Developing classical schedule technology

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In order to maximize the efficiency of crew utilization, the schedule of repetitive activities should be resource-driven. In addition, it should satisfy the work continuity in addition to logical sequence. The objective of this paper is to present current development techniques for repetitive construction process. In addition, it includes a general methodology that is easily acceptable by construction managers. The underlying principles that are extensions of the classical scheduling technology can be used in developing a computer program. These principles are discussed.

لزيادة فعالية الانتفاع من أطقم العمالة، فانه يجب تخطيط الأنشطة التكرارية تبعا للموارد الحاكمة. بالإضافة إلي ذلك فانه يجب تحقيق تواصل العمل بالإضافة إلي التتابع المنطقي لأنشطة المشروع. و الهدف من هذا البحث هو استقراء لتطوير التقنيات المستخدمة في جدولة المشرعات ذات الأنشطة التكرارية، و تشتمل أيضا علي تعميم للأنظمة المقبولة للتطبيق بمعرفة مديري المشروعات. وضمنيا يعتبر هذا البحث امتدادا إلي طرق الجدولة الزمنية التقليدية والتي من المكن استخدامها في تطوير برامج الحاسب الآلي، و التي تمت مناقشتها خلال هذا البحث.

Keywords: Construction management, Repetitive construction, Scheduling techniques

1. Introduction

Repeating activities are commonly found in construction industry such as typical floors in multistory buildings, houses in housing developments, stations in highways, pile-driving, production of pre-cast concrete units, meters in pipelines network, long bridges, tunnels, railways, airport runways, or water and sewer mains. These projects are characterized by repeating activities, which in most instances arise from the supervision of a generalized activity into specific activities associated with particular units.

Activities that repeat from unit to unit create a very important need for a construction schedule that facilitates the uninterrupted flow of resources from one unit to the next. It establishes activity-stating times and determines the overall project duration. Hence, uninterrupted resource utilization becomes an extremely important issue [1]. Scheduling the construction operations of this crew should allow its work continuity to enable the crew to finish work on one repetitive unit and then move promptly to the next immediately.

Recent literature and field studies indicate that scheduling of construction projects with repetitive activities can be improved by considering the practical requirements as follows [2].
a. Apply resource-driven methods,
b. Visual presentation of line of balance,
c. Cost optimization,
d. Optimize resource utilization,
e. Acceleration routine, and
f. Integrate LOB/CPM methods.

2. Resource-driven methods

The first scheduling requirement is the application of resource-driven scheduling for repetitive activities that:
(a) Enable crew work continuity to minimize crew idle time [3, 4, 5]; and
(b) Maximize the efficiency of resource utilization [6, 7].

2.1. Linear programming models

A linear programming model to allocate resources in linear construction projects based on resource-hour requirements has been presented [8]. This model is more realistic than any other conventional methods for allocating resources. In addition, it illustrates that the resources, which are available in limited quantities, must be shared and balanced between different activities. The model helps to determine whether it is more economical to invest in additional resources or to introduce work overtime to ensure no waste in resource utilization or delay in project duration.

A new methodology labeled by repetitive project modeling was presented [6]. This model incorporates a graphical technique, which uses the activity time-cost curve (assumed linear relationships), and an analytical technique, which uses the LP to analyze repetitive projects (no interruption were allowed). To use repetitive project modeling, cost and duration for normal and crashed conditions of each activity are required for input data. Those requirements may be difficult to apply to practical construction management. However, if the requirements can be set for the project, this methodology will be a valuable approach.

2.2. Dynamic programming models

Other models were presented to incorporate cost as a decision variable in the optimization process for repetitive projects using a dynamic programming model [9,10]. They could determine optimum crew formation but did not consider work interruptions.

In a similar effort, *N*-state dynamic model was developed to minimize total construction cost, considering both crew formations and work interruptions among limited non-serial activities [11]. None of the cost optimization models mentioned earlier, except for the one developed by previous one [11], could handle non-serial activities. Additionally, the models did not consider project deadline, crew synchronization, and resource constraints, simultaneously.

