threshold of pain', which is 140 dB (McMullan, 1998), then the value of h_i for this particular construction operation is 1. If h_i = 0, then it indicates that no hazard is detectable from a construction operation.

It is possible to identify values of h_i for all types of pollution and hazards generated by commonly used construction operations and methods. Information and data such as the emission of noise levels, harmful gases and wastes quantities are normally available in the specifications of relevant construction machinery and plant, or can be conveniently measured. These data can then be converted to h_i values by normalizing them into the range of [0,1]. In case that there is not enough data available for such conversion at present, then h_i values have to be determined using experience and expert opinions. Examples of h_i values from some construction operations are listed in Table 1.

Table 1. h_i **Values of some construction operations**

Task Name	h_i Value (per day)
Demolition	0.7
Site preparation	0.7
Cast-in-place RC Pile	0.5
Excavation & support system	0.7
Foundation baseplate	0.3
RC framework	0.5
Steel framework	0.2
Roof works	0.5
Water supply & sewerage works	0.1
Power supply system	0.1
Lighting system	0.1
Air conditioning	0.1
Computer & communication network	0.1
Floor finish & polishing	0.7
Internal wall finish	0.4
External wall finish	0.2
Internal partition wall	0.1
Ceiling work	0.2
Site improvements	0.2
Landscaping work	0.1

Figure 1 illustrates an example of project schedule that includes 20 activities. h_i values of each activities are indicated at the right side of the bars. For example, the h_i value for “RC framework” is calculated to be 0.5.

