STUDYING THE DISTRIBUTION AND LEVELING OF RESOURCES IN CONSTRUCTION PROJECTS

Mr. Shishir Dadhich[1], Dr. Jyotiprakash G. Nayak[2], Mr. Ravindra Narendra Patil[3]

Article History: Received: 12.12.2022 **Revised:** 29.01.2023 **Accepted:** 15.03.2023

Abstract

In order to avoid cost overruns and schedule delays, project scheduling is essential for all construction projects. The critical path approach is the way of scheduling that is most frequently employed (CPM). The resource allocation problem (RAP) approach is introduced since CPM ignores resource availability and only considers time as a constraint. When there are more resources needed than there are available, RAP occurs. However, in order to solve the RAP, the resource levelling problem—an additional issue—must be addressed (RLP). RLP resulted in numerous labourer hires and terminations. Numerous solutions to the RAP and RLP problems have been proposed by researchers from around the world. By using ELS and the minimal moment method (MOM) to solve the resources problem, this research intends to give an integrated methodology and analogical model for planning a building project. Also, the levelled resource histogram utilising MOM and the search for symbiotic species are compared (SOS). The use of a case study for validation is discussed, along with a comparison of the two methodologies.

Keywords: Search for symbiotic organisms, project scheduling, resource planning in construction projects, and resource allocation problem (RAP) (SOS).

[1]Assistant Professor, Department of Civil Engineering, School of Engineering and Technology, Sandip University, Nashik, Maharashtra 422213
[2]Associate Professor, Department of Civil Engineering, Sandip Institute of Technology & Research Centre, Nashik, Maharashtra 422213
[3]Assistant Professor, Department of Civil Engineering, Sandip Institute of Engineering and Management, Nashik, Maharashtra 422213

Email: [1]shishir.dadhich@sandipuniversity.edu.in, [2]jyotiprakash.nayak@sitrc.org, [3]ravindra.patil@siem.org.in

DOI: 10.31838/ecb/2023.12.s3.143

1. Introduction

Project management has recently become a critical component of every building project. There should be two primary responsibilities for project management. Secondly, the timetable for the entire project, which denotes the time frame for the entire project. Second, resource planning is the process through which we allocate the appropriate amount of workers to complete each task on schedule. Moreover, resource planning considers equipment and materials by describing the quantity and kind of materials employed in the project. Each construction project must be completed on schedule and within the budget specified in the contract. Hence, in order to prevent delays and cost overruns, contractors should think about project management. Additionally, contractors will deal with the time and cost issues by scheduling the project's activities, outlining a time limit for each activity, and identifying the number of workers required for each activity. There are several techniques used to design every job. Nevertheless, the critical route strategy, which is the one that is most frequently employed, regrettably disregards resource availability. As a result, issues like resource allocation problems (RAP) and resource-leveling issues will arise. These issues may have an impact on the project's budget as well as its length.

These two issues, RAP and RLP, have a colossal number of solutions developed by researchers from around the globe. These solutions are categorised into heuristic, met heuristic, and optimisation techniques, among others. Engineering planners must select techniques that are appropriate for the project. For instance, the RLP approach should be linear if the project is intended to be a bridge because bridges are seen as linear projects like highways.

The management of resources and assuring their availability at the anticipated time is a key challenge faced in building projects. This problem largely results from relying on certain software applications to provide a work schedule without accounting for the right allocation of resources. However, even when the resources are appropriately distributed throughout the project's many activities, a different problem still occurs since the resource histogram shows multiple variations. As a result, there is a critical requirement for a specific solution that can level all resources in order to minimise resource histogram swings and guarantee that all supplies will be available for the anticipated amount of time.

The main goal of this work is to design an appropriate levelling strategy that will lessen variations in the resources histogram and minimise having more materials on site than is necessary.

The following are the goals of this study:

- Use ELS to allocate resources in building projects.
- Use the minimal moment approach for resource-leveling the same project.
- To determine whether strategy can be more successful at balancing resources in building projects, compare the outcomes of the SOS method with those from the use of MOM.

