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RESEARCH ARTICLE

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Use of float consumption rate in resource leveling of construction projects

Abstract The management of resources has been claimed to be as important as scheduling methods. Inefficiency in managing resources may bring about severe delays and cost overruns caused by resource shortages in some cases and/or idle resources in others. Therefore, resources should be utilized efficiently to prevent project failures. Resource leveling is one of the approaches that are used for the management of resources. It aims to minimize fluctuations, peaks, and valleys in resource utilization without changing the completion time of a project and the number of resources required. Although the main principle behind traditional resource leveling is achieving an even flow of resources while the original project duration remains unchanged, the literature supports the need to develop an efficient model that discriminates among the activities that are selected for participation in resource leveling. For this purpose, this study has developed a model that considers the float consumption rates of activities in resource leveling. The float consumption rate is the percentage that is set to determine the maximum amount of float which will be consumed to shift the start time of the activity. The proposed model allows a scheduler to assign float consumption rates to each activity that can be used during the resource leveling procedure. When the required information is inputted, the proposed model automatically changes the required daily resources as it shifts the noncritical activities along their available total float times. The proposed model is expected to minimize the likelihood of severe delays and cost overruns. The model is demonstrated by constructing a network and its resource utilization histograms.

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1 Introduction

In the construction industry, construction projects must be completed within the allocated budget, on schedule, and with good quality. One of the essential factors in accomplishing these project goals is the development of a reliable schedule. To do so, a scheduler should use an appropriate scheduling technique. Therefore, scheduling techniques have been a focus of debate that is of considerable interest to researchers and professionals in the construction industry. Several scheduling techniques are used in construction projects, such as Gantt Chart, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and Line-of-Balance (LOB). Researchers and professionals in the construction industry have acknowledged the importance of scheduling techniques as they become aware of the advantages of using these methods.

The Gantt Chart is a scheduling technique that displays the durations for a set of activities (Naylor, 2012). It has universal appeal as it is graphically the most simple of the scheduling methods. However, the Gantt Chart cannot define individual activity dependencies. Therefore, it cannot be used to calculate the start/finish dates and the float of activities, which in turn makes managing resources difficult (Gould, 2012). Given these shortcomings, network-based scheduling methods, such as CPM and PERT, have been predominantly used for construction projects. A completed network defines all activity dependencies and durations. Even though network-based scheduling techniques are the workhorse of construction schedules, they focus on minimizing project duration rather than dealing with resource constraints and assume that resources are unlimited (Hariga and El-Sayegh, 2011). Moreover, they are inadequate for construction projects involving repetitive sequences of activities (e.g., railways, tunnels, high-rise buildings, pipelines, and highways) because of difficulties in the visualization of a large network that consists of repetitive activities. Therefore, scheduling techniques that are known under the generic term "linear scheduling methods" have been developed as an alternative to network-based scheduling methods (Arditi et al., 2002). All linear scheduling methods can essentially be traced back to LOB (Arditi et al., 2001). LOB, by its very nature, minimizes project duration according to the constraints on resources. However, it does not inherently minimize fluctuations in resource utilization without changing the project duration. In other words, a scheduler needs an additional algorithm to level resources in an LOB schedule. Therefore, a number of researchers have attempted to develop resource leveling models to utilize resources efficiently in LOB schedules. For example, Damci et al. (2013a) developed a genetic algorithm-based resource leveling model for LOB schedules that is based on the "natural rhythm" principle, according to which a crew of optimum size is able to complete an activity in the most productive way. However, the proposed model cannot handle multiresource leveling. Therefore, Damci et al. (2013b) modified the proposed genetic algorithm-based resource leveling model to handle multiresource leveling in schedules established by using LOB methodology. Even though this modification allows handling multiresource leveling, it does not consider the impact of different objective functions. To fill this gap, Damci et al. (2016) investigated the impacts of using different objective functions in leveling resources in schedules established by using LOB methodology.

CPM has been the most widely used scheduling technique since the 1950s. Therefore, this study focuses on CPM rather than other techniques. Even though CPM is popular in the construction industry, it has a crucial shortcoming as it assumes that resources are unlimited (Hariga and El-Sayegh, 2011). In construction projects, resources are constricted, and these limited resources may be required by several activities concurrently. Ignoring this limitation on resources may lead to shortages and idleness, which may, in turn, cause severe delays and cost overruns resulting from issues such as shortage costs and penalties. Therefore, the efficient utilization of resources may help to avoid project failures. At this point, a question arises as to how to utilize resources efficiently.

Two common approaches are used for managing resources in network-based schedules: (1) resource allocation (a.k.a., resource-constrained scheduling) and (2) resource leveling (a.k.a., resource smoothing). In resource allocation, limitations on resources are assumed. However, the project duration is flexible. This approach attempts to minimize project duration according to the constraints on resources (Senouci and Adeli, 2001). Meanwhile, resource leveling assumes that sufficient resources are available. However, the project duration is fixed (Hashemi Doulabi et al., 2011). The main goal of resource leveling is to minimize fluctuations in resource utilization without changing the completion time of a project and the number of resources required (Son and Skibniewski, 1999; Christodoulou et al., 2009; Hariga and El-Sayegh, 2011; Hashemi Doulabi et al., 2011). To achieve this goal, the start times of the noncritical activities are shifted along their available float times (Lu and Li, 2003). However, if one reviews *A Guide to the Project Management Body of Knowledge* (*PMBOK*) published by Project Management Institute (2017), one will see that the definitions of resource allocation and resource leveling are different from the ones made in the literature of construction management. In *PMBOK*, resource leveling is used for minimizing the project duration according to the constraints on resources (known as resource-constrained scheduling or resource allocation in the literature of construction management), while resource smoothing is used for minimizing fluctuations in resource utilization without changing the completion time of a project and the number of resources required (known as resource leveling in the literature of construction management). The definitions used in the literature of construction management are preferred in this study.

In a typical resource leveling problem, the float times of noncritical activities that are derived from basic CPM calculations are used without considering the schedule flexibility. However, the excessive consumption of the float times of noncritical activities may result in severe delays. The specific question to be answered here is: "Why do construction researchers and professionals ignore the schedule flexibility in resource leveling even though it is of great value in preventing severe delays?" Perhaps, this shortcoming is caused by the lack in the number of studies that focus on resource leveling models that allow a scheduler to achieve a balance in resource utilization and schedule flexibility. Indeed, a review of the literature on resource leveling in construction projects reveals a limited number of studies that focus on leveling resources while considering the schedule flexibility.

