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Analyzing Resource Allocation and Levelling in construction Projects

Ahmed Alhady[1], Shahir Ashraf[1], Mohamed Eizeldin[1'2], Mohamed H Hegazy[1'*]
[1]*Civil and Construction Department, Faculty of Engineering, the British University in Egypt (BUE), Cairo, Egypt.*
[2]*Civil Department, Faculty of Engineering, El-Mataria, Helwan University, Egypt.*

ABSTRACT:*Project scheduling has been crucial in any construction project since applying poor scheduling may lead to cost overruns and delays. The most commonly used technique for scheduling is the critical path method (CPM). As CPM neglects the availability of resources and assumes only time as a constrain; therefore, the resource allocation problem (RAP) technique is introduced. RAP appears when the number of resources required exceeds the number of resources available. Moreover, as a result of solving the RAP, another problem will occur known as the resource leveling problem (RLP). RLP lead to lots of hiring and firing of laborers. Researchers all over the world have come up withan enormous number of solutions to solve these two problems RAP and RLP. This research aims to provide an integrated methodology and analogical model for planning a construction project with the employment of ELS and the minimum moment method (MOM) for solving the resources problem. Furthermore, a comparison takes place between the leveled resource histogram using MOM and symbiotic organisms search (SOS). Applying a case study for validation purposes and identifying the differences between both approaches is introduced.*

KEYWORDS *Project Scheduling, Resource Planning in Construction Projects, Resource Allocation Problem (RAP), Symbiotic Organism Search (SOS).*

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I. INTRODUCTION

Recently, project management is a crucial element in any construction project. Project management should be responsible for two main things. Firstly, the schedule of the whole project which means the specified period of the whole project. Secondly, resource planning is where we place the right number of laborers in order to finish each activity on time. Moreover, resource planning also takes into account material and machines; by specifying the amount and type of material used in the project. Any construction project should be finished on time and at the cost agreed on in the contract. Therefore, contractors should consider project management to avoid delays and cost overruns. Moreover, contractors will handle the cost and time issues by planning the project activities and illustrating a specified duration for each activity, and also by listing the number of laborers needed for each activity. There is a gigantic amount of methods used to plan any project. Nevertheless, the most commonly used is called the critical path method; unfortunately, it does not consider resource availability. As a result, problems will occur such as resource allocation problems RAP and resource-leveling problems these might affect the project's duration and also the project's budget.

Researchers all over the world had figured out an enormous number of solutions for these two problems RAP and RLP. These solutions are divided into different categories such as heuristic, metaheuristic, and optimization approaches. Planning engineers must choose the methods which match the project. For example, if the project is meant to be a bridge; therefore, the RLP technique used should be linear as bridges are considered as a liner project like roads.

A significant obstacle that is tackled in construction projects mainly is related to the management of resources and ensuring their availability at the expected time. This issue significantly arises due to depending on certain software programs to assign a schedule of work without taking into account the proper allocation of resources. Moreover, even when the resources are properly allocated for various activities in the project, the other issue that arises is basically related to having several fluctuations in the resources histogram. Thus, there is

a significant need for having a certain solution that can level all resources to reduce numbers of fluctuations in the resources histogram and ensure the availability of all supplies for the expected duration.

The most significant aim of this paper is to establish a proper leveling method in order to reduce fluctuations in the resources histogram and prevent having an excess amount of materials than needed on site. Below are the objectives of this research:

- Apply resource allocation in construction projects using ELS.
- Apply resource-leveling on the same project using the minimum moment method.
- Compare results of the SOS method with the use of MOM to estimate which technique can be more effective in terms of leveling resources in construction projects.

One of the major aspects that are applied in the construction sector is the planning of resources. Even though it can affect the performance of work in the project by multiple means, but yet several projects do not take into account its effect. Poor management of resources can result in unwanted circumstances that could be related to time overruns, and cost overruns. Hence, proper allocation and leveling of resources can be significant in ensuring the success of construction projects.

Rationalizing an investment in a facility's infrastructure can be a difficult prospect for any plant engineer or technician, often requiring extensive justification. Investments that are deemed “low-risk” by upper management and have a fast return on investment (ROI) are typically the easiest to substantiate. One such investment that will pay considerable dividends over the course of its operating life is a comprehensive power monitoring system.Even though increased energy prices have become a larger influence on the balance sheet, many facilities do not take advantage of opportunities to better manage these expenses. Those without monitoring systems likely have no understanding of their energy usage; those with them may not be using their systems to the fullest potential.

Because the quality of energy supplied can adversely affect its operation, oftentimes leading to loss or degradation of equipment, product, revenue, and reputation, plant managers must weigh the advantages of implementing a monitoring program.