The planning of resources is one of the key elements used in the building industry. Despite the fact that it may do so in a variety of ways, many initiatives fail to consider its impact on work performance. Unwanted events that might be connected to time and expense overruns can be the outcome of poor resource management. Therefore, wise resource allocation and levelling can play a big role in ensuring the success of construction projects.

Any plant engineer or technician may find it challenging to justify an investment in a facility's infrastructure since it frequently calls for substantial reasoning. The investments that are often the simplest to back up are those that senior management has judged "low-risk" and have a quick return on investment (ROI). A thorough power monitoring system is one such investment that will yield sizable returns over the course of its operational life. Even while rising energy costs are having a bigger impact on the balance sheet, many facilities miss out on possibilities to better control these costs. Those without monitoring systems probably have no idea how much energy they use, and those who do may not be making the best use of them.

Plant managers must assess the benefits of having a monitoring programme since the quality of the energy provided can severely influence its performance, frequently resulting in loss or deterioration of equipment, product, income, and reputation.

Three techniques for monitoring solar plant systems are presented in the paper's second section. The communication and monitoring system for wind turbines is covered in the third portion, and the conclusion is covered in the fourth section.

2. Literature Survey

As a result, all necessary resources for the project should be properly allocated and scheduled in order to assure a smooth conclusion. The essential aspect of paying proper attention to and managing resources is making sure that the necessary supplies, labourers, and equipment are available when needed and are managed effectively.

Each component included in the project's resources can be impacted by a variety of variables, such as experiencing various uncertainties, a material shortage on the market, labour disputes, delays in the delivery of supplies, and equipment breakdown. On the other hand, when a project is running behind schedule or on budget, another critical situation that might arise is related to the management of assets. In order to resolve this issue, more workers, tools, and supplies are required. As a result, the main purpose of using resource allocation and planning is to give the necessary supply to execute any operation in the project in order to maintain it within the anticipated budget and achieve necessary objectives at the conclusion of this project. In order to avoid any unfavourable situations, the project manager is often in charge of estimating and assigning all necessary supplies to the project (Kumar et al., 2017; Mendoza, 1995).

Without the fundamental idea of resource levelling, there can be no resource allocation in projects. Moreover, resource levelling is the process of minimising the total of squares created in the resource histogram, which yields a rectangular shape and is the primary method of resource levelling (Mattila & Abraham, 1998).

How the available resources are going to be allocated to different activities in a way that ensures the work is completed on time, within budget, and with the quality expected by the planner engineer, is now the biggest challenge facing all construction projects. Resources are separated into two primary categories: consumable and non-consumable. Labor and machine are considered consumable resources because they have a limit and can run out, but money and machine are categorised as non-consumable resources since they will not run out (Prayogo & Kusuma, 2019). Managers mostly employ the critical path approach to guarantee that a project will be completed on schedule and within a certain budget. Although the critical path method (CPM) considers the time value, it also ignores resource availability since (CPM) always operates under the assumption that resources are limitless (Koulinas & Anagnostopoulos, 2013). Although though CPM causes the two primary issues RLP and RAP, it is still widely utilised since it merely takes into account the availability of resources. As a consequence, when contractors are allocated for a bid, those that used CPM will have the advantage in terms of timing and will most likely sign a contract.

