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Schedule Optimization in Resource Leveling through Open BIM Based Computer Simulations

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ABSTRACT: In this research, schedule optimization is defined as balancing the number of workers while keeping the demand and needs of the project resources, creating the perfect schedule for each activity. Therefore, when one optimizes a schedule, multiple potentials of schedule changes are assessed to get an instant view of changes that avoid any over and under staffing while maximizing productivity levels for the available labor cost. Optimizing the number of workers in the scheduling process is not a simple task since it usually involves many different factors to be considered such as the development of quantity take-offs, cost estimating, scheduling, direct/indirect costs, and borrowing costs in cash flow while each factor affecting the others simultaneously. That is why the optimization process usually requires complex computational simulations/modeling. This research attempts to find an optimal selection of daily maximum workers in a project while considering the impacts of other factors at the same time through OPEN BIM based multiple computer simulations in resource leveling. This paper integrates several different processes such as quantity take-offs, cost estimating, and scheduling processes through computer aided simulations and prediction in generating/comparing different outcomes of each process. To achieve interoperability among different simulation processes, this research utilized data exchanges supported by buildingSMART-IFC effort in automating the data extraction and retrieval. Numerous computer simulations were run, which included necessary aspects of construction scheduling, to produce sufficient alternatives for a given project.

KEYWORDS: Urban Renewal, Preliminary Cost Estimation, Unit Space, BIM

키 워 드: 도시재생사업, 개산견적, 단위공간, 빌딩정보모델

1. Introduction

Scheduling is one of the essential parts of most construction projects, but remains a time-consuming, error prone and tedious task done manually. The process involves many different factors such as various activities, sequences/relations, a project deadline, equipment, resource leveling, cost estimation, cash flow, labors and so on while each factor affecting the others simultaneously. This paper focuses on one of the factors, resource leveling in determining the number of daily maximum workers in a project while demonstrating how other factors such as cost estimating, total durations and borrowing costs in cash flow are related to each other in terms of determining the maximum workers in resource leveling. To generate an accurate schedule of a project based on the consideration of the resource leveling, the optimized scheduling process that considers these aspects simultaneously is required. In considering different factors simultaneously, this research ran numerous computer simulations to produce sufficient alternatives for a given project.

In this research, schedule optimization is defined as

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balancing the number of workers while keeping the demand and needs of the project resources, creating the perfect schedule for each activity. Therefore, when one optimizes a schedule, multiple potentials of schedule changes are assessed to get an instant view of changes that avoid any over and under staffing while maximizing productivity levels for the available labor cost.

As an emerging technology facet of the architectural, engineering, and construction (AEC) industry, Building Information Modeling (BIM) plays an important role in helping to resolve the complexity of the scheduling process. Using BIM-produced models, this paper demonstrates automating the generation of construction schedules by retrieving the data (e.g. spatial, geometric, quantity, relationship and material layer set information) stored in a BIM and generating a construction schedule by computing all the necessary activity durations, sequencing rules, multiple considerations in resources, and finally outputting a schedule.

The Industry Foundation Class (IFC) is a standard established by buildingSMART International (previously IAI-International Alliance of Interoperability) to allow for the interoperability between its various commercial software vendors. IFC provides a system containing entities related to building components for extraction of data. Each entity within IFC contains nomenclature related to the component itself, such as IFCSLAB or IFCWALLSTANDARDCASE. This allows for precise extraction of the required data.

As for the resource analysis/management, there are several researchers who worked on the topic. Ibbs and Nguyen (2007) argue that planning involved in resource scheduling can significantly determine the success of a project schedule. In fact, failing to involve resource analysis in the planning of schedules early on can eventually cause even more delays when managers implement "unrealistic resource allocation in downstream work." Castro-Lacouture et al. (2009) also draws on a study by Perdomo-Rivera (2004) that indicates "labor productivity improved by 6% when resources were considered in CPM schedules and an additional 4-6% improvement was obtained when using computerized systems." There is also the need providing multiple construction schedule alternatives in a timely manner. BIM has been used to produce visually construction schedule data, but has been limited in generating different alternatives (Kim et al., 2013).