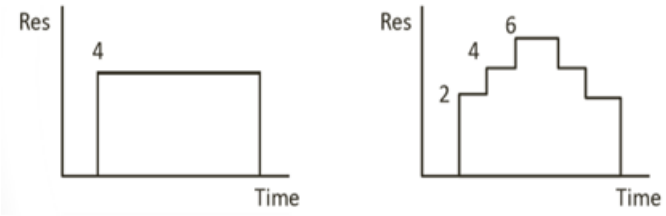
The second section of this paper shows three methods for monitoring systems of solar plants. The third section discusses the communication and monitoring system for wind turbines, and finally, the conclusion is discussed in the fourth section.

II. Literature Review

Hence, to ensure the completion of projects smoothly, then there should be adequate allocation and scheduling of all needed resources in the project. Proper attention and management of resources are mainly related to providing required materials, laborers, and equipment on time while managing them adequately. Multiple factors can influence each element included in the project’s resources such as suffering from various uncertainties, shortage of materials in the market, disputes between laborers, delays in delivery of supplies, and breakage of equipment. On the other hand, another critical situation that could be faced is associated with the management of assets when the project is not meeting the expected budget and time, and in order to overcome such a situation, more laborers, equipment, and supplies are essential to accomplish such goal. Hence, the major goal of applying resources allocation and planning is to provide the needed supply to conduct any operation in the project to keep the project within the expected budget and accomplish required objectives by the end of this project. Normally, the project manager is the party that is responsible for estimating and allocating all needed supplies to the project to prevent any unwanted circumstances [1].

There is no allocation of resources in projects without including the basic concept of resources leveling. Moreover, resources leveling can be defined as reducing the summation of squares that are produced in the resources histogram, this results in having a rectangular shape which is the major form of resource leveling [2].

Recently, all construction projects are facing a huge obstacle is that how the available resources are going to be assigned to different tasks in a way where the task is finished on time, cost and quality planned by the planner engineer. Resources are divided into two main categories either consumable or non-consumable, for consumable they are two elements labor and machine as they are classified as a non-consumable resources as they are not going to finish while money and machine are under the category of consumable resources as they have a limit and they can come to an end [3]. The critical path method is mainly used by managers to make sure that the project will be held on time and within a specific budget. Although, the critical path method (CPM) takes into consideration the time value it also discards the availability of resources as while using (CPM) it is always assumed that resources are unlimited [4]. Although, CPM results in two major problems RLP and RAP nevertheless it is mostly used as it considers time only and neglects resource availability therefore as contractors are assigned for a bid the ones who used CPM will have the upper hand in terms of time and will most probably sign a contract.



Uniform loading …. Non-uniform loading

Fig.1. Difference between uniform and non-uniform loading of resources

Moreover, another scheduling technique is also used widely called the critical chain project method (CCPM). This method was developed by Dr. Elyahu M. Goldratt (1997). Goldratt is also well known all over the world as he is the originator of the theory of constraints (TOC). TOC is used for managing projects that are considered repetitive like the construction of roads, tunnels, etc based on that each system has its constraints. Moreover, system performance will only be improved by increasing the performance of the constraining resources. CCPM is mainly based on the TOC. According to the writings of Homer (1998), Leach (1999), and Simpson (1999) CCPM is used rather than using the traditional methods of scheduling. CCPM aims for decreasing the delivery time of the project, meet the schedule, and do not increase the budget approved on the first basis.

Another technique that is also used widely, especially for linear projects or repetitive projects and this method is called the line of balance (LOB). LOB was originally created by Goodyear company in the 1940s then the US Navy developed it in the 1950s. it was created for production control in the manufacturing industry [5]. LOB is a graphical method of scheduling that produces a diagram where it shows the project's repetitive works as a single straight line on a graph. Fig.2 shows the graph where the x-axis signifies the whole period of the projectin months, and the y-axis represents the number of floors. Then the straight line that is drawn in the diagram represents an activity.