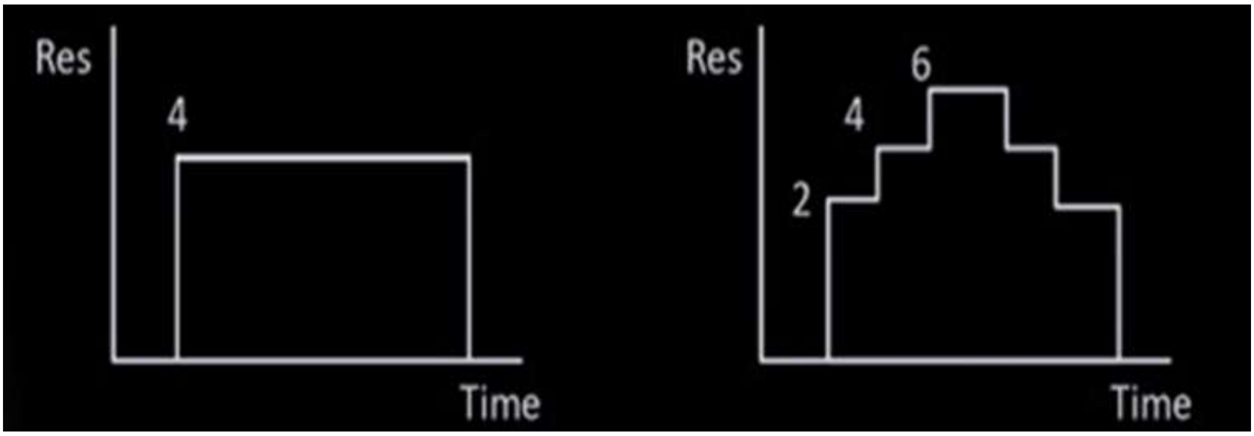

Figure 1: The distinction between uniform and non-uniform resource loading

Additionally, the critical chain project approach, another scheduling tool, is also commonly employed (CCPM). Dr. Elyahu M. Goldratt created this approach (1997). As the creator of the notion of limits, Goldratt is likewise highly recognised around the world (TOC). As each system has limitations, TOC is used to manage projects that are seen as repetitious, such as building roads, tunnels, etc. Furthermore, the performance of the restricting resources can only be increased by doing so. The TOC is the basic foundation of CCPM. Homer (1998), Leach (1999), and Simpson (1999) all advocate adopting CCPM as opposed to more conventional scheduling techniques. The goal of CCPM is to reduce project delivery time, adhere to the schedule, and maintain the initial budget approval.

The line of balance approach is another commonly employed tactic that is particularly useful for linear or repeating undertakings (LOB). LOB was first developed by the US Navy in the 1950s after being first invented by the Goodyear Company in the 1940s. It was developed for manufacturing industry production control (Koulinas & Anagnostopoulos, 2013). A diagram created by the LOB graphical scheduling method depicts the project's repetitive tasks as a single straight line on a graph. The graph in Fig. 2 has the number of floors on the y-axis and the project's total duration in months on the x-axis.

The action is then represented by the straight line in the diagram.

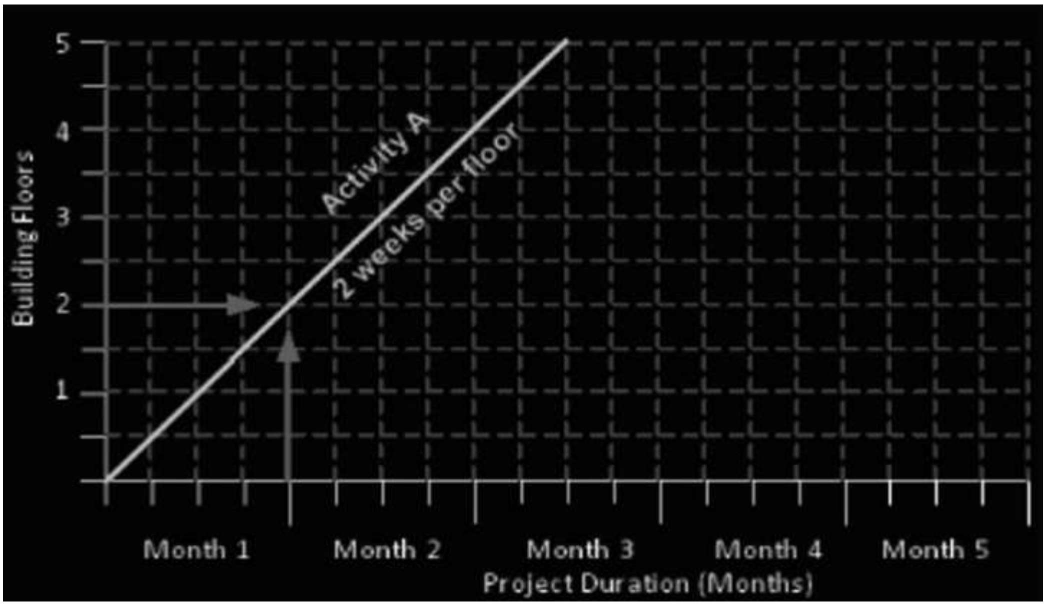

Figure 2: Project length and building floors have a relationship.