Such resource-driven scheduling for repetitive activities should be capable of maintaining job logic, crew availability, and crew work continuity; and accounting for practical factors commonly encountered during repetitive construction.

A flexible algorithm based on the resource driven scheduling method was developed to identify the scheduled start and finish times as well as the crew assigned to any activity in repetitive construction projects [7]. The proposed model considers five basic requirements:

a. The type of activity (typical or atypical),
b. The number of crews assigned to work simultaneously on a task,
c. The interruption of crew work continuity,
d. The crew availability period on site and,
e. The order of executing repetitive units.

The scheduling algorithm is carried out in two main stages: the first achieves compliance with precedence relationships and crew availability constraints, and the second achieves compliance with the constraint of crew work continuity. The capabilities of the developed algorithm were illustrated by scheduling a highway project. The scheduling process was done with and without activity interruption to demonstrate that the involvement of interruption times can help reduce project duration also the algorithm allow for user participation in the scheduling process for more flexibility.

Another model was developed which arrange the basic construction process [12]. It is repetitively performed on both the horizontal range among structural units, which identified as work zone and the vertical range among floors within a structural unit.

The model try to minimize the loss in construction cost by optimizing project duration, organization of the work zone, number of crews to be used, proper repetitive number of horizontal work areas in each work zone and rotation technique of crew groups to improve work continuity associated with short duration. The capabilities of the proposed methodology were illustrated by scheduling an apartment house complex consists of eight buildings of fifteen stories with the same structural type. However, there is some limitations in this method, at first cost loss can be greatly reduced only if there is extra time in project completion date in addition this method can't be considered as the optimal solution if all operations have a finish to start relationship and if all operations aren't repetitive.

3. Visual presentation

A major difficulty in preparing the LOB diagram lies in plotting overlapping activities that have the same rate of production. For example, if two consecutive activities are overlapping, it is difficult to differentiate between them unless colored lines indicate them. The choice of the appropriate scale is also critical for better understanding and for communicating the information contained in an LOB schedule. It has been observed that supervisors and subcontractors are more receptive to LOB diagrams than to arrow network diagrams, but are not receptive enough to use them in lieu of bar charts [13, 14, 15, 16, and 17]. The LOB schedule has to be converted into weekly bar charts where critical activities and floats are clearly marked.

The degree of the detail of the LOB diagram must be carefully evaluated. If too many activities are plotted, the diagram becomes a jungle of oblique lines that also sometimes cross each other. An alternative is proposed that displays the LOB diagram of each individual path, one path at a time. The use of color-filled lines as well as vertical and horizontal lines showing the movement of the crews can also help. An experienced scheduler can select an optimum level of detail.

A probabilistic simulation model was developed by using the techniques applicable to the simulation of repetitive construction operations, including a practical example to demonstrate how they can be applied [18].

A prototype was built, fig. 1, to demonstrate the use of features for annotation of 4D models, the associations between the schedule times and building space [19]. This work includes issues such as how best to display additional types of information in a visually rich 3D environment. Also, how can visually assign construction-planning features to CAD components?

4. Cost optimization

Most available scheduling techniques based on the LOB concept have been developed to reduce project duration with little or no regard for project cost. Given the concept of the optimum crew size and the natural rhythm, the cost optimization issue, i.e., finding the shortest project duration for the least total