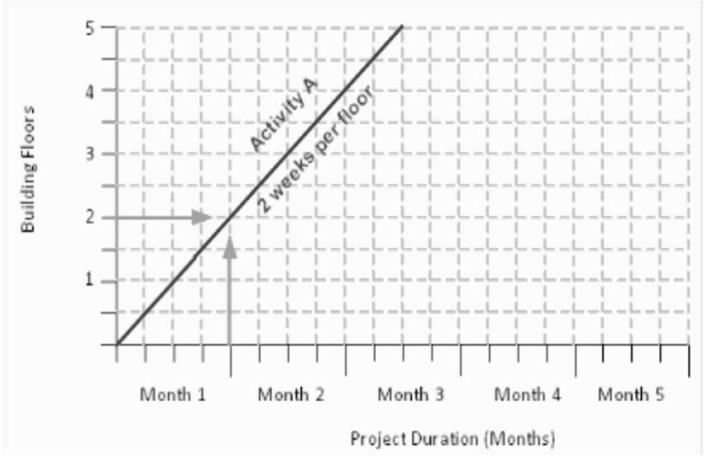


Fig.2. Relationship between project duration and building floors

LOB has been considered in most papers that it is more suitable to be used when the project's activities are repeated or linear and will not be effective when used for normal projects [6]. On the other hand, the line of balance in Finland is mainly used by the largest construction companies in the 1980s.

2.1. Resource Planning

There is a variety of resources that must be included in any construction project to maintain progress. These resources are usually known as the four M and they are money, machine, material, and manpower. Nevertheless, Halpin and Woodhead 1980 both together added information and management decisions to the resources. Also, time should be taken into consideration while planning any construction project as it is meant to be a key resource [7]. By applying any planning method production rate of each activity must be determined. Production rate controls activity duration. Simply by increasing the number of resources used for a task, the production rate of this task will increase, resulting in a decrease in activity duration [8]. Therefore, trying to increase the production rate of critical activities will result in accomplishing the project in a shorter time period.

2.2. Problems of Conventional Project Scheduling:

The main issues that appear after planning the project take place at the site These problems are known as resource allocation problem (RAP) also known as resource investment problem and in some papers, it is called resource-constrained scheduling problems (RCSPs) the other problem is known as resource leveling

problem (RLP) also known as resource smoothing. Where resource allocation is how the resources are going to be assigned to different tasks in a way that decreases the cost of the resources needed and finishes the project on the planned time [9]. In this paper resource allocation problem (RAP) is going to be defined as the problem that appears when the number of resources required is greater than the number of resources available this problem will indicate an increase in the whole duration of the project. Resource allocation must be applied efficiently to reduce the extent of the whole project time as much as possible. Moreover, resource leveling is one of the hardest difficulties faced in project management due to its complexity [10]. Resource leveling aims to drop the peaks of resource demand and smooth the quantity of resource consumption through the project days. Furthermore, there are several reasons why RLP techniques must be applied. firstly, by Appling resource-leveling resource fluctuations will decrease in a significant way [4]. Secondly, the importance of maintaining an even flow resource histogram. And finally, to meet a physical limit of resources [11].

2.3. Importance of Solving (RAP) & (RLP)

Resource leveling solves a huge number of problems, from a resources point of view resource-leveling reduces the hiring and firing of laborers as the difference between resources usage from a day to another is not huge therefore no need to hire or fire laborers. Therefore, the work at the site becomes more stable [12]. Not only does resource leveling solves problems from a resources point of view but also it solves equipment usage problems. By having a well-leveled project the usage of equipment will be more efficient as the cost associated with equipment mobilization and demobilization will decrease. For example, if excavation works for building A is going to take place today while for building B it is going to start after five days then excavator mobilization and demobilization cost is going to be paid twice. hence, resource leveling solves these kinds of problems [13] [14].