The study presented in this paper is initiated as a response to the lack of recognition that schedule flexibility in resource leveling models has received over the years. Therefore, the main objective of this study is to develop a resource leveling model in which a scheduler can assign float consumption rates to each activity to achieve a balance in resource utilization and schedule flexibility. The research presented in this paper contributes to the body of knowledge by showing that resource leveling can be performed without sacrificing schedule flexibility. In other words, this study proves that a scheduler can assign different float consumption rates to each activity while ensuring that schedule flexibility is not diminished. The study (1) proposes a resource leveling model in which a scheduler can assign float consumption rates to each activity and (2) demonstrates the positive impact of assigning different float consumption rates to each activity in terms of schedule flexibility.

Understanding the positive impact of assigning different float consumption rates to each activity on schedule flexibility can be useful for researchers and professionals in the construction industry. Armed with such knowledge, schedulers may prevent severe delays in construction projects.

This paper is the revised version of the paper that has been published in *the Proceedings of the Creative Construction Conference 2019* (Damci et al., 2019). The introduction section has been revised to provide a better understanding of the justification and objective of this research. New references have been added to improve the literature review and to address the importance and contribution of this paper to the existing body of knowledge. In the conclusions section, the future direction of this research has been clearly stated.

2 Research methodology

Achieving a balance in resource utilization and schedule flexibility is one of the factors that may help in developing reliable schedules. Therefore, this study intends to develop a model in which a scheduler can level resources by achieving a balance in resource utilization and schedule flexibility. To achieve this objective, the following tasks were performed:

1) Reviewing the literature on resource leveling in network-based schedules to establish a justification for the research showing that schedule flexibility in resource leveling is mostly ignored;

2) Developing an Excel-based model for the resource leveling of network-based schedules that allows a scheduler to assign float consumption rates to each activity to achieve a balance in resource utilization and schedule flexibility;

3) Finding a network from the literature to use in the demonstration of the impacts of using float consumption rate on resource utilization;

4) Determining the total duration, the critical path, start/finish times of activities and activity floats through basic CPM scheduling calculations using the Excel-based model;

5) Identifying the particular activities that are eligible for resource leveling according to their floats and generating a resource utilization histogram before resource leveling for the example network;

6) Running the proposed model for resource leveling by using the example network found from the literature;

7) Generating the resource utilization histogram after performing resource leveling and comparing the resource utilization histograms plotted before and after performing resource leveling.

3 Literature review

Several studies have been conducted to solve resource leveling problems since the 1960s. Studies conducted by Burgess and Killebrew (1962), Wagner et al. (1964), Ahuja (1976), Popescu (1976), and Wiest and Levy (1977) are among the earliest attempts to propose resource leveling models. All of them are focused on the traditional resource leveling approach that assumes a resource level thought to be satisfactory. Then, such approach assesses the resource demand against this assumption on a predetermined time-interval basis. Unlike the earliest attempts in the resource leveling literature, Harris (1978) proposed a resource leveling model called “minimum moment algorithm”, which offers a different approach for resource leveling by minimizing the moment of the resource histogram around the horizontal axis. Notably, the minimum moment algorithm found in the resource leveling literature has been widely used as much as the traditional resource leveling approach. Despite its popularity, this algorithm has shortcomings, as it assumes that activities cannot be interrupted and resource assignments for each activity are considered constant. A number of researchers (Harris, 1990; Hiyassat, 2000; 2001; Christodoulou et al., 2009) have modified the approach to overcome the deficiencies of the minimum moment algorithm. Over the years, researchers have also used different methods to solve the resource leveling problem, such as integer linear programming (Easa, 1989), genetic algorithms (Hashemi Doulabi et al., 2011; Ponz-Tienda et al., 2013; Damci and Polat, 2014; Kyriklidis et al., 2014; Benjaoran et al., 2015), simulated annealing (Son and Skibniewski, 1999; Anagnostopoulos and Koulinas, 2010), particle swarm optimization (Qiao and Li, 2018), ant colony optimization (Christodoulou et al., 2010; Kyriklidis et al., 2014), entropy maximization method (Christodoulou et al., 2010), and neural networks (Savin et al., 1996; Senouci and Adeli, 2001). Each of these methods has its own advantages and disadvantages. Regardless of the methods used to solve the resource leveling problem in these studies, all of these studies provide invaluable information about solving the resource leveling problem in the construction industry.

The main objective of this literature review is not to describe or summarize all the resource leveling models in the literature but to summarize the studies focused on resource leveling models that attempt to consider the schedule flexibility. Even though researchers have attempted to solve the resource leveling problem by offering different approaches, most of these attempts have ignored the notion that the float used in resource leveling provides flexibility for both contractors and owners. In other words, the float is commonly considered as an asset by contractors and owners in the construction industry (de la Garza et al., 2007). From the perspective of contractors, they need the float to have schedule flexibility. However, owners need the float to be able to request for changes without having delays in the project completion (Ammar, 2003). Given the importance of the float for both contractors and owners, float ownership has been a focus of debate that is of considerable interest to researchers and professionals in the construction industry. Several researchers have proposed various approaches for float allocation on the basis of the responsibilities of the parties (Householder and Rutland, 1990), a pre-agreed ratio (de la Garza et al., 2007), the amount of risk owners and contractors encounter in the project (Al-Gahtani, 2009), and the idea that no one has the right to use the float (Ponce de Leon, 1986). Regardless of who owns the float in a construction project, the consumption of the float may have a negative impact on the successful completion of the project. Indeed, studies exist revealing that float consumption may have a negative impact on project goals (e.g., to complete construction projects within budget and on schedule). For example, Gong and Rowings Jr (1995) proposed that a safe float range for noncritical activities should be used to avoid severe delays on the project completion time. Sakka and El-Sayegh (2007) stated that float consumption may have a negative impact on the overall cost of a project.

In sum, the review of the current literature on resource leveling reveals that researchers ignore the fact that a scheduler should achieve a balance in resource utilization and schedule flexibility while solving the resource leveling problem. Indeed, El-Sayegh (2018)'s work is the only study that focused on trade-offs between resource leveling and schedule flexibility. The author proposed a nonlinear integer programming model that solves the resource leveling problem while incorporating float loss cost and used the float commodity approach suggested by de la Garza et al. (1991) to quantify the float loss cost. The findings revealed that the proposed resource leveling model decreases the fluctuations in resource utilization while improving the probability of project completion successfully. Even though El-Sayegh (2018)'s study attempts to achieve a balance in resource utilization and schedule flexibility, the impact of float consumption on schedule flexibility is evaluated by float loss cost. In other words, one needs the cost data to use this model. Hence, the literature supports that a model that provides a tool for adjusting float consumption rates without the need for float loss cost data must be developed. Therefore, the main objective of this study is to develop a resource leveling model in which a scheduler can assign float consumption rates to each activity to achieve a balance in resource utilization and schedule flexibility.