Borrowing cost and quantity take off (QTO) are additional items related to optimizing a construction schedule. Managing the cash flow in the construction industry is a critical aspect of a construction manager's economic success. Cash flow can also have an effect on whether a construction project is successful or not. Due to the effect cash flow can have on a construction project, researchers have applied cash flow to the construction scheduling process. QTO is an important factor for construction projects. Poor QTO calculations can have a negative impact on the duration of a project, starting with planning and continuing through the construction phase. Commercial products have been developed aid in the QTO estimation. Examples of these programs are AutoDesk's Revit, AutoCAD Civil 3D, Solibri, DDS-CAD and so on. Even though there are many research papers or commercial products related to QTO available, very few have been linked to scheduling efforts.

This research develops a computer simulation algorithm for optimizing the schedule by choosing the maximum number of daily workers in a project while integrating all possible factors, generating multiple results and identifying the most optimal choice by comparing the different outputs. To demonstrate the functionality of optimizing the number of workers through multiple scheduling factors, a prototype system has been developed to exchange BIM representations in IFC with basic building elements such as slabs, walls, doors, windows, roofs, floors, ceilings in two office buildings. However, the application can be extended to scheduling of more complex building with necessary information. After describing this process in detail in this paper, there will be a discussion of a graphical depiction that compares how resource leveling is optimally achieved before and after a resource requirement is declared.

2. Implementating a procedure for automating daily resource leveling

The general progression leading up to a developed resource schedule involves several major stages. Figure 1 shows the proposed system that cycles though the various processes and associating outputs. The processes run from

BIM Model Production in IFC through Cash Flow Analysis. At any step in the process the system can return to a previous step for additional data or analysis and continue through the process. The following sections will discuss how the each consecutive method essentially builds upon the output data gathered from the previous method.

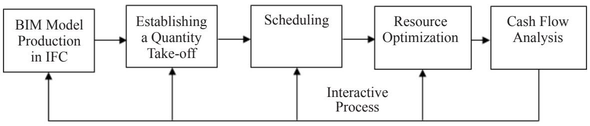

Figure 1. Schedule/Resource Optimizing Process using BIM based Computer Simulations

2.1 BIM Model Production in IFC

This research utilized an international standard format, IFC. Through the IFC, various geometrical and numerical data about the structure and its parts can be extracted and executed through various programs, such as Microsoft Excel and Microsoft Project. After the orientation transformation of a space from a BIM model, each length and name can be extracted from an IFC entity such as IFCSLAB, IFCWALL or IFCWALLSTANDARDCASE.

In Figure 2, an example of a BIM model in Autodesk Revit is shown with a gypsum board wall where the geometric (length: 13.857 feet) and material data (2X4 + ½ Gyp Board) are extracted from a wall element.

2.2 Establishing a Quantity Take-Off

Once identified in IFC, each component within a BIM model is compiled into a quantity take-off and exported to a Microsoft Excel's spreadsheet format. The methods in achieving our quantity take-off rely on the extraction of numerous data that are specific to certain construction components. The displayed chart represents the possible, customized information that can be extracted for the

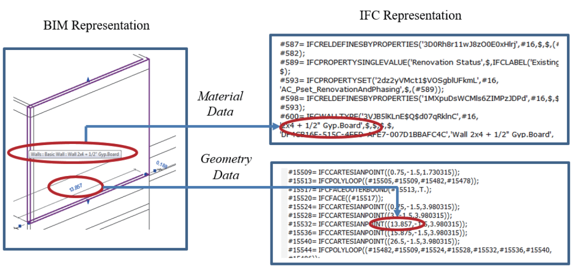

Figure 2. BIM / IFC Data Exchange Process

elements of walls, floors, doors, windows, and fixtures. In addition, it can be seen that there is a standard set of data that is applicable to all building components which involves an element's unique model identification, name, and assignment to a specific story level and building. Capturing this information lays the foundation for the extraction of data specific to the element type. For example, quantity take-off for both wall and floor construction concerns the names for the material types and the various layer descriptions, as well as the geometric data used to quantify the physical units involved. Doors and windows share similar attributes in geometry, and can be further defined by a unique wall association. Figure 3 shows an expression-g diagram of quantity take-off process in IFC. In this research, there are several entities used such as slabs, walls, roof, columns, windows, and ceilings. IfcElementQuantity itself has properties of global ID, description, object type, method of measurement, quantity and tag.