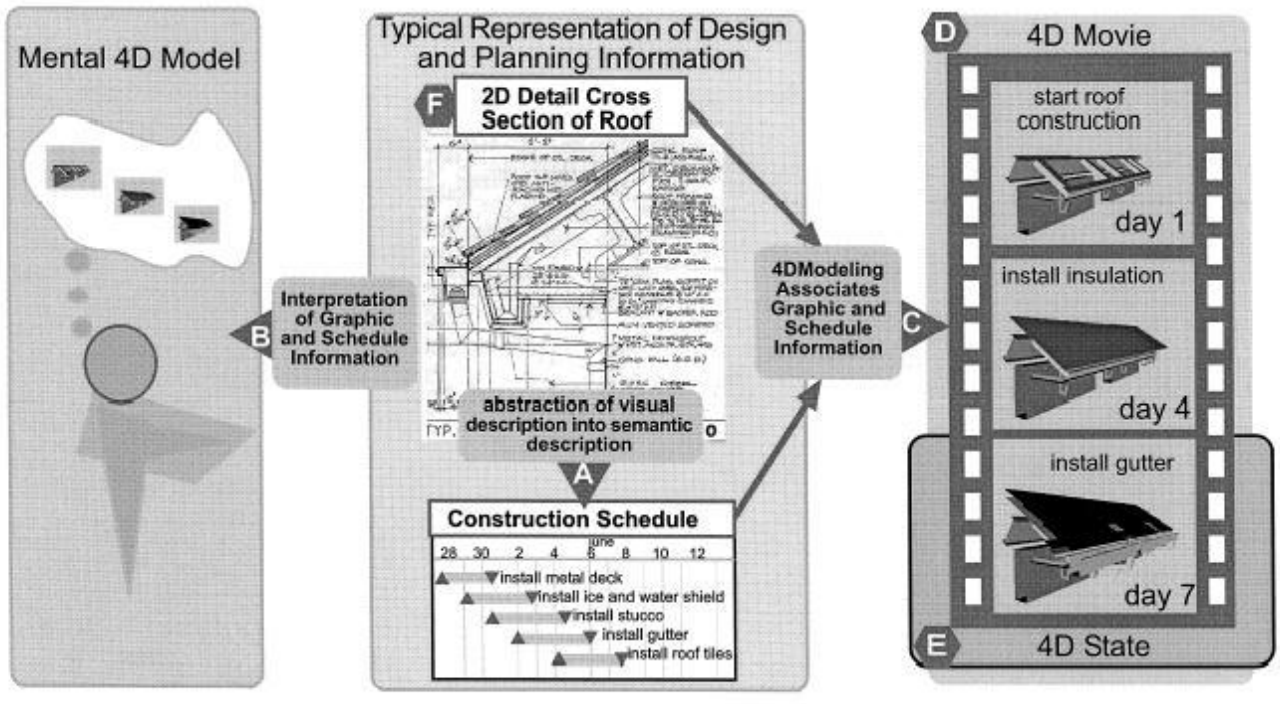

Fig. 1. Traditional planning process vs. 4D modeling process [19].

production cost, becomes obvious; the shortest project duration corresponds to the least cost solution. This can be explained by the utility relationship between direct cost and activity duration. This relationship is linear because an activity's duration can be reduced only in direct proportion to increasing the numbers of crews working on it, with each crew working in a different unit and not interfering with each other.

Minimizing the project duration is a more complex process for repetitive projects than that for non-repetitive ones. For non-repetitive construction projects, the acceleration (crashing) of critical activities often leads to a shorter overall duration for the project. For repetitive construction projects, however, this is not always true due to the compliance with the constraint of crew work continuity. This led to the development of Linear Programming (LP) models and Dynamic Programming (DP) formulations for optimizing the schedule of repetitive construction that are capable of minimizing either the duration or the overall cost of the project. A number of dynamic programming formulations have been developed to optimize the scheduling of this class of projects.

Some researchers focused on:

a. Minimizing project cost [10, 20]; or
b. Minimizing project duration [21, 22].

A DP model for scheduling repetitive projects to minimize overall project duration was presented [21]. However, this model did not consider cost or work interruptions. A modification of *Selinger*'s model was developed later [22], who introduced a two-state variable, *N*-stage dynamic model with the objective of minimization project duration. The state variables represented sets of the activities' durations and interruptions. This model, similar to *Selinger*'s, did not include cost in the optimization process.

These formulations are either one-state variable [21,10] or two-state variable [22,20], aiming to determine the optimum crew formation or the optimum crew formation and the optimum interruption vector, respectively.

Despite the apparent advantages of available two-state variable formulation in minimizing the duration of repetitive construction projects, they require construction planners to arbitrarily specify, prior to scheduling, a set of interruption vectors for each crew formation in the project. Moreover, the mathematical optimization techniques do not guarantee an optimum solution. It may be trapped in local optima [24,25].