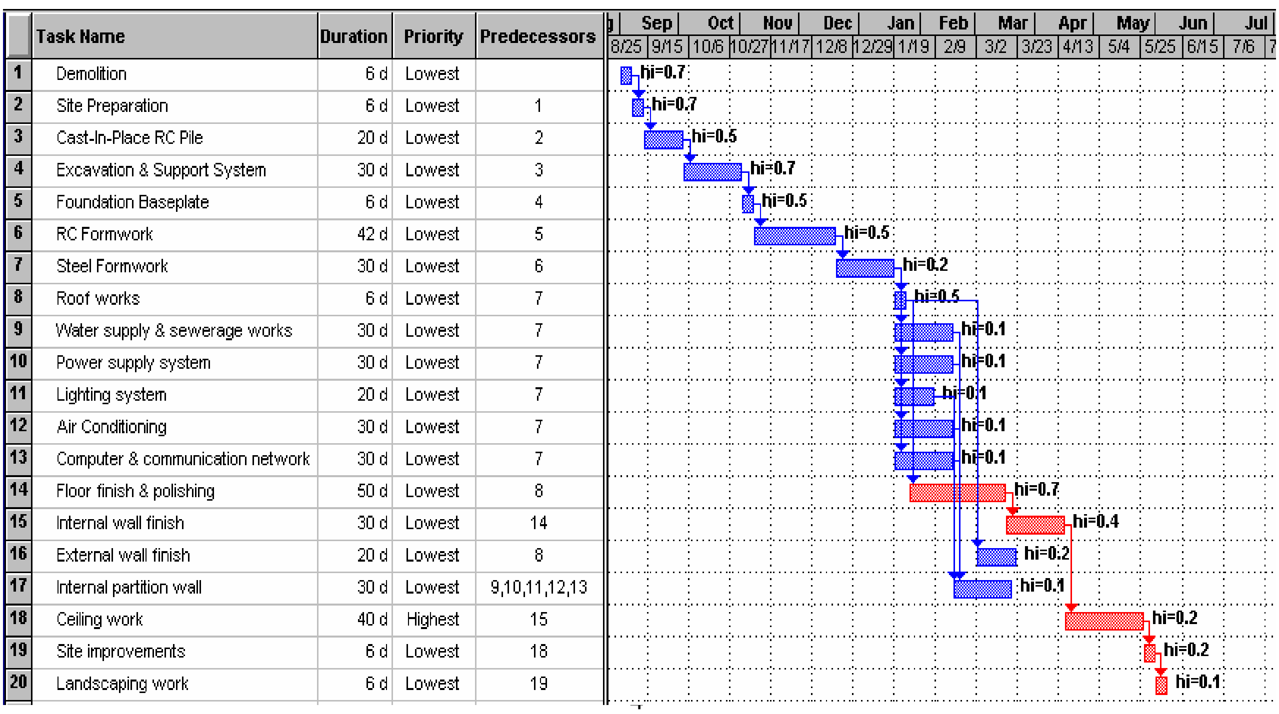


Figure 1: Initial schedule of a project

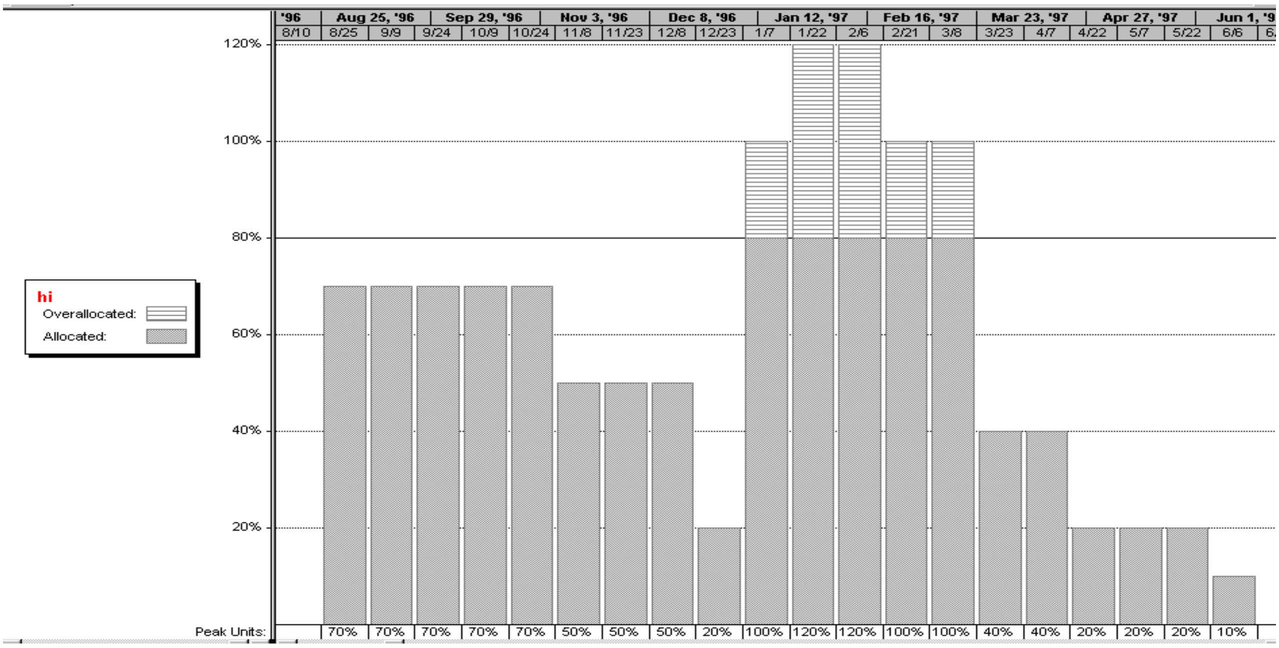


Figure 2: Histogram of h_i in the initial schedule.

In Figure 2, the y-axis represents the accumulated h_i value and the x-axis the project duration. Thus, the shaded area is the total *CPI* value. It is suggested that the maximum permissible level of h_i is 0.8 at any point of time. It is necessary to note that the definition of maximum level of h_i value is based on the authors' estimate of the average allowable pollution level. The value of maximum h_i value can be adjusted to reflect the level of pollution control: the lower the maximum h_i value, the tighter control on pollution, and vice versa.