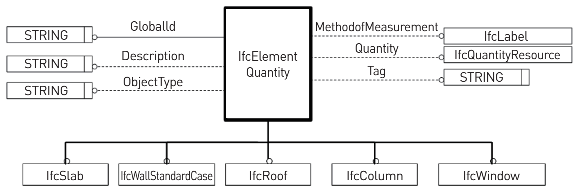

Figure 3. Express-G diagram of Quantity Take-off process

2.3 Producing a Standard Schedule (using Durations, Precedents and Activities)

Our framework uses a national-standard, building reference book, named as RS-Means, to establish a database for the duration and crew size for the construction of specific building elements. The elements' quantity data is converted into units of measurements that are relevant to a duration or resource definition in our compiled RS-Means database. For example, if the object of interest is a concrete wall, the process will seek the volume value in IFC as the desired unit of measurement and convert it to the duration length of construction and standard crew size that can be associated in the database. Similarly, a set number of workers associated with the daily output for the construction of a concrete wall will be processed on the basis of the total volume value acquired.

Figure 4 shows the Express-G diagram of a scheduling process. Its properties include Global ID, description, object type, creators, unit, duration, start date, end date, creation date, tag and predefined type.

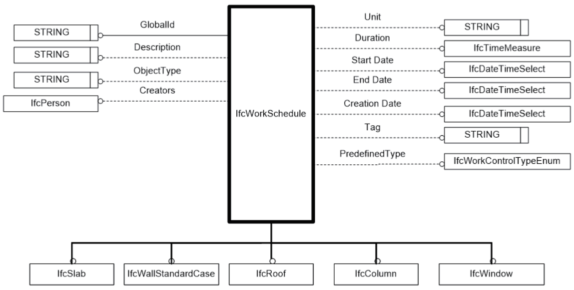

Figure 4. Express-G diagram of Scheduling

2.4 Cash Flow

Cash flow analysis for the purpose of this project consists of the monthly expenditures of for the project based on the maximum number of workers. Cash flow analysis is conducted for each alternative of maximum number workers considered for this research. The assumptions for this analysis includes incremental indirect costs at the range of 10.47 – 12.47% of the direct cost, 5% markup, 10% client retainage, 2 month payment delay from owner to contractor, and an incremental 1 – 2% interest on borrowed funds of the contractor. The total profit of each alternative is compared to identify optimum cash flow based on maximum number of workers.

2.5 Optimizing a Resource Schedule

The framework for the automation of a resource leveling procedure for scheduling uses the same preliminary stages in achieving the standard schedule, as discussed previously. These steps include defining the quantity take-off, durations, precedents, activity groups, and finalizing in cash flow.

As expected, the essential component will be the resource demand. The main objective of this paper is to complete our project as early as possible, but because of the resource constraint we have to have the maximum number of workers per day. In an attempt to identify the maximum number of workers, we ran numerous computer simulations and found a procedure to identify the optimum maximum number of workers of the project. An attempt at resource leveling may desire a schedule that has a set maximum number of workers per day, which will be the focus of our paper. The need for limiting the number of resources (i.e., workers) can be used to help plan against potential over-crowding at a job site.

Using these assumptions, the leveling procedure requires an ideal arrangement for the set of activities that is able to satisfy the resource demand. Consequently, this trial and error process naturally lends itself to being developed in this paper through an automated procedure. A more detailed account of how the resource allocation process will be implemented in our system is followed by step-by-step discussion.