Most studies have concluded that LOB is best employed when a project's activities are repetitive or linear and that it is ineffective when used for more typical projects (Cheng & Prayogo, 2014; Prayogo & Kusuma, 2019). On the other hand, in Finland, the biggest construction firms tended to use the line of balance in the 1980s.

2.1. Resource Management

Every building project needs a range of resources to continue moving forward.

The four Ms—money, machine, material, and manpower—are commonly referred to as these resources. But, information and management choices were added to the resources by (Prayogo & Kusuma, 2019). Also, as time is a crucial resource, it should be taken into account while planning any building project (Arditi et al., 2002). Any planning method must be used to calculate the production rate for each activity. Activity duration is controlled by production rate. The production rate of a job will simply grow by using more resources, which will shorten the length of the activity (Halpin & Riggs, 1992; Khabiri, 2016). Hence, attempting to speed up the production of essential tasks will enable the project to be completed sooner.

2.2. Issues with Traditional Project Scheduling:

After project planning, the site is where the majority of problems arise. These issues are referred to as resource allocation problems (RAP), resource investment difficulties, and resource-constrained scheduling issues in various works (RCSPs) The resource levelling problem (RLP), also known as resource smoothing, is the other issue. Where resource allocation refers to how the resources will be distributed among various activities in a way that lowers the cost of the resources required and completes the project within the anticipated time frame (Halpin & Riggs, 1992). The term "resource allocation problem" (RAP) will be used to refer to the issue that arises when there are more resources needed than there are resources available. This issue will result in an extension of the project's overall length. Effective resource allocation must be used to cut the length of the project as much as feasible. In addition, because of its complexity, resource levelling is one of the most challenging project management challenges (Khabiri, 2016). Resource levelling tries to reduce resource demand peaks and even out the amount of resource consumption over the course of the project days. Additionally, there are a number of justifications for using RLP approaches. First off, resource swings will be significantly reduced by Appling resource leveling. Second, the significance of maintaining a resource histogram with an equitable flow. Finally, to reach a physical resource limit (Möhring, 1984).

2.3. Solving is important (RAP), and (RLP)

Resource levelling offers solutions to a wide range of issues. From the perspective of resources, resource-leveling lowers the need for recruiting and dismissing labourers since there is no variation in resource utilisation from one day to the next. The work at the site becomes more stable as a result (Hegazy & Kassab, 2003). Resource levelling not only addresses issues with resources, but it also addresses issues with equipment consumption. The use of equipment will be more effective with a well-leveled project since the cost of mobilising and demobilising the equipment will be lower.

Excavator mobilisation and demobilisation costs, for instance, will be paid twice if excavation work for building A begins today but not for building B for another five days. Hence, resource levelling resolves issues of this nature. (Harris, 1990)