4 Proposed resource leveling model

In this study, Visual Basic Programming Language is integrated with Microsoft (MS) Excel to develop a resource leveling model. An Excel-based approach has been selected because it is reliable. One can observe the performance of the program in every step of the process.

The proposed model consists of two modules. The first module performs basic calculations to set up a CPM schedule (Fig. 1). In this module, information about activity codes or activity names A_i (i = 1, 2,..., n), the duration of each activity (d_i), the precedence relationships, and the number of resources used in each activity (NR_i) are inputted by the scheduler. After inputting the necessary information, the module automatically calculates the start/finish times (ES_i, EF_i, LS_i, LF_i), floats of activities (TF_i, FF_i) in the network, and the total project duration. Once the start/finish times and floats of all activities are determined, an initial CPM network and its resource histogram can be plotted, which uses the specified resources in each activity.

The second module of the model deals with resource leveling (Fig. 2). Four consecutive steps are followed in the development of the resource leveling module, namely, (1) specifying the MS Excel cells that represent the variables, (2) defining the constraints C_j (j = 1, 2,..., m), (3) specifying the objective function (Z), and (4) assigning float consumption rates FCR_k (k = 1, 2,..., l) to each activity. The first step involves defining the MS Excel cells that represent the variables, which are the start times of the noncritical activities. These noncritical activities have a total float that makes them eligible for resource leveling. The total float is the time by which the completion of an activity can be delayed beyond its earliest finish time.

The constraints for resource leveling is specified in the second step. If an activity is eligible for resource leveling, then the first constraint ensures that the start times of this activity may assume only integer values within the limitations of its total float as expressed in Eq. (1).

$$\text{Early start time} \leqslant \text{Start time of the activity} \\ \leqslant \text{Early start time} + \text{Total float}. \tag{1}$$

The start time of an eligible activity is shifted forward or backward by using the total float. However, the total float does not only associate with any specific activity on the same path in a network because it is an attribute of the path in that network (Prateapusanond, 2003). In other words, the total float is shared with other noncritical activities on the same path in a network. If a scheduler ignores the sharing of the total floats, a violation of precedence relationships may occur. Therefore, the resource leveling module must also ensure that the precedence relationships between network activities are not violated when the total float of an activity is used for shifting its start time. The second constraint prevents violating the precedence relationships between network activities by recalculating the start/finish times and floats of activities after using the

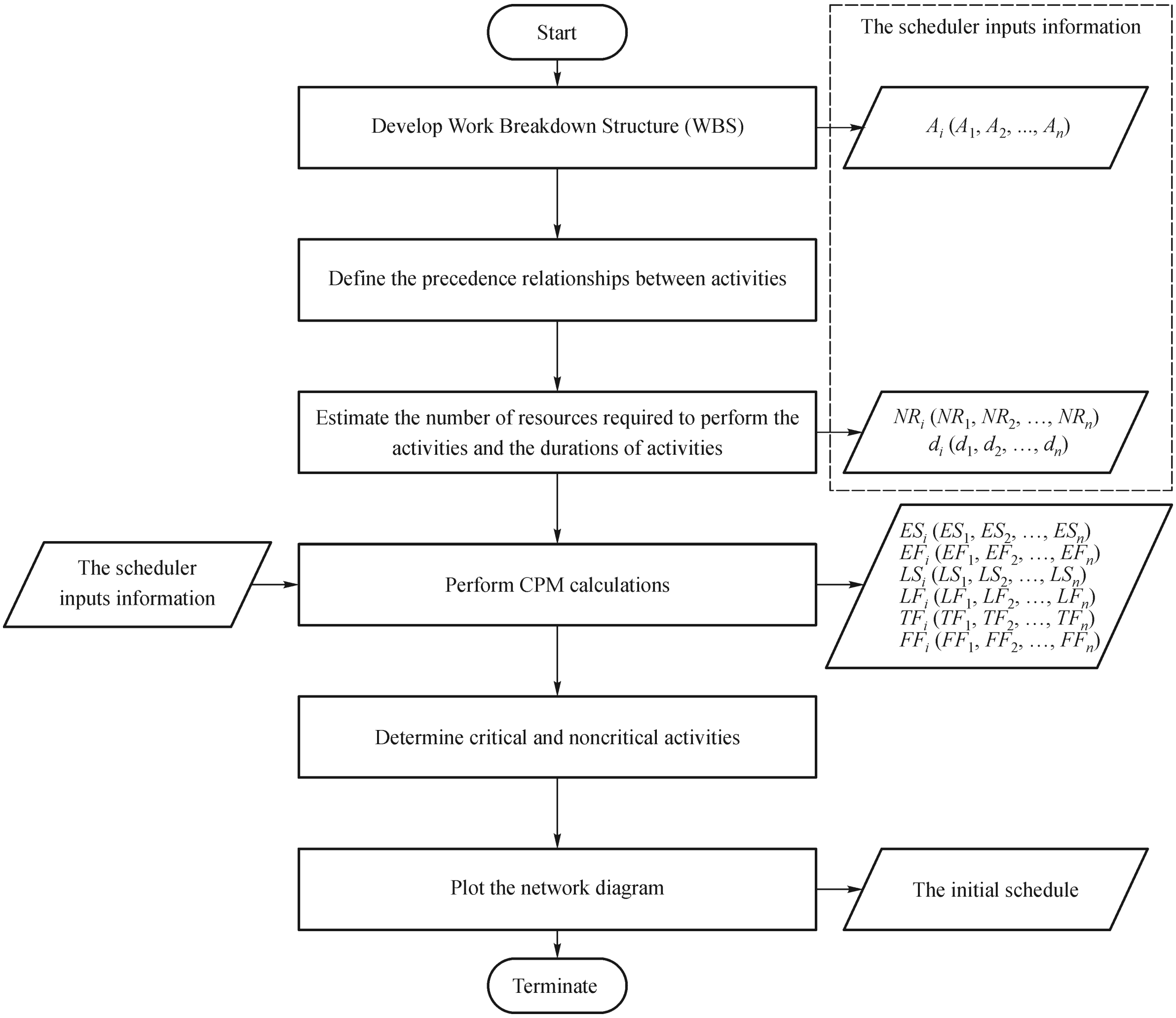

Fig. 1 Flowchart of the first module.

float of activities. Thus, shifting the start times of the noncritical activities within the limitations of their total floats does not violate the precedence relationships in the network. Moreover, the second constraint that prevents violating the precedence relationships between network activities is unnecessary if free float is used. In other words, shifting the start times of the noncritical activities within the limitations of their free floats, by its very nature, does not violate precedence relationships between network activities. Nevertheless, using free float to shift the start times of activities may limit the number of possible solutions that can be obtained in resource leveling compared with using total float. A noncritical activity may have total float even if it does not have free float, but not the other way around. Therefore, the total float in this study is used in resource leveling to increase the number of possible solutions that can be obtained.