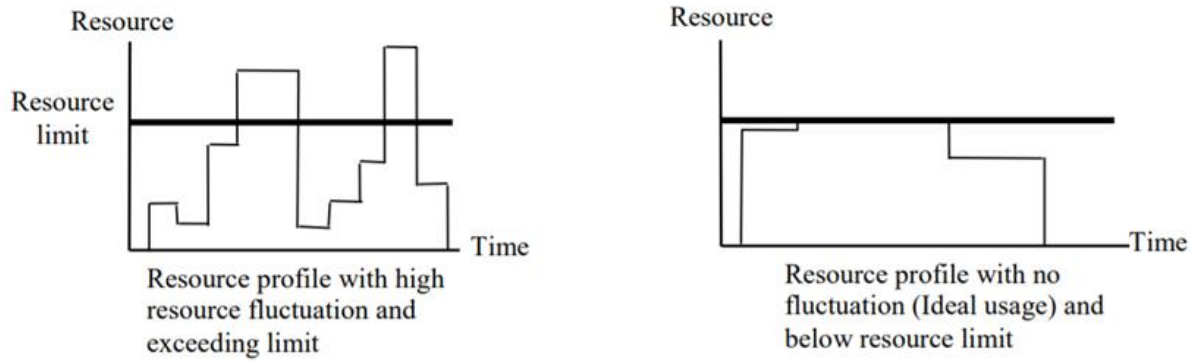


Fig.3. Before and after applying a resource allocation

It is crucial to solve resource allocation problems and resource-leveling problems to have a stable working site with no conflicts and also to balance the amount of work wisely throughout the construction project [4] [15]. Fig.3 shows a major effect that happens on resource histogram after applying any method that solves resource leveling and resource allocation problems. As Fig.3 shows that the resources required are exceeding the number of resources available and also, we can investigate the existence of fluctuations for a resource. Nevertheless, after applying resource allocation and resource leveling (resource smoothing) the maximum amount of resources needed per day does not exceed the number of resources available, and also the resource histogram has taken the shape of a rectangle which means that it is leveled as much as possible without extending the project duration [16]. Moreover, figure 4 simplifies the importance of applying resource allocation and leveling to construction projects.

III. METHODOLOGY

As mentioned previously moment method model is used to level the resource histogram which works by decreasing the number of fluctuations in the graph. The minimum moment method operates by calculating the moment of each bar in the resource histogram around its x-axis the lower the total value of the moment calculated the more leveled histogram produced. Fig.4 shows how MOM concept, by taking a look at the first histogram after calculating each bar moment around its x-axis the result was 84 while, in the second graph two resources were shifted to another day which makes the moment value less than the first one. Finally, the third graph shows that having the two-day occupied by the same amount of laborers will result in having the least value of moment around the x-axis which means that this resource histogram is the most leveled one of the three histograms. Also, the total amount of laborers never changes with the total amount of 16 laborers.

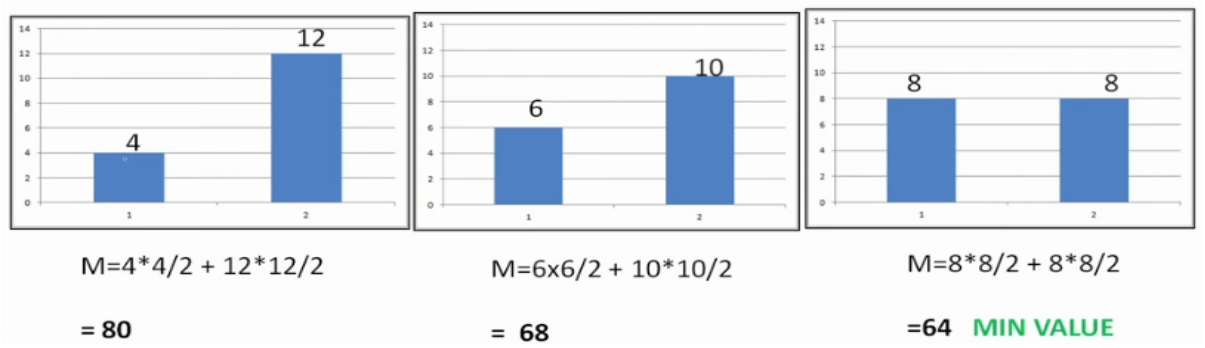


Fig.4. Minimum Moment Process

Moreover, this was the basic concept of MOM while in real life it would require a lot of time to apply this method for each activity. Therefore, an improvement function was developed. This function has been discovered by these two functions (1) and (2) shown, where M1 refers to the moment calculated for the histogram before shifting the activity while the function M2 represents the value of the moment calculated after shifting the activities.

$$M1 = 1/2 * \sum_{1}^{m} Xi\text{^}2 + 1/2 * \sum_{1}^{m} Wi\text{^}2 \quad (1)$$

$$M2 = 1/2 * \sum_{1}^{m} (Xi - r)\text{^}2 + 1/2 * \sum_{1}^{m} (Wi + r)\text{^}2 \quad (2)$$

The question that must be asked is what are the preferable values of these two functions. The answer is very simple, M1 must be greater than M2 to get an improvement in the resource histogram. As the main concept of the MOM is that by having the lowest moment value around the x-axis of the resource histogram a more leveled histogram is going to be produced. Therefore, having M1 which is the value of moment before shifting greater than M2 which is the value of moment after shifting means that the resource histogram is more leveled. According to this a function was developed called improvement function (If) and this function is created due to the concept of requiring M1 > M2. The improvement function is shown below in equation (3)

$$IF_{A,d} = r\left(\sum_{1}^{m} x_i - \sum_{1}^{m} w_i - mr\right) \quad (3)$$

Each variable represents the following:

- Xi = daily resource sum for the current time frame over which resources will be deducted
- Wi = daily resource sum for the time frame over which resources will be added
- M = minimum number of days that the activity is shifted or the duration of the activity
- R = daily resource rate for the activity

Furthermore, this function should be applied to all non-critical activities available in the case study drawn before in this paper.