A recent development method for searching complex solution spaces for the global optimum was developed by aids of Artificial Intelligence (AI), a non-traditional optimization technique, and Genetic Algorithms (GA) [26].

GA work is emulating the natural evolution in living organisms through a process of crossover and mutation among a group of random parent solutions and cycles of generating and testing offspring solutions until the optimum solution is found. GA has already been applied successfully to numerous areas in civil engineering and construction including time-cost trade-off analysis of non-repetitive projects [27,24,28, and 29].

A dynamic model for scheduling repetitive projects with cost optimization had been presented [10]. The model depends on determining the minimum overall cost of the project for various crew formations assigned for each activity, which represents the first stage, the second stage is to identify the optimum crew formation for each repetitive activity, which leads to the minimum overall cost of the project. To obtain the minimum total cost of the project, the project duration must be reduced which leads to decreasing the indirect costs of the project but will increases its direct cost so the model try to balance between the reduction in indirect costs and the addition in direct costs.

A mathematical model for time-cost trade-off based on the integration between the principles of LOB and CPM [30]. The output of this model is to determine the crashed duration for each activity which corresponding to minimum project total cost.

A non-traditional optimization technique was presented based on GA to develop a practical model for scheduling repetitive construction projects [29]. The objective of this model is to minimize total project cost including direct cost, indirect cost, interruption cost, incentives cost and liquidated damages by determining the optimum combination of construction methods, number of crews and permitted interruption times for each repeti-

tive activity. To achieve this objective a spreadsheet macro was developed to perform the followings:
a. CPM calculations for a single unit to identify the early start and finish times, late start and finish times the free and total float for each activity based on the construction method to be used, additional crews required and interruption times.
b. The line of balance method is used in the calculations to ensure crew synchronization and work continuity.
c. Detailed schedule calculations to correct start and finish times for each activity due to rounding activity production rate. The results of the optimization conducted on the case study introduced prove the robustness of the model and its suitability to large size projects.

5. Resource utilization

One of the main practical requirements in scheduling repetitive construction projects is that ability to optimize scheduling and resource utilization to minimize the project duration [31].

The author developed a tool for time and resource scheduling for repetitive construction projects, this has been done in three stages [32]. This model called modified repetitive project model, which depends on the integration between the principles of line of balance method and critical path method. The output of the model is to determine the crashed duration for each activity which corresponding to minimum project total cost. This model represents a modification to the (RPM) model developed by Reda [6], the advantages of this model that it has fewer variables than (RPM) model and fewer constraints thus saving computation time without scarifying the required accuracy.

A LP model related to the resource allocation problem was proposed [33]. Two models have been developed, the unlimited resource model and resource limited model. the objective of the first model is to determine the early and late start times for each activity based on the availability on unlimited resources while the second model correct the early and late start times based on the required shifting due to limited resources.

A LP model concerning the resource-leveling problem, which differs according to the type of resource, was presented [34]. Three models have been developed using mixed integer programming. The first model called (ORL-1) which tries to minimize the deviations between the resource requirements and the target resource profile. The second model called (ORL-2) aim to minimizing the number of changes in resource profile along the project duration. The third model, which called (ORL-3), tries to build up the resource requirement to a peak and then decreasing gradually. The last model is used when training and licensing for labors is carried out.

An object-oriented model to schedule repetitive construction projects had been presented [35]. The model consider three main practical requirements, the first one is to minimize crew idle time & maximizing resource utilization by using resource driven scheduling method. The second requirement is to optimize the schedule by minimizing the project duration; the third practical requirement is to integrate of repetitive and non-repetitive scheduling techniques in an efficient scheduling model. The model has been developed in three main stages: analysis, design, and implementation. The analysis stage provided an outline of the model classes, their sequence of operations, the design stage provided a detailed design of data members, and their functions, the implementation stage produced a windows application that runs on Microsoft windows.