3. Case study

This section of the paper will show how the resource scheduling procedure can be implemented through a case-study BIM model, while abiding by the following assumptions.

Assumptions:

1) Various building fixtures, staircases, and mechanical, electrical, and plumbing work that are potentially required have indeed been excluded from both the schedule of activities and the model. Nevertheless, investing in a more detailed approach is certainly possible. Various fixtures could be incorporated as smaller, minor activities throughout the construction process. The activity of staircase assemblies could also be integrated between the activities of floor to floor constructions. In addition, the mechanical, electrical, and plumbing conveyance layout can take place throughout the construction of the floors and walls.

2) For the purpose of maintaining a straightforward analysis of duration computations, the summation of an activity's duration for all the contributing quantities will be rounded to the next whole day.

3.1 BIM Model Production in IFC

For the purpose of this report a 3D BIM file was created in ArchiCAD. The two buildings were drafted as office use buildings with concrete structural components, timber framed partition walls, and no-slope concrete roofs. The first building is a single-story structure and the second building is a three-story structure. This case study uses this BIM model and is illustrated in the 2D layout of the first floor plan shown in Figure 5. Figure 6 presents the same buildings in 3D view from ArchiCAD.

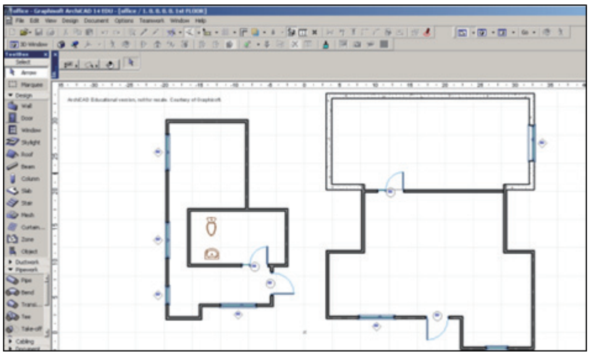

Figure 5. 2D display of 1st floor plan of BIM model generated in ArchiCAD

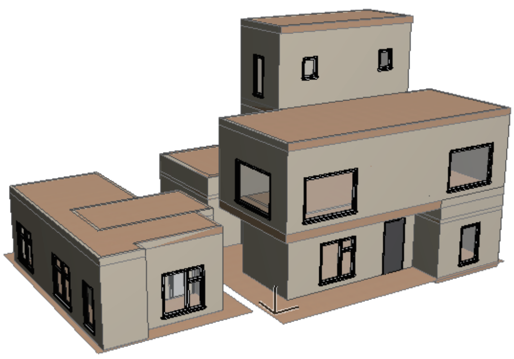

Figure 6. 3D display of the two office buildings generated in ArchiCAD

After the two office buildings were created in ArchiCAD, the file was exported as an IFC file. The IFC file is used due to its interoperability with other programs. The IFC file is parsed to identify the required information from the building components. That information is obtained to calculate quantity take offs, create schedules, and create cash flow diagrams.

3.2 Establishing a Quantity Take-Off

The quantity take off of the two office buildings is based on the information extracted from the IFC file. The IFC file contains the geometric data for each building component. Examples of these components within IFC are IFCSLAB, IFCWALLSTANDARDCASE, IFCDOOR, and IFCWINDOW. Within each of those IFC entities is the Cartesian coordinates for each particular building component. The volume or surface area is calculated based on those coordinate points. For example, the volumes of the slabs for each building are calculated to determine the amount of concrete required for the project. Also, the surface area of the walls, the number of doors and windows, and the number of fixtures is extracted from the IFC file. In addition to the geometric data, the material type for each component is obtained from the IFC file. Table 1 presents the quantity take-off (QTO) values for the project.