There is a function that is represented below that indicates whether the resource histogram is getting improvement or not. the value resulting due to applying this function ranges from 1.1 to 1.3 and the lower the value the more leveled resource histogram is going t be produced. the variables of this equation represent the following:

- n = total number of days of the whole project
- r = total amount of resources needed for the whole project

$$\frac{n * r^2}{\sum r} \quad (4)$$

After applying MOM to the non-critical activities available in the case study this process should be repeated until no more positive values resulted after applying the improvement function.

3.1. Model development

In order to schedule any construction project we should use a proper scheduling technique the project; for example, if it is required to plan a project where a bridge is to be constructed, therefore, Line of balance (LOB) method will be the most efficient method to plan that project as it is considered as a linear method used for linear projects such as bridges and roads. While in this case study it was preferred to use the Critical Path Method (CPM) for scheduling as it is not a linear project. also, CPM will result in having the shortest period of the whole project as it does not consider resources as a constraint perhaps taking only time as a constraint.

Firstly, the information about the project should be given in a form of a table. the table views each activity name, duration required to finish the task, demand of laborers (the number of laborers needed to finish the task), early start (the preferred date to start the activity), late start (the latest date where the activity will start

) and the relations between the activities. By using the data shown in the table then we can construct a Primavera model to maintain a resource histogram for this project.

3.2. Primavera model

The Primavera model requires several steps to reach the resource histogram. First, we started by placing all activities and assigning the original duration required for every activity. Second, the relations between activities will take place, the relation between activities can have different forms from start to start (SS), start to finish (SF), finish to start (FS), and finish to finish (FF). In this case study, all relations between all activities were given as SS.

3.3. Model validation

In order to assure that the model developed to solve the resource leveling problem using the minimum moment method is working correctly, a solved example using the developed minimum moment model is introduced and a comparison between the two results will take place. Table 1 shows the example that should be solved to assure that the model developed functions correctly. While Fig.5 shows the final result, which is considered to be the model answer. As shown in the figure that the improvement factor is 1.1392 which is considered to be leveled perfectly as it is close to 1.1.

Table 1. Solved Example

Activity	Pred.	Duration	Res/day	Total Float
A		5	3	0
B	A	5	4	0
C	A	4	6	4
D	B	10	5	0
E	B, C	3	7	7
F	C	7	7	4
G	D	5	4	0
H	E, F	5	3	4
I	G, H	5	10	0

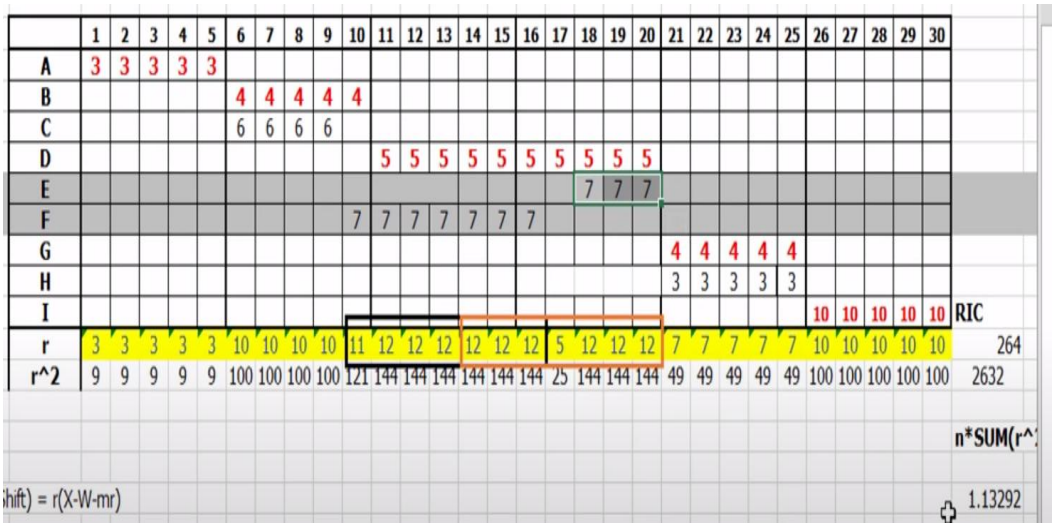


Fig.5. Solution

IV. COMPARISON AND DISCUSSION

4.1. Case Study

Table 2 represents the case study that was solved using SOS and it is going to be solved one more time using MOM in order to compare the results.