In the third step, the objective function for resource leveling process is determined. Various objective functions are used in previous studies to perform resource leveling (Damci et al., 2016). If one reviews these objective functions, one will notice that each of these objective functions have different mathematical formulations. However, all of them have a common objective of providing a smooth resource distribution. In this study, the minimization of the sum of the absolute deviations between daily resource requirements and the average resource requirement is selected as the objective function. It is one of the most commonly used objective functions for resource leveling (Hashemi Doulabi et al., 2011; Damci and Polat, 2014; Damci et al., 2016). An MS Excel cell is set up to represent the objective function in Eq. (2).

$$Z = \min\sum_{i=1}^{T} |R_i - A_{\mathrm{rr}}|, \tag{2}$$

where i is the day under consideration, T is the duration of the project, R_i represents the resources required on day i, and A_{rr} stands for the average resource usage.

Determining the preferred float consumption rate is the final step in the development of the resource leveling

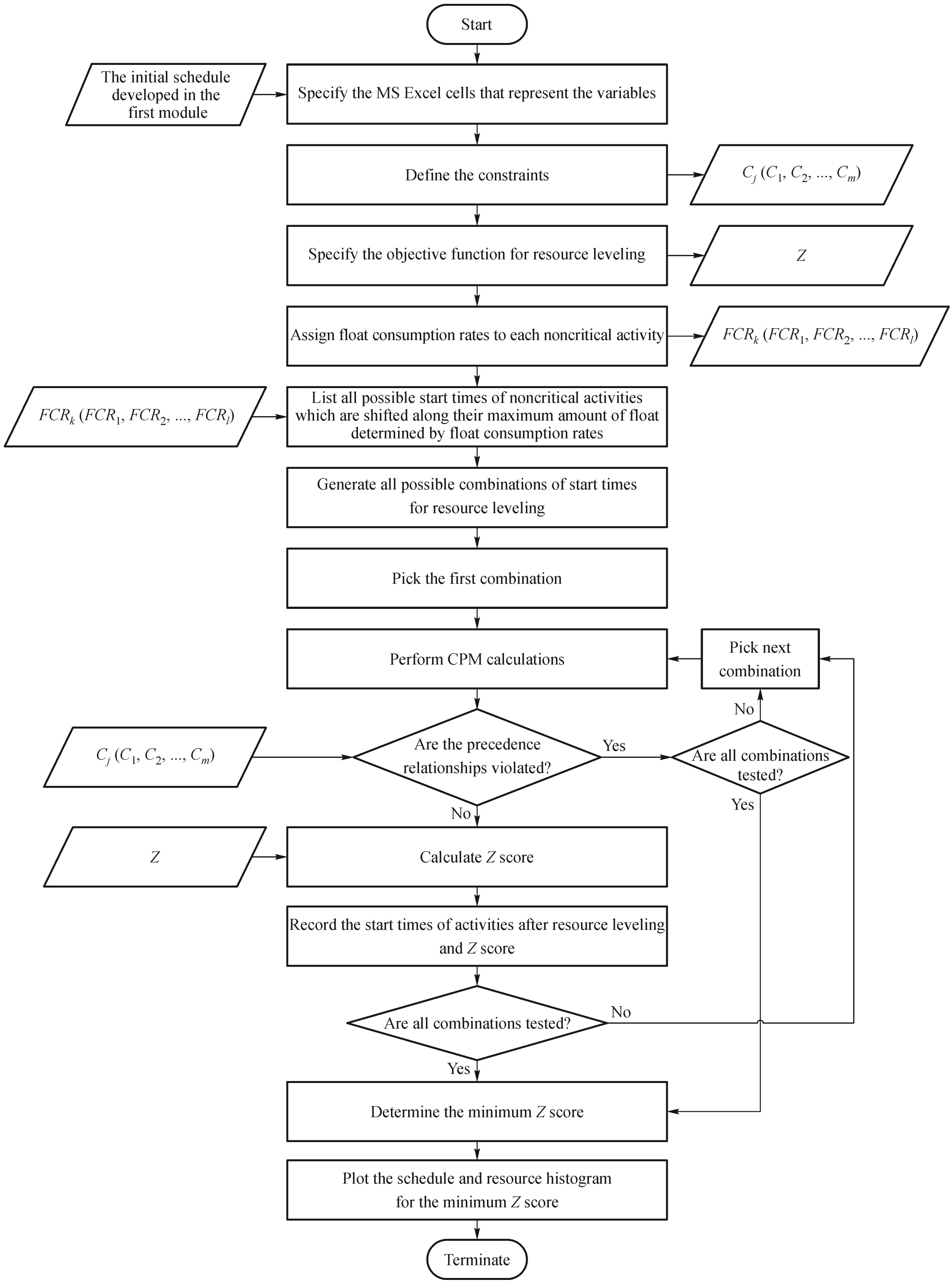

Fig. 2 Flowchart of the second module.

module. The float consumption rate is the percentage that is set to determine the maximum amount of float that will be consumed to shift the start time of the activity. The resource leveling module allows a scheduler to assign float consumption rates to each activity according to a preferred criterion. For example, a scheduler may pursue a strategy implying that additional attention should be paid to complex activities because it is more likely to have a delay on these activities due to their complexity. Therefore, to prevent delays in these activities, a more complex activity deserves a lower float consumption rate in leveling compared with a less complex activity. In sum, one of the most important advantages of the proposed model is that it provides flexibility to a scheduler to pursue different trade-off strategies in resource leveling.

When the required information is inputted, the proposed model automatically changes the required daily resources as it shifts the start times of noncritical activities. Notably, the start times of noncritical activities are shifted along their maximum amount of float determined by float consumption rates. Thus, the model finds the optimum start times of activities to level resource usage. It also automatically generates the schedule and the resource histograms after resource leveling. The total project duration, the precedence relationships between activities, and the durations of activities remain unchanged after resource leveling. However, the proposed model also has limitations, as it does not consider the point-to-point relations that are claimed to be better than the traditional precedence relationships of CPM (Hajdu, 2015; 2018). Assessing the point-to-point relations, different objective functions for resource leveling and multiple resources are potential improvements for this model.