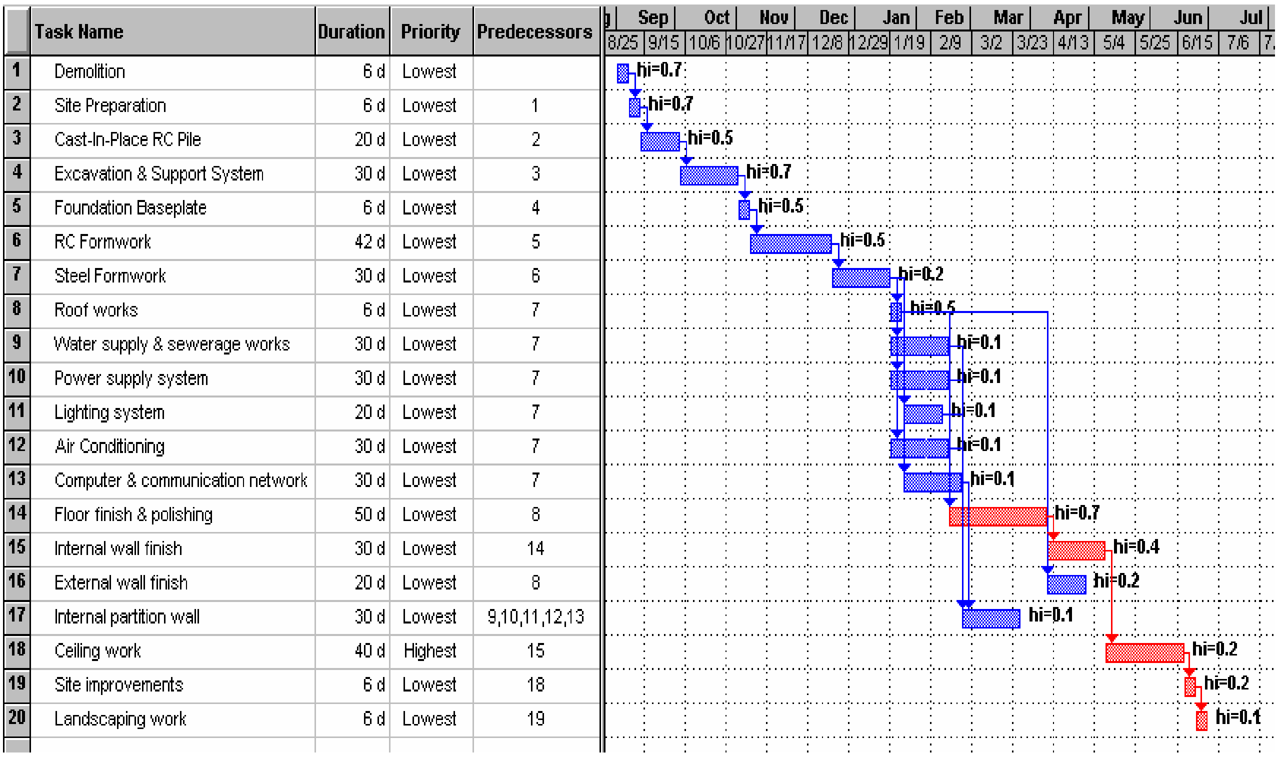
It is necessary to note the histogram is produced by linearly accumulating h_i values. This may cause inaccuracies as some pollution measurements cannot be linearly added up. For example, the noise levels. We are currently examining the effect of nonlinearity and aiming to develop a revised method to accumulate h_i values so that accurate histograms can be produced.

From Figure 2, it can be seen that during the period Dec. 1996 to Mar. 1997 of the project duration, the level of h_i values will exceed its maximum value, indicating that during this period, the accumulated level of pollution will exceed the limit. Therefore, it is necessary to re-arrange the project schedule so that the excessive level of pollution can be reduced to a level below the limit.

A PSEUDO RESOURCE APPROACH FOR LEVELING CONSTRUCTION POLLUTION

Resource leveling is an effective tool for project scheduling when there is a conflict or shortage of resources. This section presents a method to combine the pollution control with resource leveling at project scheduling stage. h_i values are treated as a pseudo resource, and the maximum h_i value as the limit of the "resource". This "resource" together with other types of resources can be leveled by using the traditional project resource leveling methods (Pilcher, 1992).

In order to test the pseudo resource approach for reducing construction pollution level in a project schedule, we used the Microsoft Project 98 as a tool for scheduling and resource leveling. The project schedule leveled by the MS Project© as well as the histogram of h_i values are illustrated in Figure 3 and 4.