Table 1. Quantity take-off (QTO) values for the two buildings

Location	Slab Vol. (yd3)	Wall SA (ft2)	Windows (ea.)	Doors (ea.)	Fixtures (ea.)
Building 1, Floor 1	258.00	914.20	3	1	2
Building 1, Floor 2	322.50				
Building 2, Floor 1	610.89	1978.30	3	1	
Building 2, Floor 2	1045.23	1111.70	3		
Building 2, Floor 3	533.23	592.10	3		
Building 3, Floor 4	154.35				
Total	**2924.18**	**4596.30**	**12**	**2**	**2**

3.3 Producing a Standard Schedule (using Durations, Precedents and Activities)

The construction schedule for the two office buildings is based on the components identified within the IFC file. Those components are linked to a database of information obtained from RS-Means. Multiple schedules are produced from multiple computer simulations. The computer simulation runs an analysis on the data related to the buildings and a schedule is output to Microsoft Project. One schedule is produced from each alternative of maximum resources (workers).

3.4 Resource Simulations

Running the resource simulation is an essential aspect to schedule optimization. For this case study resources are identified as the number of workers on the construction site on a particular day. The project duration is based on the maximum number of workers as well as on the critical path of activities for the project. Figure 7 is a summary of the total project duration based on the maximum number of workers.

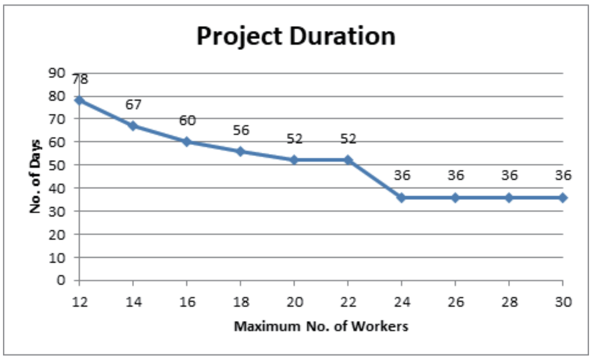

Figure 7. The total project duration based on the maximum number of workers

Figure 8 presents the number of workers on the construction site for each day for the limitation of 12 workers maximum on the site at one time. Given this maximum, the construction schedule is optimized for maximum use of resources. As the graph shows, even though the maximum number of workers is 12, the number of workers on the site for each day does not reach this maximum. The range is from 2 workers to 12 workers on the project for a day. This is due to the fact that construction activities must follow a critical path schedule. For example, the walls cannot be painted until the wall gypsum boards of those same walls are installed. Wall painting requires two workers, but those two workers must wait until the two workers on wall gypsum board installation complete their task before beginning.

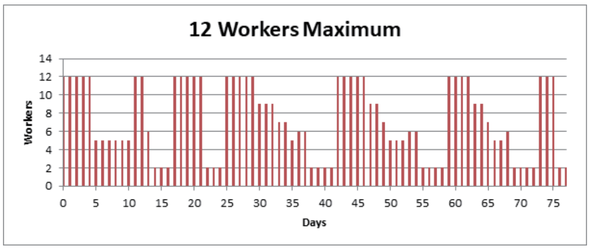

Figure 8. Number of workers per day based on 12 workers maximum

Figure 8 shows the number of workers per day based on 30 workers maximum on the project site. This figure has similarities to Figure 9 in that the maximum number of workers is not reached for each day. Increasing the number of maximum workers does have a direct effect on the total duration of the project. For 12 maximum workers the total duration is 78 days, while the total duration for 30 maximum workers is 36 days.

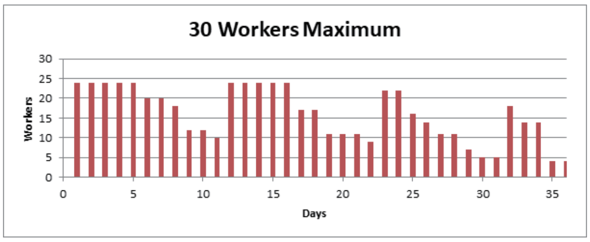

Figure 9. Number of workers per day based on 30 workers maximum

Figure 10 shows the number of workers per day and the total duration based on the number of workers for all iterations performed for this case study.