5 Implementation of the model: Example network

The illustration of the proposed model can be best demonstrated by an example. A network from the literature is used for this purpose (Christodoulou et al., 2009). The network consists of 11 activities and requires a single type of resource. Even though other resources may be necessary for completing the activities, only a single resource type is considered in this study for demonstration purposes. The information for each activity concerning precedence relationships, durations (in days), and daily resource requirements is shown in Fig. 3. When the scheduling module of the model is run, the early start/finish times, early/late finish times, and total floats of activities are calculated (Fig. 3). The schedule and resource histogram before resource leveling are presented in Figs. 3 and 4. The sum of the absolute values of the deviations between resource usage on any day and the average resource usage is 69 for the initial resource histogram (Fig. 4).

After plotting the initial schedule and resource histogram, noncritical activities are automatically identified by the scheduling module. Before running the resource leveling module, the model asks for assigning a float

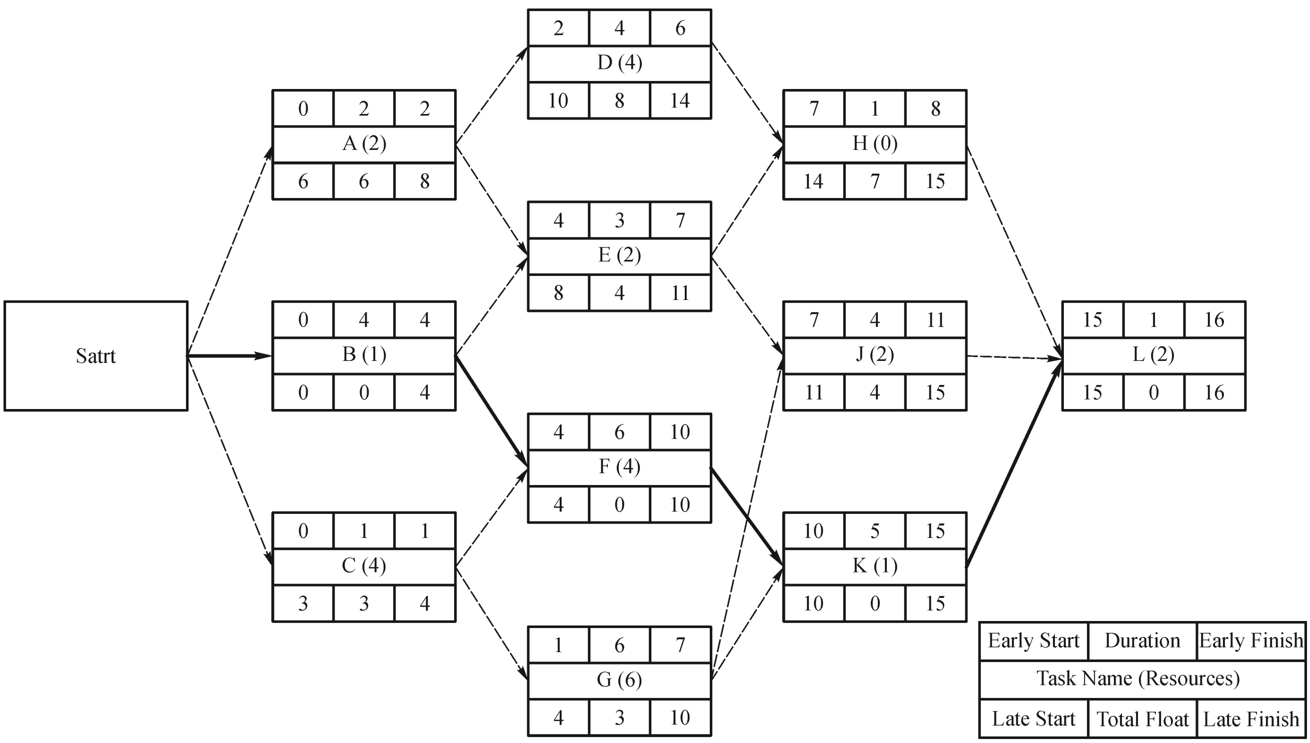

Fig. 3 Network before leveling.

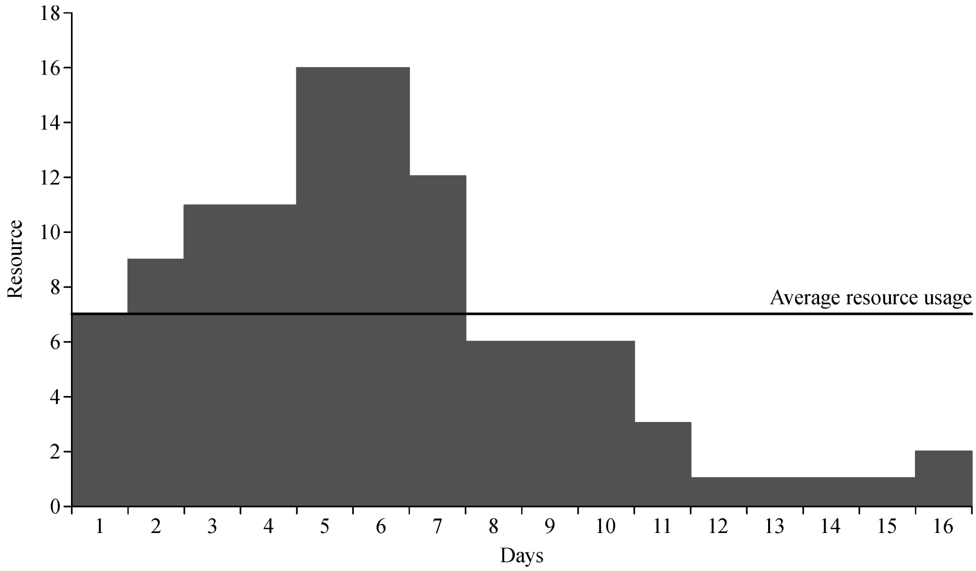

Fig. 4 Resource histogram before leveling.

consumption rate to these activities. In the resource leveling module, the scheduler is allowed to assign float consumption rates to each activity according to a preferred criterion. In this example, the maximum rate is set as 90% for the float consumption of the activities that are scheduled to start before and on the eighth day. In other words, setting a float consumption of 90% implies that an activity that is scheduled to start in the first half of the project cannot consume more than 90% of its float in resource leveling. In contrast, a lower maximum float consumption rate (i.e., 50%) is assigned to the activities that are scheduled to start after the eighth day. This float consumption rate implies that an activity that is scheduled to start in the second half of the project cannot consume more than 50% of its float in resource leveling (Scenario 1). The preferred trade-off strategy intends to provide flexibility to the activities scheduled to be completed in the second half of the project. Providing this flexibility may help in preventing severe delays in the project completion, which improves the project performance in return.