An automated model for optimizing the resource utilization, which leads to reduction in the duration and consequently the cost of repetitive construction projects, was presented [36]. The model consists of two algorithms: the scheduling algorithm, which identifies the start and finish, times of each repetitive unit in compliance with both the job logic and the crew availability constraints; however, this stage did not necessarily maintain the work continuity constraint for assigned crews. The second stage is the interruption algorithm in which the idle time resulting from the first stage was eliminated by shifting the start of some units to a later date, the required shift of a unit is identified as the summation of all idle times of later scheduled units. This optimization problem was formulated using dynamic programming in two paths. The first path is to identify for each pair of crew formation and interruption vector for any activity in the project (a local optimum predecessor crew formation and interruption vector). The backward path (the global optimum crew formation and associated interruption vector for the last activity) yields the minimum project duration is selected then tracing backward the predecessor local optimum which leads to this minimum duration becomes the global optimum.

6. Acceleration routine

In the last unit of any project, the finish time of the last activity on the critical path indicates the total project duration. The project duration obtained in the first run of the proposed system is the minimum project duration obtained with only one crew used per activity. In most cases, this project duration will exceed the required project completion time. The production rates of selected activities have to be increased in order to reduce the total project duration to the level specified by the contract.

It is assumed that the only way to accelerate production without increasing cost is to increase the number of crews. Other alternatives including overtime, more equipment, and expanded crew size increase the direct cost of an activity because only the optimum crew size can achieve maximum productivity in an activity. Alternatives such as using faster and more efficient equipment and more sophisticated construction methods could accelerate production, but may often be impossible in practice; had a company been in possession of more productive equipment or more advanced construction expertise, it would have used these resources in the first place.

Cost optimization can therefore be achieved by using a multiple of the natural rhythm of the activity because the natural rhythm of the activity is the optimum rate of output that a crew of optimum size can produce. Once the number of crews used in an activity, and by implication its rate of production, is established, it should remain constant throughout the completion of the entire project in order to take advantage of the continuity in the labor force, unless the learning effect requires the disbanding of some crews ahead of project completion. Using partial crews and adjusting production rates up and down during the course of the project by changing the number of crews may increase costs due to the associated disruption.

In the compression analysis, activities on the critical paths of the LOB schedule are compressed in order to meet the required completion date. A priority system that selects the activities to be accelerated is established to perform cost-effective compressions. The number of available crews is the first priority in this selection. If an additional crew is not available, there is no physical way to accelerate the activity. The rates of production of activities constitute the second priority in the selection process. Since the rates of production of activities are first calculated based on only one crew of optimum size, the activity with the longer unit duration has a slower rate of production, which in turn means a higher potential to compress the overall project duration. Once the activity with the longest unit duration is identified, it is compressed by adding a second crew, which doubles its rate of production; in the next iteration, the total duration (over the totality of the units) of this activity drops to half of its original duration.

Another reason why an activity with the longest unit duration (and therefore the lowest production rate) must be compressed first is that increasing the production rate of an activity with shorter unit duration (and therefore a higher production rate) may delay the start time of the succeeding activity and, in turn, increase the total duration of the project.

6.1. Illustrative example

Fig. 2 shows an illustrative example to stuffy the effect of changing production rate on project duration.

Fig. 3 shows that increasing the rate of productivity of Activity “B” (which has the longest duration and therefore the flattest production slope) would enable Activity “C” to start earlier, in this way the total project duration.

On the other hand, in fig. 4, increasing the rate of production of Activity “C” (which does not have the longest duration and the flattest production slope) delays the start time of Activity “E” and ends up increasing the total project duration. Compression analysis of an LOB schedule should consider these possible conditions before increasing the number of crews/ amount of equipment in a particular activity.

An estimated rate of project progress is often required by contract-letting agencies in the form of progress curve (percent of cost). In bar chart development, the percent monthly progress on each activity is often estimated by the scheduler, based on judgment and the classical S-shaped activity tie-progress curve. Progress control by LOB becomes quite efficient, especially when it is used in association with cost data.

7. Integration methods

The last practical requirement in scheduling repetitive construction is the integration of repetitive and non-repetitive scheduling methods in an efficient scheduling model. Repetitive construction projects often include repetitive as well as non-repetitive activities. In a high-rise building, for example, the concrete activity that is repeated in each typical floor can be considered repetitive, while the excavation activity that is performed only once can be considered non-repetitive.