Table 2. Case Study

	Task	Predecessor	Duration	Resource needed	Early start ES	Late start LS
1	A		0	0	0	0
2	B	A	10	5	0	0
3	C	A	5	2	0	9
4	D	A	15	3	0	3
5	E	A	3	2	0	12
6	F	A	10	2	0	8
7	G	B	15	6	10	10
8	H	C	7	10	5	14
9	I	E	3	6	3	22
10	J	E	3	2	3	15
11	K	E	2	2	3	16
12	L	D, J, K	3	6	15	18
13	M	J	2	1	6	19
14	N	H, L	2	5	18	21
15	O	L, M	3	2	18	21
16	P	N	1	6	20	23
17	Q	O	1	7	21	24
18	R	P	1	7	21	24
19	S	G, I, Q, R	4	13	25	25
20	T	O, R	2	9	22	30
21	U	S	2	4	29	29
22	V	T	1	6	24	32
23	W	U	3	8	31	31
24	X	V	1	3	25	33
25	Y	W, X	4	8	34	34
26	Z	Y	2	7	38	38
27	AA	F	25	10	10	18
28	AB	W	3	6	34	40
29	AC	W	3	2	34	40
30	AD	Z	3	9	40	40
31	AE	AD	3	10	43	52
32	AF	AD	3	3	43	46
33	AG	AA, AC, AD	2	4	43	43
34	AH	AF	0	0	46	49
35	AI	AG	4	1	45	45
36	AJ	AH, AI	3	12	49	49
37	AK	AJ	3	12	52	52
38	AL	AB, AE, AK	3	3	55	57
39	AM	AB, AE, AK	5	8	55	55
40	AN	AJ	1	2	52	59
41	AO	AL, AM, AN	3	10	60	60
42	AP	AO	1	3	63	63
43	AQ	AP	6	3	64	64
44	AR	AQ	0	0	70	70