	Task Name	Duration	Priority	Predecessors
1	Demolition	6 d	Lowest	
2	Site Preparation	6 d	Lowest	1
3	Cast-In-Place RC Pile	20 d	Lowest	2
4	Excavation & Support System	30 d	Lowest	3
5	Foundation Baseplate	6 d	Lowest	4
6	RC Formwork	42 d	Lowest	5
7	Steel Formwork	30 d	Lowest	6
8	Roof works	6 d	Lowest	7
9	Water supply & sewerage works	30 d	Lowest	7
10	Power supply system	30 d	Lowest	7
11	Lighting system	20 d	Lowest	7
12	Air Conditioning	30 d	Lowest	7
13	Computer & communication network	30 d	Lowest	7
14	Floor finish & polishing	50 d	Lowest	8
15	Internal wall finish	30 d	Lowest	14
16	External wall finish	20 d	Lowest	8
17	Internal partition wall	30 d	Lowest	9,10,11,12,13
18	Ceiling work	40 d	Highest	15
19	Site improvements	6 d	Lowest	18
20	Landscaping work	6 d	Lowest	19

Figure 3. Microsoft Project 98© leveled project schedule

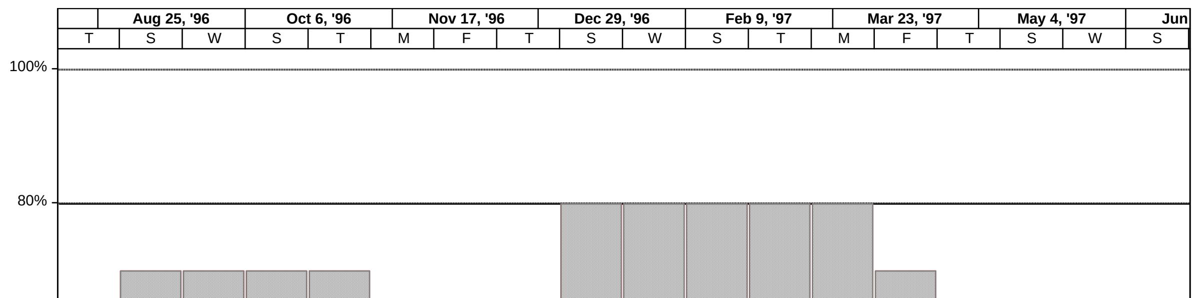


Figure 4. Histogram of h_i value associated with the schedule leveled by Microsoft Project 98©

Experimental results from Figure 3 and 4 indicate that construction pollution level spreads out under the line of the maximum permissible level of h_i (Maximum h_i =0.8) when other five resources (Table 2) are also leveled down to their individual resource limit. So the pseudo resource approach for reducing construction pollution level is feasible at project scheduling stage. However, the total construction period is stretched 22 days, about 8 percent longer than the original schedule in Figure 1, after resource smoothing. Similar results also occurred from our other experimental schedules which are not presented here. It is necessary to find an alternative approach to get a shorter schedule with every resource leveled, including the pseudo resource.

COMBINING CONSTRUCTION POLLUTION CONTROL WITH RESOUCE LEVELING USING GA

Resource leveling and allocation can be performed mainly by heuristic methods and analytic methods (Farid and Manoharan, 1996). In recent years, there have been several studies on applying heuristic methods as well as analytical methods in solving resource-leveling problems. For example, artificial neural networks (ANN) is used to minimize project duration and cost by using a mathematical model based on precedence relationships, multiple crew-strategies, and time-cost tradeoff (Adeli and Karim, 2001; Senouci and Adeli, 2001), and genetic algorithms (GA) is used to search for near-optimum solution to the problem of resource allocation and leveling integrated with time-cost tradeoff model, resource-limited/constrained model, and resource leveling model (Chan, *et al*., 1996; Chua, *et al*., 1996; Li and Love, 1997; Hegazy, 1999; Leu, *et al*., 1999; and Leu and Yang, 1999). To integrate various heuristic methods into the resource leveling, the methods used by Harris (1978) and Hegazy (1999), which minimize both daily fluctuations in resource use and the resource utilization period, have been adapted. According to Hegazy (1999), the moment of fluctuations in daily resource use can be calculated as follows:

$$M_x^R = \sum_{j=1}^{n} RP_j^2 \qquad ...(2)$$

and the moment for measuring the resource utilization period is calculated as:

$$M_y^R = \sum_{j=k}^{n} (j-k) RP_j \qquad ...(3)$$

The above two moment calculations can be used in either reducing resource fluctuations, or minimizing the duration of resource use, or minimizing both resource fluctuations and duration's. However, concurrent optimization of resource leveling and pollution control is a nonlinear searching problem that is suitable for using the Genetic Algorithm (GA) to solve.