Each of this type requires a unique scheduling technique. Non-repetitive activities can be scheduled using a traditional network-based technique. Repetitive activities, however, require a resource-driven scheduling technique that is capable of maintaining crew work continuity. These two scheduling techniques need to be integrated in an efficient scheduling model [37 to 40].

The Repetitive Scheduling Method (RSM) was represented [41]. It is a schedule graphically as an *X-Y* plot of a series of production lines, each of which show a repetitive activity by using control points and the controlling sequence. This graphically methodology enables a project manger to control the work interruption period by arranging the resource production rate.

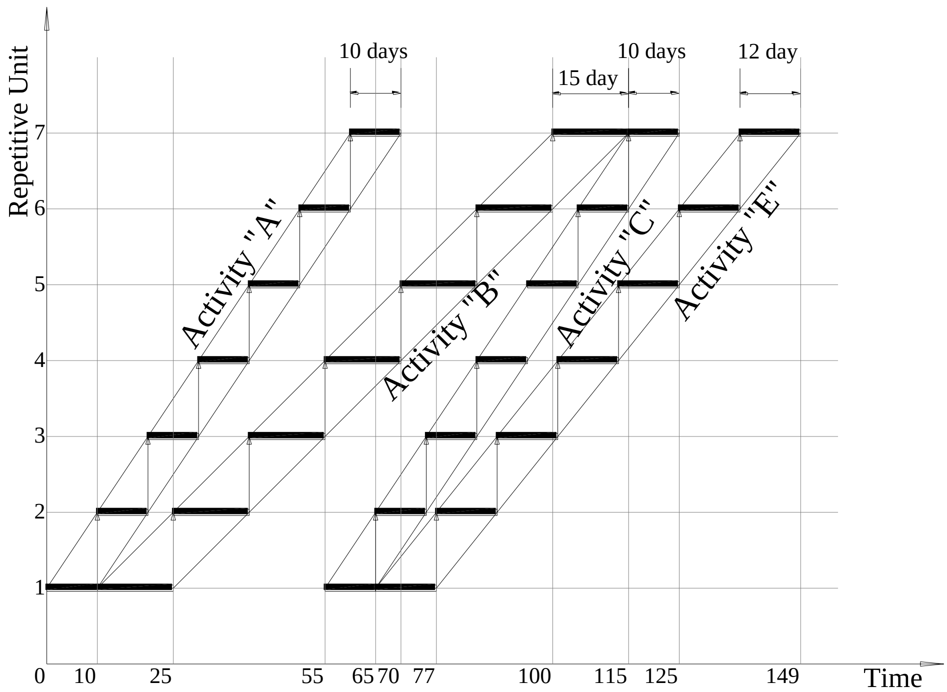

Fig. 2. An illustrative example to study the effect of changing production rate on project duration.