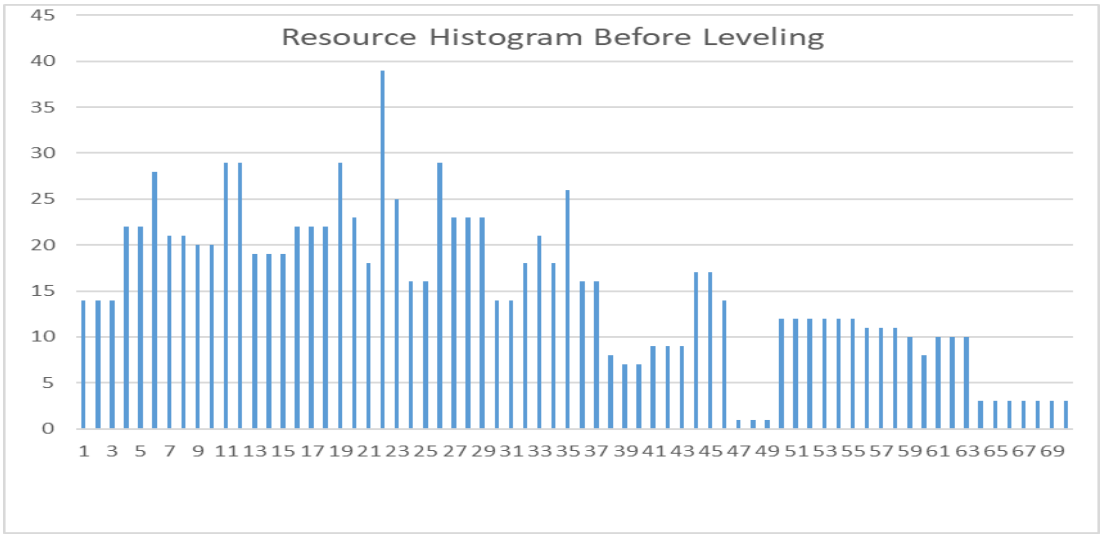


Fig.6. Resource Histogram Before leveling

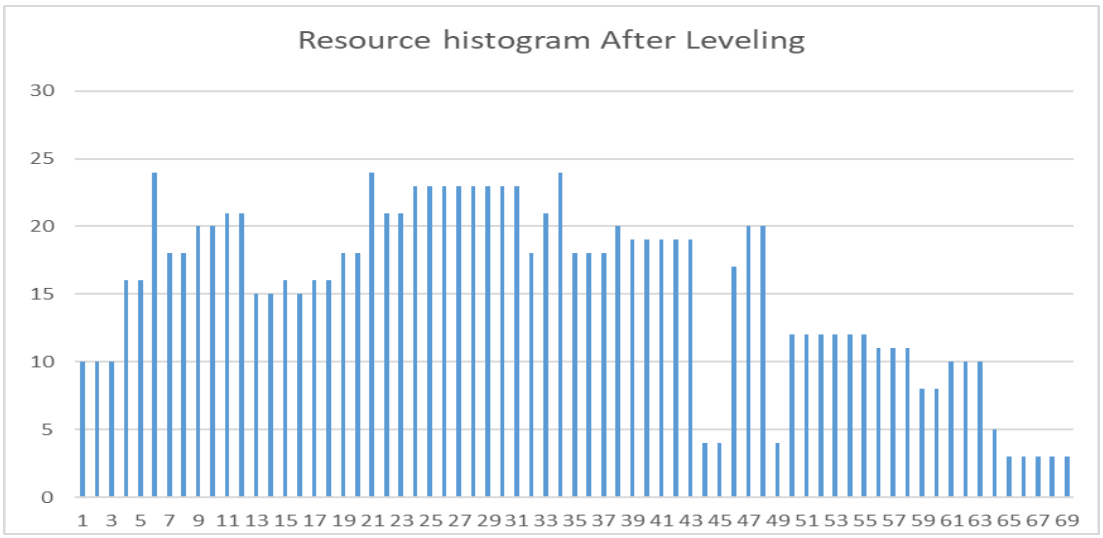


Fig.7 Resource Histogram After Leveling

By comparing these resource histograms with each other according to the fluctuations it is very simple to know or figure that the resource histograms hold fewer fluctuations than before leveling. also, the daily demand for laborers has decreased than they were before leveling. for example on day 22 of the project amount of laborers that were required before leveling was 39 while on the same day but after leveling the number of laborers required was 24 and that is a great change that enables the company to decrease the amount of laborers needed by 15 laborers which means that not only stability has been reached in the field but also a huge cost reduction has resulted.

On the other hand, the question that must be asked at this point is if this leveled resource histogram is the best solution for leveling the resource histogram available in this case study. Moreover, there are lots of methods used to level resource histograms for any construction project to maintain stability at the site. The method that is going to be used in order to compare MOM solutions is Symbiotic Organisms Search (SOS). SOS also level resource histograms by moving non-critical activities along their total floats nevertheless, SOS gives as an outcome nine different resource histograms as it uses nine different functions each one of them works on different variables.

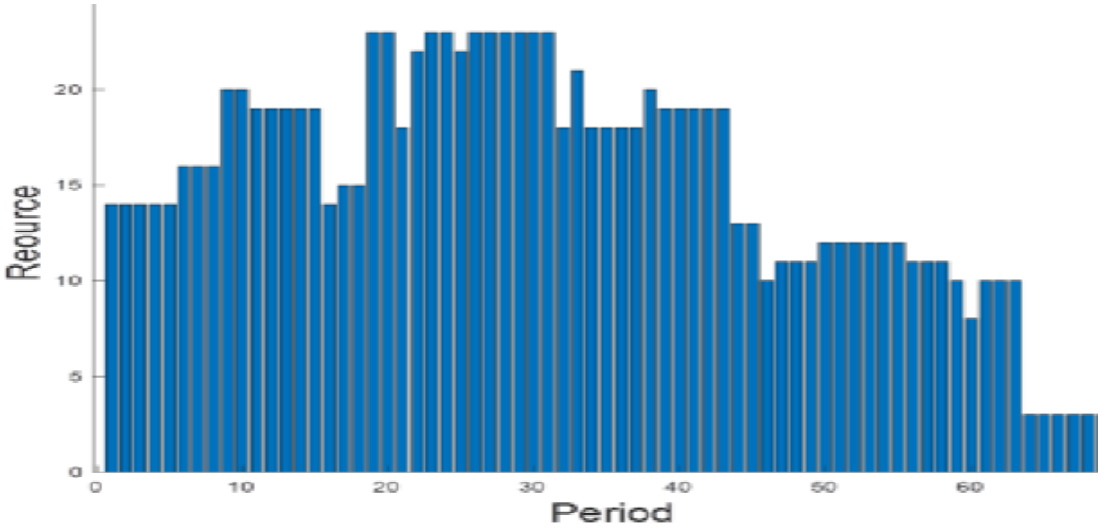


Fig.8 Resource Histogram Leveled by SOS

Thus, the results were maintained by leveling the resource histogram using the minimum moment method is going to be compared with the best-shaped resource histogram that was maintained by solving the same case study using SOS, to make it clear for project managers and specialists which method is more efficient to be used when it comes to resource-leveling.