Gene Formation

In a number of commercial resource leveling software packages, the user is allowed to set priority levels to tasks. Priority is an indication of a task's importance and availability for leveling (that is, resolving resource conflicts or over allocations by delaying or splitting certain tasks). The task priority setting controls leveling, which allows users to control the order in which software systems, such as MS Project©, delay tasks with over allocated resources. Tasks with the lowest priority are delayed or split first, and tasks with a higher priority are not leveled before other tasks sharing the over allocated resources. Thus, to apply the GA system to solve the multiple resources leveling problem, it is essential to have a gene structure that facilitates the operations of GA. Bearing this in mind, the following gene format used by Syswerda and Palmucci (1991), Grobler, *et al*. (1996), Boggess and Abdul (1997), and Hegazy (1999) has been adopted:

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*		*j*
P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	…	P_j

Note: 1. P_j is the priority of active j, $P_j \in [0,8]$.

P_j =0, activity priority is highest; P_j =1, activity priority is higher;
P_j =2, activity priority is very high; P_j =3, activity priority is high;
P_j =4, activity priority is medium; P_j =5, activity priority is low;
P_j =6, activity priority is very low; P_j =7, activity priority is lower;
P_j =8, activity priority is lowest

2. The priority values are in accordance with the priority grades of actives in Microsoft Project 98.

Figure 5: Gene formation (adopted from Hegazy (1999))

In Figure 5, a string has *j* genes, and each box represents a gene. The number inside the box is the priority setting for a particular task labeled by the number above the box. A string is a particular combination of priority settings that determines a specific schedule. The fitness of the string is evaluated by the following set (Hegazy 1999),

$$\omega_d (D_i / D_0) + \sum_{j=1}^{n} [\omega_j^R (M_{xji}^R + M_{yji}^R)/(M_{xj0}^R + M_{yj0}^R)] \qquad ...(4)$$

Where M_x^R is the moment of fluctuations of daily resource use as defined in (2); M_{xji}^R is the moment of fluctuations of resource use in a specific schedule determined by string *i* in day *j*; M_{xj0}^R is the initial value of M_x^R in day *j;* M_y^R is the moment of resource utilization period, as defined in (3); M_{yji}^R is the moment of resource utilization period of a schedule determined by a string *i* in day *j;* M_{yj0}^R is the initial value of M_y^R in day *j;* D_i is the new project duration of schedule determined by string *i*, D_0 is the initial project duration determined by any resource allocation heuristic rule, ω_d is the weight in minimizing project duration, ω_j^R is the weight in leveling every resource in day *j*, i is the generation number of genes, j is the representative day during a project's total working-day, and n is the working-day number of a project's duration.

By selecting different weights, the fitness function (4) enables the user to conduct different heuristics based resource leveling including reducing resource fluctuations, or minimizing the duration of resource use, or minimizing both resource fluctuations and durations.

EXPERIMENTAL RESULTS

This section presents experimental results from using GA to combine pollution control and resource allocation into the task of resource leveling. The schedule used in the experiment is collected from a construction project in Shanghai in which there are 20 activities for general control, and initial schedule of the activities and their associated level of pollution emission (h_i value) are shown in Figure 1. From the histogram of h_i value, which is illustrated in Figure 2, it can be detected that the accumulated level of pollution emission exceeds the permissible limit.

In this project, there are six kinds of construction resources, which represent workers, materials, machines, instruments, and power denoted as *R1*, *R2*, *R3*, *R4*, and *R5*. Pollution is treated as a pseudo resource and is denoted as *R6*. These resources are listed in Table 2. For the purposes of convenience in calculation, the values of the resources are adjusted so that there will be no very large or small figures.