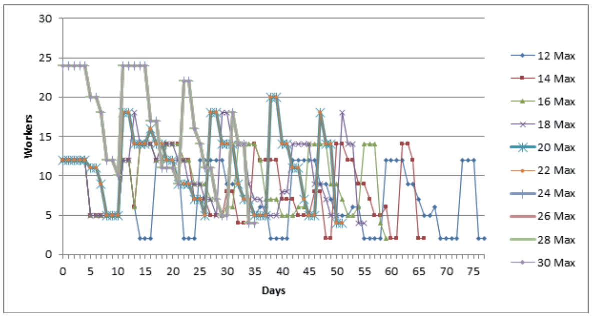

Figure 10. Number of workers per day based on 12 through 30 workers maximum

The general trend from Figure 10 shows that the number of workers is near the maximum allowed at the beginning of the project, but the number of workers needed decreases significantly as the project progresses. The lines for 24 maximum workers through 30 maximum workers followed the same trend. At the beginning it is beneficial to have a higher number of workers, but that need quickly decreases as activities are complete. For this project, both the 1-story building and the 3-story building can be constructed simultaneously when there is a higher number of maximum workers, such as 24 through 30. The 1-story building will be completed early on in the project schedule and only the 3-story building will require the workers for construction. The latter phases of the project will not need the additional workers. By recognizing these factors within the resources management, it can be identifying the optimal maximum number of workers for this project is in the range of 20 to 24 workers.

3.5 Cash Flow

Cash flow analysis for this case study was performed based on each alternative of maximum workers for the project. Information for cash flow analysis was collected from the 10 alternatives. Cash flow analysis includes the following items: one general contractor without sub-contractors, indirect cost, contractor markup, client retainage, payment delay, interest on borrowed funds from the contractors, cash outflow, cumulative outflow, and cumulative payment. The indirect cost, or overhead rate, is the expenses for the contractor in addition to direct cost which includes administration costs, job trailer costs, project site lighting, etc. The indirect cost rate for this case study is 10.47%, 11.47%, and 12.47%. The indirect cost is calculated by equation (1) and the direct cost is shown in equation (2).

$$\boldsymbol{OR = OVERHEAD\ RATE = \frac{TOTAL\ OVERHEAD}{TOTAL\ DIRECT\ COST + TOTAL\ SUB}} \quad (1)$$

$$DC_m = DIRECT\ COST = MATERIAL\ COST_m + LABOR\ COST_m + EQUIPMENT\ COST_m \quad (2)$$

The contractor markup is a set percentage of the total cost of the project for the contractor to attribute to project profit. The contractor markup is set to 5%. On the side of the client there is the client retainage and the payment delay. The client, or owner, retains 10% of the monthly cost to pay the contractor at the end of the project to ensure project completion. The payment delay is due to the time required for verification of construction progress, bank processing, and other issues related to the payment. The payment delay for this project is set to two months. Equation (3) shows the payment with delay.

$$PWD_m = PAYMENT\ WITH\ DELAY = PAY_{m-delay}\ (delay\ normally = 2) \quad (3)$$

The interest on borrowed funds from the contractors is set at 1% compounded monthly. Cash outflow, cumulative outflow, and cumulative payment are presented in equations (4), (5), and (6).

$$OUT_m = CASH\ OUTFLOW = TC_m - SUB_m + SPWD_m \quad (4)$$

$$CO_m = CUMULATIVE\ OUTFLOW = +CO_{m-1} - OUT_m \quad (Note\ Negative) \quad (5)$$

$$CP_m = CUMULATIVE\ PAYMENT = +CP_{m-1} - INT_{m-1} \quad (6)$$

The first step of cash flow analysis was to identify the monthly costs for the project. This was estimated by identifying which activities were performed on each day. The cost for each activity was based on unit rates from RS-Means.

Figure 11 shows the monthly project cost for each alternative. Each project alternative begins on the same date, August 19, 2013, but due to variations in maximum number of workers the end date is varies between the alternatives. As the maximum number of workers increases, the total duration of the project decreases. Based on these observations, the overall trend of monthly cost is similar between alternatives. The cost in August is low and then is a higher value in September and October and decreases until the project is complete. Because trend for each alternative is similar for this project so this graph is needed in conjunction with additional graphs for optimum alternative selection.