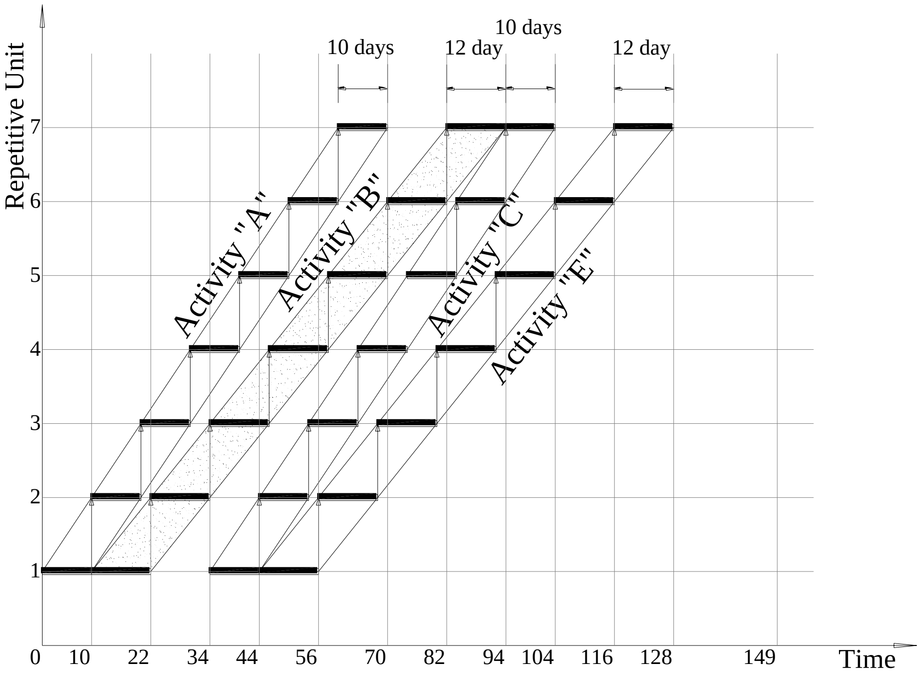

Fig. 3. The effect of increasing production rate for activity B on project duration.

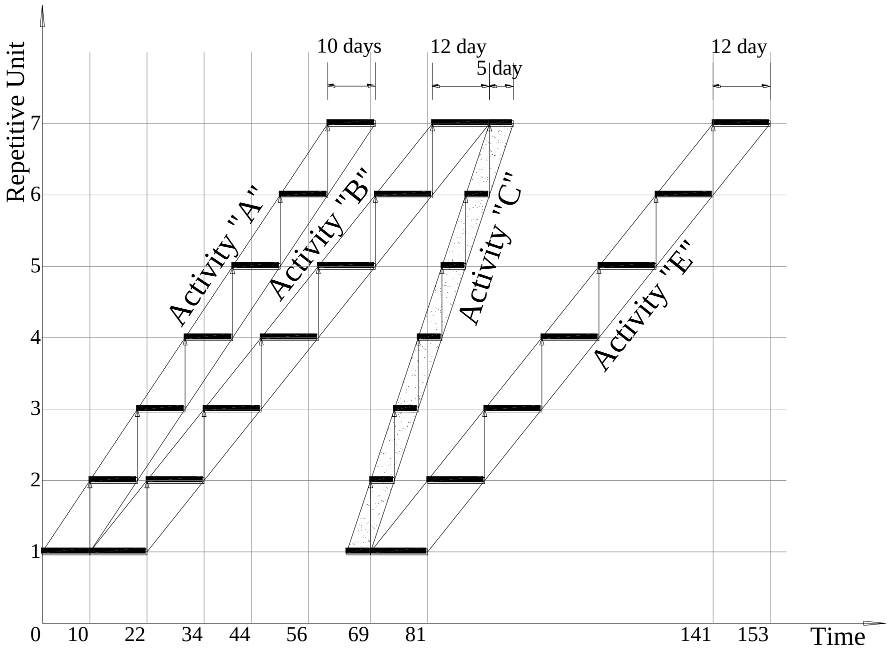

Fig. 4. The effect of increasing production rate for activity C on project duration.

Accordingly, it can be useful for understanding RSM in easy coordinates considering the productivity of resources. Although the RSM uses a new concept for analyzing a repetitive process, the project cost during interruption time and the organization of the crew group to minimize cost are not analyzed in the methodology.

8. Conclusions

The objective of this paper is to survey the different issues, which related to schedule repetitive construction process. It can be used in the development of a computerized scheduling system. Several issues associated with scheduling repetitive construction process have been identifies in this research. Firstly, applying resource-driven scheduling methods, visual presentation of line of balance diagram, optimize project cost, and resource utilization is discussed. Finally, it studied the acceleration routine, and integration scheduling methods.

There is evidence that linear construction has a repetitive nature that does not allow the efficient use of bar charts and network methods, because bar charts and networks sometimes generate inaccurate and misleading information in repetitive situations. Hence, there is a need for more powerful methods of scheduling that will allow the user to make optimum use of time and resources, run the project efficiently, and monitor progress effectively. A computerized system that addresses the issues discussed in this study could be of great value to project managers of repetitive construction.

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