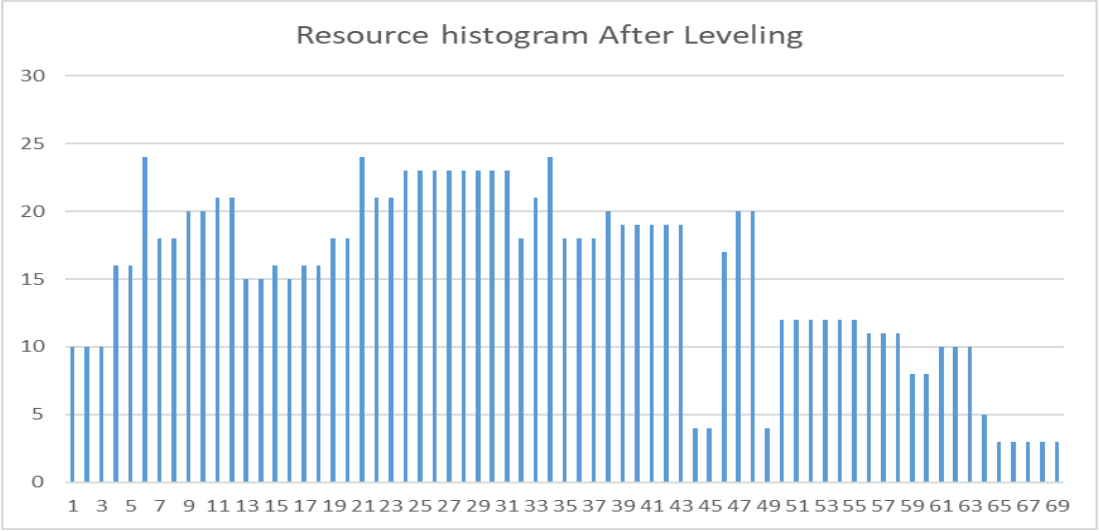


Fig.9 Resource Histogram Leveled by MOM

4.2. Comparing results of MOM vs SOS

Fig.8 represents the resource histogram that was leveled using MOM while Fig.9 represents the best resource histogram resulting from applying resource-leveling using SOS. First, a comparison will take place at the highest peak available in each resource histogram. As shown by these two figures the highest peak in other words the highest resource demand daily at both of these resource histograms is the same with a value of 24 laborers per day. Nevertheless, the SOS resource histogram shows that it consumes 24 laborers per day for 9 days while in the MOM resource histogram the demand of having 24 laborers per day is only needed for 3 days. Therefore, according to comparing the results by their peaks of labor demand MOM is more efficient in decreasing the number of laborers needed per day. Second, the results of both SOS and MOM must be compared with each other according to the fluctuations available in each histogram. It is clear that after applying resource-leveling using SOS and MOM the fluctuations in the resource histograms have been decreased bya huge amount nevertheless, SOS results show that the fluctuations have decreased even more than by using MOM [17]. It is shown in the SOS histogram that on day 43 resource demand has dropped from 19 laborers per day to 14 laborers per day while on the same day but in the MOM resource histogram resource demand dropped from 19 laborers per day to 4 laborers per day. Moreover, at SOS resource histogram on day 48, the total

amount of labor required is 12 laborers per day and on day 50 the required amount of laborers was the same on the other hand, the resource histogram developed by MOM on day 48 the amount of laborers required is 20 laborers per day but at day 50 the amount of laborers required per day has dropped to 4 laborers per day. Therefore, according to comparing both histograms to each other using the fluctuations available in both of these resource histograms SOS has proved that it develops a resource histogram with fewer amount of fluctuations than MOM resource histogram. Thus, as SOS develops a resource histogram with fewer amount of fluctuations by applying SOS for any construction project stability at the site will be maintained overusing MOM.

By comparing the results of both MOM and SOS it was shown that according to the peaks of both resource histograms (the number of resources required per day) by SOS the peaks have resulted in a huge amount of overusing MOM. On the other hand, by comparing the results to each other according to the fluctuations available in each resource histogram it was shown that the amount of fluctuations is available in the MOM resource histogram with a huge amount over the SOS resource histogram. Therefore, SOS is more useful to be used over MOM as stability at the site will be maintained in a better way by using SOS over MOM.

V. CONCLUSION

Resource leveling is the process used to minimize the fluctuations presented in the resource histogram, which will maintain more stability in the field. As was mentioned in the Literature review that there are hundreds of methods available to apply resource leveling to any construction project. However, in this paper, the main focus was on the Minimum Moment method which is a metaheuristic technique used to solve resource leveling problems by shifting the non-critical activities among their total floats. Moreover, a comparison took place between the minimum moment method and symbiotic organisms search, which is another method of leveling which performs nine different resource histograms as a result of applying it to any construction project. The comparison result proved that SOS is a more efficient technique when it comes to resource-leveling.

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