Once all the parameters are set, the resource leveling module is run. Resource leveling is made within the completion time of the project (i.e., 16 days) and by ensuring that the interdependencies are not violated. The schedule and resource histogram generated after resource leveling are presented in Figs. 5 and 6. After resource leveling, the sum of the absolute deviations between the daily resource usage and the average resource usage is reduced from 69 to 35, which corresponds to an improvement of 49% (Table 1). Thus, one of the most important benefits of the proposed model is that it provides a smooth resource histogram while maintaining the schedule flexibility. Notably, if this trade-off strategy is ignored, the resource histogram can be smoother, but the schedule flexibility will suffer. Implying this trade-off strategy provides schedule flexibility because none of the activities consume all their available floats.

The model is also run with a float consumption rate of 100% for all activities in the network (Scenario 2). Using a float consumption rate of 100% is a trade-off strategy that attaches more importance to resource utilization than to schedule flexibility (Fig. 7). Indeed, after the resource leveling, the model generates a better resource utilization histogram than the one obtained by assigning a lower float consumption rate to the activities in the network. The sum of the absolute deviations between daily resource usage and average resource usage is reduced from 69 to 25, which corresponds to an improvement of 64% (Table 1). This improvement is better than the one obtained by using float consumption rates of 90% and 50% for activities that are scheduled to start in the first and second half of the project, respectively. Even though this strategy provides a better resource utilization in terms of decreasing the fluctuations in resource usage, only two activities (i.e., Activities C and G) with available float after resource leveling remain (Figs. 7 and 8). The findings reveal that an extra 15% improvement (i.e., 49% vs. 64%) in resource utilization has been gained in return of losing schedule flexibility.

To compare the performance of the proposed model with that of an alternative one, the network used in this study is also established by MS Project. MS Project is selected as an alternative because it is one of the most popular scheduling software packages used by professionals. After resource leveling, the sum of the absolute deviations between daily resource usage and average resource usage is reduced from 69 to 37, which corresponds to an improvement of 46% (Table 1). According to this result,

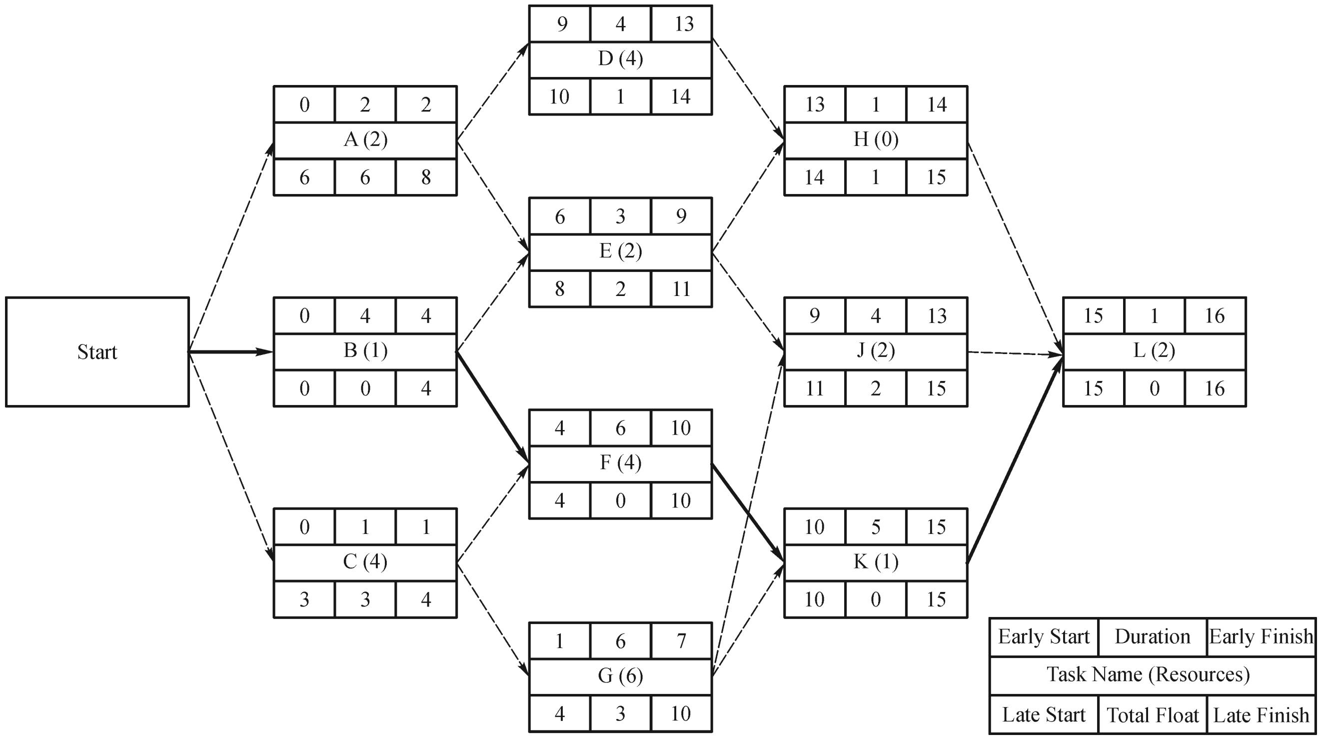

Fig. 5 Network after leveling with float consumption rates of 90% and 50%.

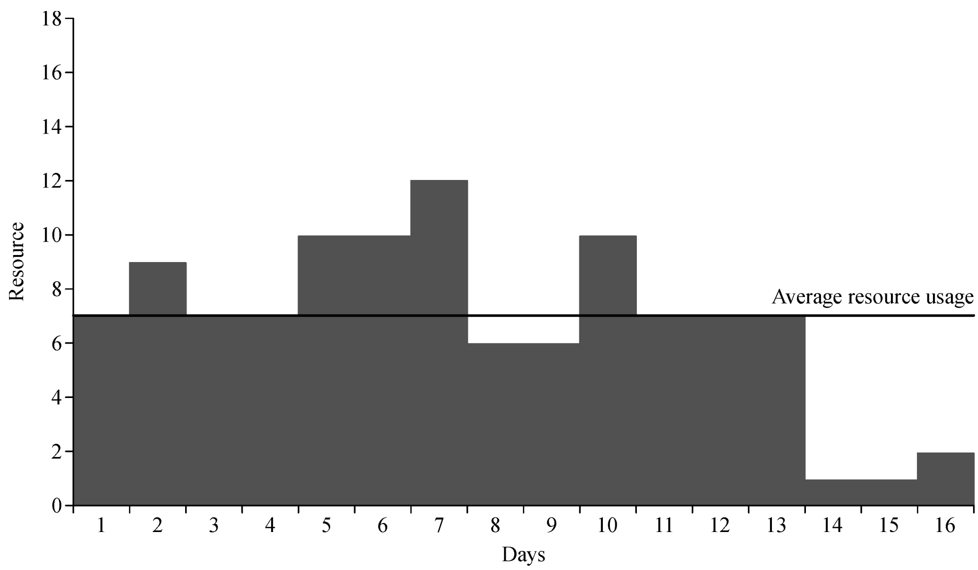

Fig. 6 Resource histogram after leveling with float consumption rates of 90% and 50%.

the improvement of the proposed model (49% in Scenario 1 and 64% in Scenario 2) is better than the one obtained by MS Project. In other words, when resource leveling is performed by MS Project, the proposed model generates a better resource utilization histogram than the one obtained by MS Project (Figs. 9 and 10).