Table 2. Resources treatment of initial construction schedule

Resource Name	**Mark**	**Max units available**	**Adjustment**
Workers	R1	1900	Workers No. $\times$ 10
Materials	R2	2200	Materials Cost $\times$ 0.01
Machines	R3	2100	Machines Cost $\times$ 0.01
Instruments	R4	3100	Instruments Cost $\times$ 0.01
Power	R5	3400	Power Cost $\times$ 0.01
h_i	R6	80	$CPI \times 100$

In the experiment, the initial population size is set at 100. Also, to minimize both resource fluctuations and period, the weightings in (4) are given an equal weighting of 1. The resultant schedule and associated histogram of value are illustrated in Figure 6 and 7.

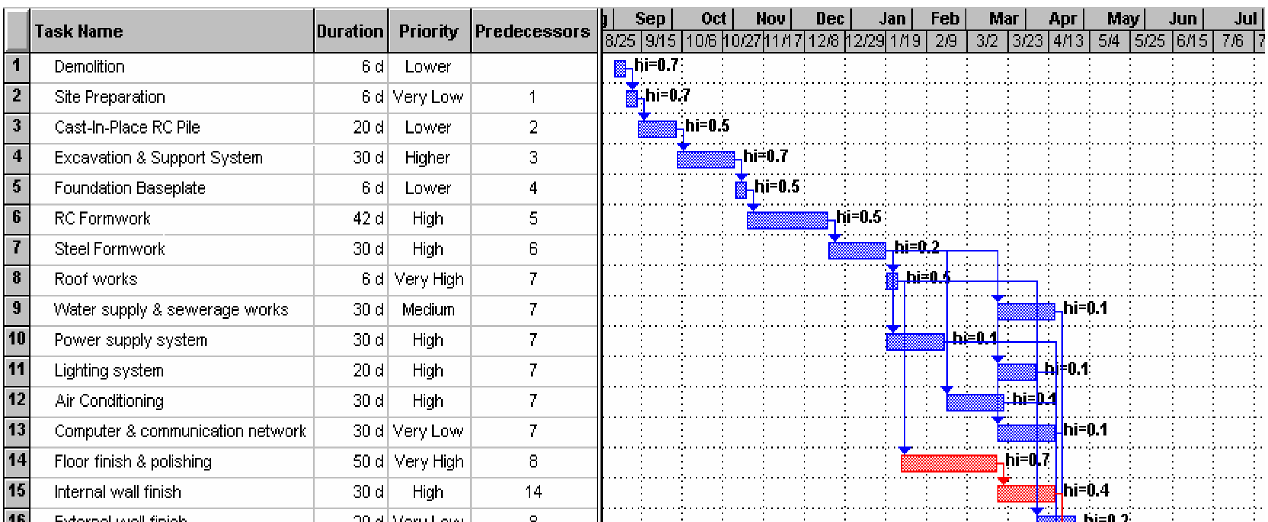


Figure 6. GA optimized construction schedule

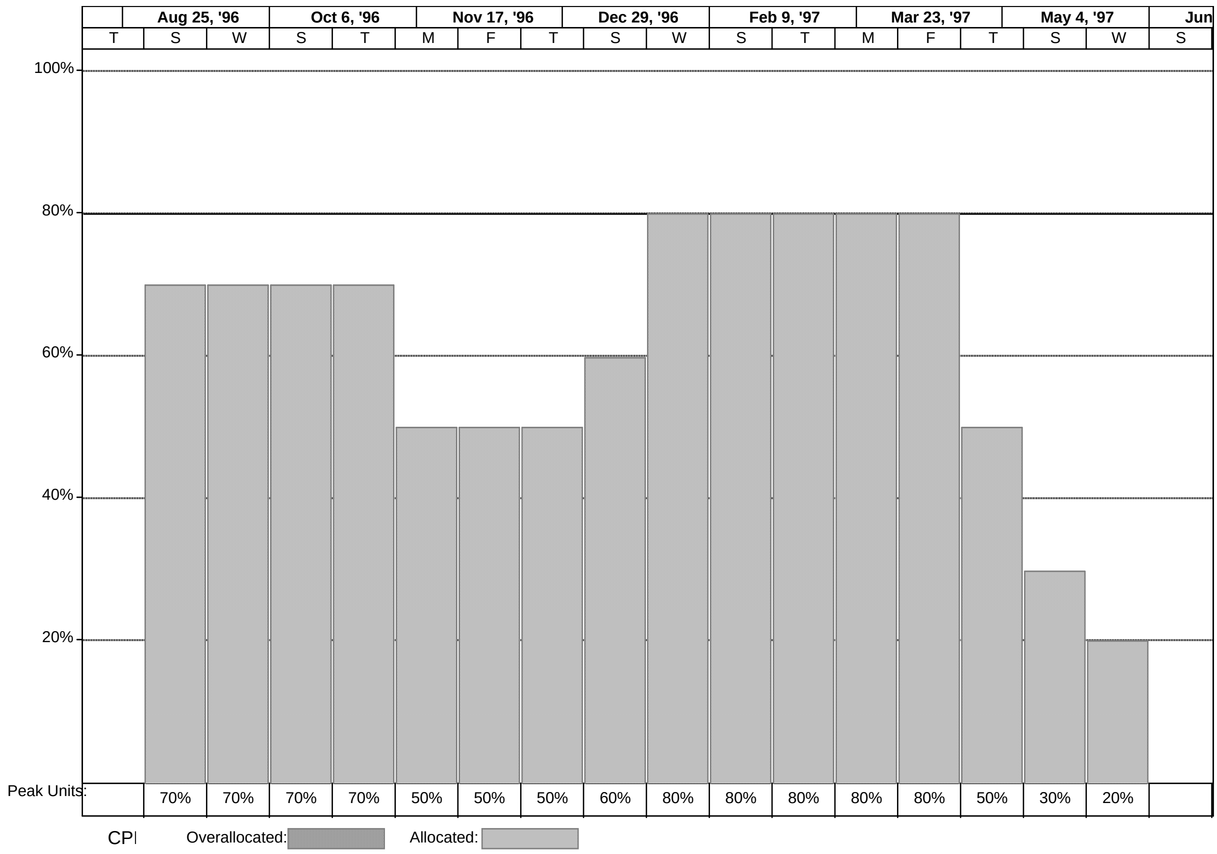


Figure 7. Histogram of h_i value associated with the schedule leveled by GA

Comparing the GA leveled schedule with the MS Project© leveled schedule, it can be seen that the priorities of resource use in the GA leveled schedule are set at different values (Figure 6); whereas priorities in the MS Project© leveled schedule (Figure 3) do not have any changes from the original schedule (Figure 1). In addition, the duration of the GA leveled schedule is 298 days, which is shorter than the duration of the schedule leveled by the MS Project© (302 days). Our additional two experiments with different number of populations also lead to similar results. From the experiments, we can conclude that the GA system can adjust the task priorities that lead to the re-distribution of resources that meets the resources constraints and produces a shorter schedule. The GA system enhances the leveling function of MS Project©, as it enable the user to identify the optimal settings of task priorities automatically in resource leveling.

CONCLUSIONS AND DISCUSSIONS

A quantitative approach to construction pollution management by introducing parameters of construction pollution index (*CPI*) and hazard magnitude h_i has been proposed. Using these parameters, a method to predict the distribution of accumulated pollution level generated from construction operations is presented. It is suggested that if the pollution level exceeds the allowable limit, then construction activities need to be re-scheduled to 'spread' the pollution emissions. In doing so, pollution emission is treated as a pseudo resource, and then applied to a GA based leveling technique to re-schedule the project activities. The GA system allows the user to concurrently minimize fluctuations and period of resource use by assigning different priorities to project activities. Experimental results indicate that GA enhanced resource leveling performs better than the traditional resource leveling method used in the MS Project©.

The authors suggest that the proposed method for controlling construction pollution is an effective tool that can be used by project managers to reduce the level of pollution generated from a project at a certain period of time. This method is useful when there is no other ways to reduce the level of pollution. However, it is necessary to point out that the method proposed here can only redistribute the amount of pollution over a project duration so that at any specific period of time, the level of pollution will not exceed the legal limit. In order to reduce the overall amount of pollution, other methods, such as alternative construction technologies, new materials, have to be applied.

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