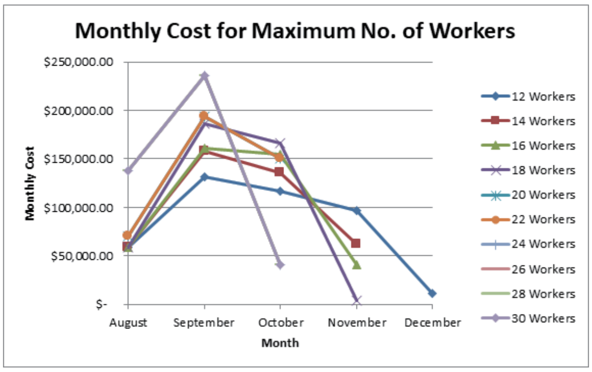

Figure 11. Monthly project cost based on maximum number of workers

Figure 12 shows the total cost of the project for the contractor which is based on direct costs, overhead costs, and the interest paid on funds borrowed. The total cost has a direct correlation to the total profit for this project. Comparing Figure 12 and Figure 13, the trends appear to be very similar. For each of these figures, the total cost and the profit are based on the alternatives of varying maximum number of workers. One aspect to note from the trend is neither the total cost nor total profit does increase continuously as the maximum number of workers increases.

Figure 12. Total cost of the project based on maximum number of workers

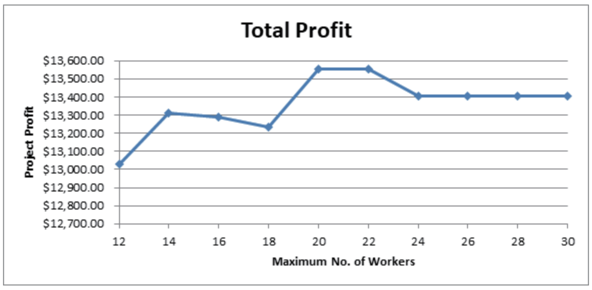

Figure 13. Total profit of the project based on maximum number of workers

The aspect the contractor will be most interested in is the total profit for the project. Figure 16 shows the trend of total profit as the maximum number of workers increases. The total profit increases relatively significantly from 12 maximum workers to 14 maximum workers. From 14 to 16 and 18 maximum workers the total profit decreases gradually. This decline in profit could be due to the higher amount of interest required by the contractor to pay for costs from the earlier months. The profit again significantly increases from 18 maximum workers to 20 maximum workers. This could be due to a more optimal number of workers on the site to complete tasks efficiently and timely. Both 20 maximum workers and 22 maximum workers produce the same amount of total profit. 24, 26, 28, and 30 maximum workers show a decrease in total profit. It appears as more workers are added to the project past 20 workers there is little benefit for the contractor.

Each alternative was analyzed based on indirect cost rates of 10.47%, 11.47%, and 12.47%. Also, the interest rates were adjusted at intervals of 1%, 1.5%, and 2%. This figure clearly shows that as the indirect cost rate goes up, the profit goes up and as the interest rate goes up, the profit goes down. The general trend is that as the interest rate increases from 1% to 1.5% to 2% the total profit decreases approximately $5,000 each interval. For example, when the indirect cost rate for 12 maximum workers is set at 10.47% and the interest rate is 1%, the total profit is $12,910.71. With the same indirect cost rate and an increased interest rate to 1.5% the total profit is $7,697.98. The difference between the two is $5,212.73. The trend is similar between the alternatives analyzed for this project. As the indirect cost rate is increased, the total profit slightly increases. Considering the alternative of 12 maximum workers, applying an interest rate of 1% and increasing the indirect cost rate from 10.47% to 11.47% to 12.47% the total profit increases from $12,910.71 to $13,027.58 to $13,144.45. The incremental increased profit between each indirect cost rate increase is $116.87. This trend is also similar between the alternatives analyzed for this project. When considering the options for each alternative this is a slight difference of total profit with 12 maximum workers showing the least amount of total profit and 20 maximum and 22 maximum workers showing the most amount of total profit.