Although the main idea behind leveling resources with and without a float consumption rate is the same, namely, achieving an even flow of resources while the original project duration remains unchanged, each of them aims to pursue different strategies and generates different resource utilization histograms. Therefore, a scheduler should be aware of the possible outcomes of using float consumption rate and carefully select the one that yields the resource utilization histogram that fulfills the special requirements of the project.

Table 1 Percentages of improvement

	Number of noncritical activities	$Z=\min\sum_{i=1}^{T}\lvert R_i - A_{\rm rr}\rvert$	Improvement percentage (%)
Before leveling	7	69	–
After leveling with float consumption rates of 90% and 50%	7	35	49
After leveling with a float consumption rate of 100%	2	25	64
After leveling by MS Project	3	37	46

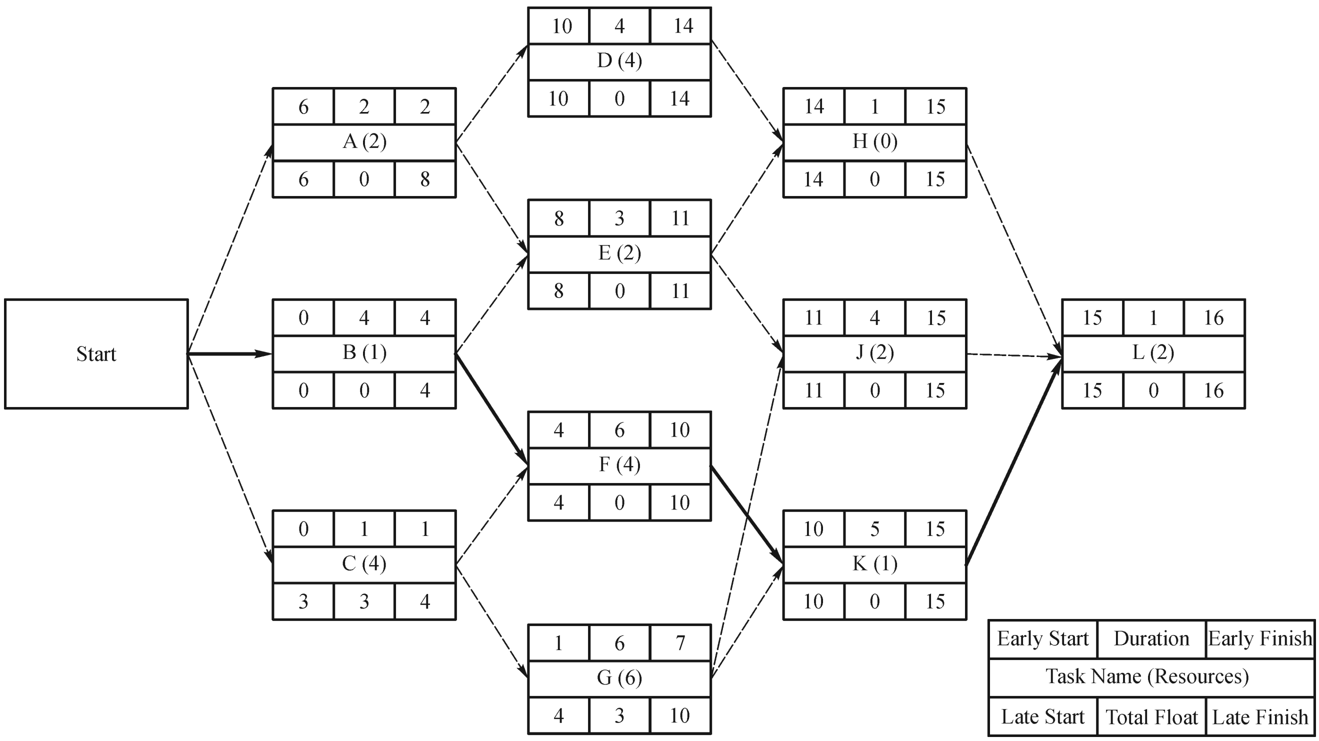

Fig. 7 Network after leveling with a float consumption rate of 100%.

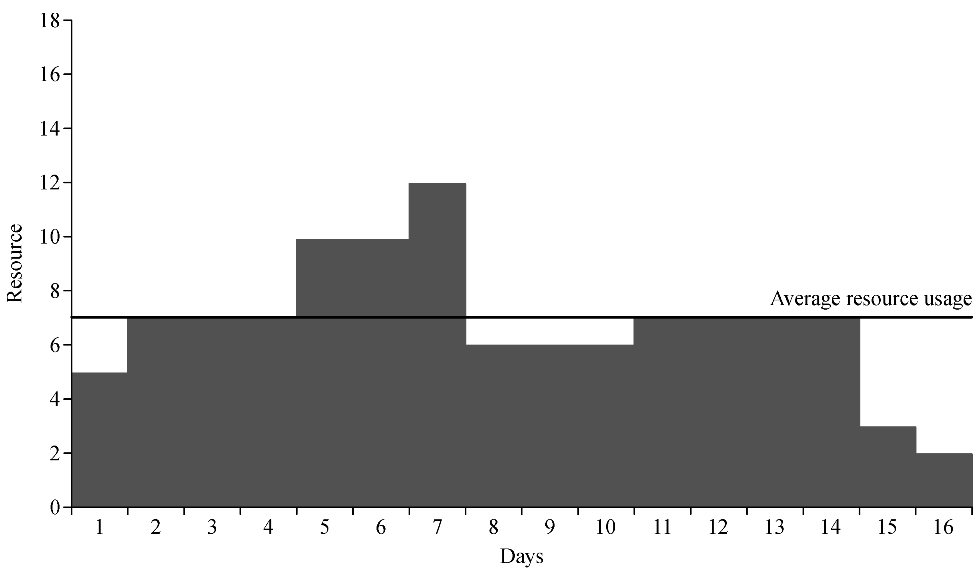

Fig. 8 Resource histogram after leveling with a float consumption rate of 100%.