4. Refinement

The refinement process identifies the optimum schedule based on the factors identified for the case study. Each factor is taken into account to determine the optimum alternative. These aspects include the construction schedule, resource simulations, and cash flow analysis. Based on the analysis of the aforementioned items, the optimum maximum number of workers for the 2 office buildings construction project is 20 maximum workers. The construction schedule for this alternative produced a 52 work-day schedule. Figure 14 shows the number of workers per day for 20 workers maximum. This was not the shortest duration from the alternatives available, but the cash flow analysis was taken into consideration for the decision. Figure 15 presents the construction schedule diagram with the total duration of 52 days in building two buildings simultaneously. The activities included are the constructions of foundation, slabs, walls, columns, doors, windows, ceilings and roof only.

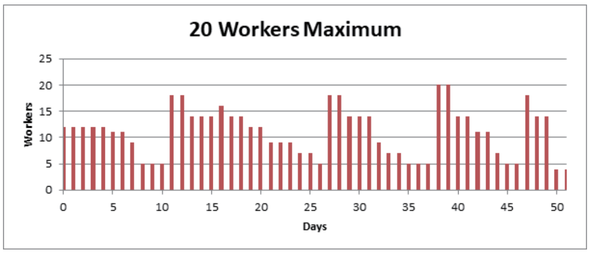

Figure 14. Number of workers per day based on 20 workers maxim

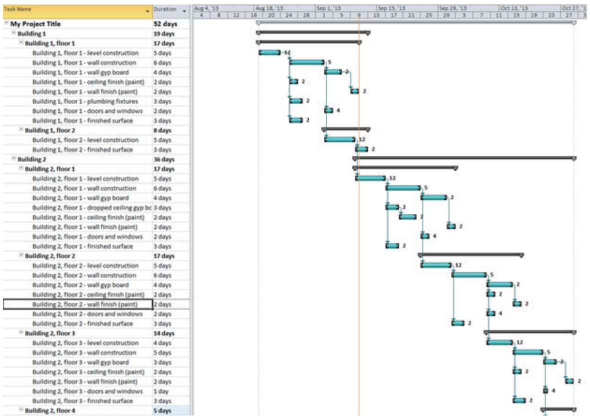

Figure 15. Construction schedule for 20 workers maximum

5. Conclusion

The resource scheduling framework introduced in this paper utilizes the reliable scheduling system found in the critical path method. Using logic and reasoning, the procedure seeks an ideal schedule that satisfies the resource demand, as well as all the precedent constraints that are set forth in the standard scheduling framework. Consequently, the IFC extraction process of element data from BIM models naturally lends itself to incorporate various construction engineering methods and analysis procedures. This has been accomplished thus far in the interaction between quantity take-offs, schedules, and resource management.

In this paper, the explicit claim to the existing body of knowledge is that this research automated the processes of quantity take-offs, scheduling, resource leveling, cash flow analysis and integrated them through the data exchange of IFC in BIM technology so that the construction management team might be able to identify/resolve a potential resource conflict(s) before they occur in a construction project.

We realize that there is indeed a great need to consistently take advantage of the capabilities of BIM. Among the disciplines of the AEC community, the construction engineering and management team stands to directly benefit from this study's proposed computerized handling of resource leveling. In fact, future research will ultimately extend the topic of resource leveling to resource allocation, as well as engage in studying the effects of shared resources between activities in order to minimize the total duration. However, the long-term goal is to see that all the architectural and engineering collaborators can appreciate the efficiency and performance of the construction process to which they contribute. The prototype at this time is limited in scope and requires further development to extend the range of items in schedule optimization. While the proposed methodology is able to quickly optimize construction schedules, there are a few limitations observed and further research is recommended to make it more applicable in reality.

Acknowledgements

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