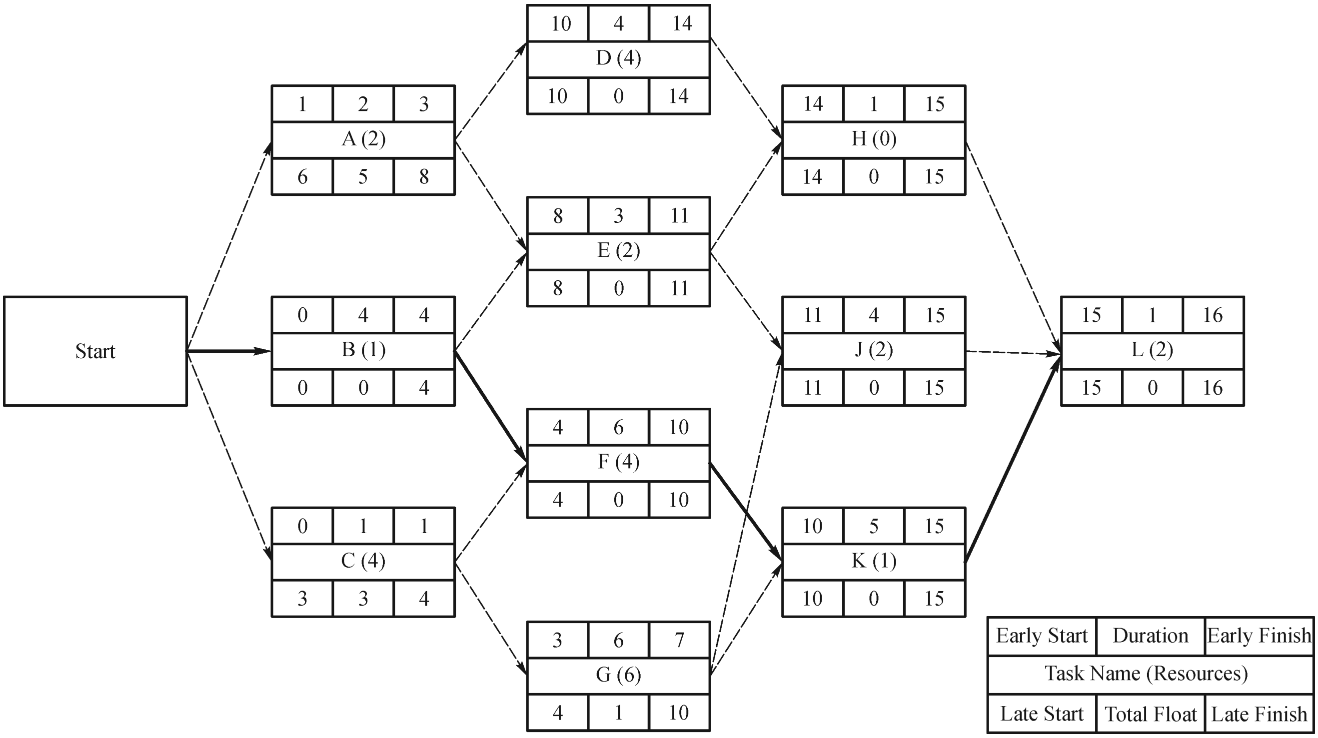

Fig. 9 Network generated by MS Project after leveling.

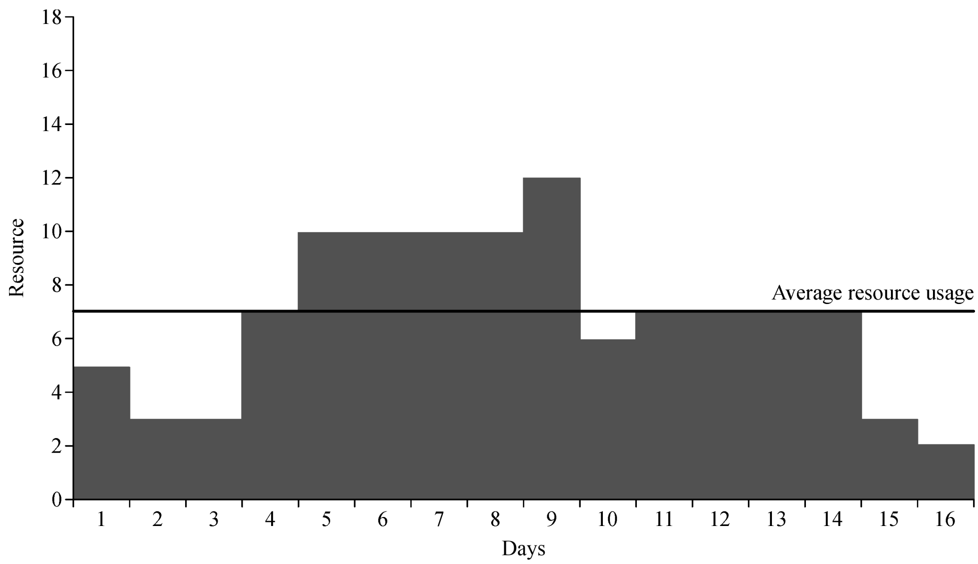

Fig. 10 Resource histogram generated by MS Project after leveling.

6 Conclusions

The use of all available float of activities in a project can easily result in severe delays, which may lead to a failure in achieving project goals. The literature review reveals that only a limited number of studies focus on trade-offs between resource leveling and schedule flexibility. However, in these studies, float loss cost has been considered instead of a float consumption rate. To fill this gap, an Excel-based resource leveling model that allows a scheduler to assign float consumption rates to each activity according to a preferred strategy is proposed in this study. Thus, a scheduler can achieve a balance in resource utilization and schedule flexibility. The proposed model has two modules, namely, (1) scheduling module and (2) resource leveling module. A scheduler does not need an extra scheduling software because the scheduling and the resource leveling are handled by the proposed model. An example network from the literature is used to demonstrate the application of the proposed resource leveling model. Indeed, the model provides a smooth resource histogram while maintaining the schedule flexibility. However, the proposed model has limitations, as it considers only one objective function. It assumes that resource assignments for each activity are constant. Moreover, it does not allow activity interruption and cannot handle multiresource leveling. It also does not consider the maximal relationships, point-to-point relationships, continuous relationships, Boolean OR relationships, and bidirectional relationships, which are claimed to be better than the traditional precedence relationships of CPM. Developing a model that considers different objective functions, multiple resources, activity interruption, nonconstant resource assignments, and nontraditional relationships is a potential improvement for this study. The proposed model may consume too much time to find the optimal solution on large-scale problems as a great number of activities and dependencies exist among these activities. To overcome this shortcoming, future research can consider using metaheuristics (e.g., genetic algorithms, tabu search, and simulated annealing) to solve large-scale resource leveling problems. In addition, comparing the developed resource leveling model with alternative models can be explored in future research.

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