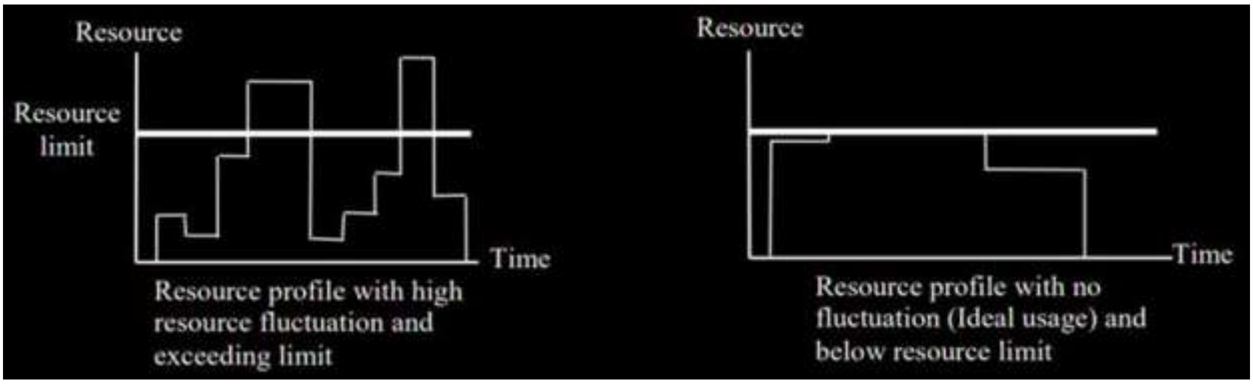

Figure 3: The use of a resource allocation both before and after

To maintain a stable working environment free from disputes and to carefully balance the quantity of work during the building project, resource allocation and resource levelling challenges must be solved (S. E. Christodoulou et al., 2010). Every strategy that addresses resource levelling and resource allocation issues has a significant impact on the resource histogram, as shown in Fig. 3. As Fig. 3 demonstrates, there are more resources needed than there are resources available. We may also look at if there are resource fluctuations. However, after implementing resource allocation and resource levelling (resource smoothing), the maximum number of resources required per day does not exceed the number of resources available. Additionally, the resource histogram has assumed the shape of a rectangle, indicating that the resources have been levelled to the greatest extent possible without lengthening the project's duration (S. Christodoulou et al., 2009). Figure 4 also makes clear how crucial it is to apply resource allocation and levelling to building projects.

3. Proposed Methodology

As was already said, the resource histogram is levelled using a moment method model, which works by reducing the amount of oscillations in the graph. The minimal moment technique works by computing the moment of each bar around the x-axis of the resource histogram; the more balanced the histogram is, the lower the overall value of the estimated moment must be. When each bar's moment is calculated around its x-axis in the first histogram, the result is 84. In the second graph, however, two resources have been moved to another day, resulting in a moment value that is lower than the first. The third graph demonstrates that, when the two days are filled with the same number of workers, there will be the least amount of moment around the x-axis, indicating that this resource's histogram is the most levelled of the three. Moreover, the overall number of workers remains constant at 16 workers.

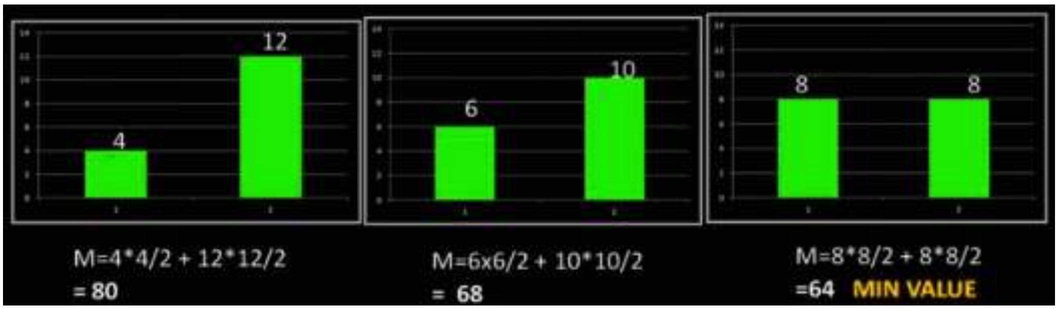

Figure 4: Lowest Moment Procedure

Furthermore, while this was the fundamental idea behind MOM, using it in practise would take a lot of time for each activity. Consequently, a function for improvement was created. These two functions (1) and (2), where M1 denotes the moment computed for the histogram prior to shifting the activity and M2 denotes the value of the moment derived following activity shifting, are how this function was discovered.

$$M_1 = \frac{1}{2} \times \sum_{1}^{m} {X_i}^2 + \frac{1}{2} \times \sum_{1}^{m} {W_i}^2$$

$$M_2 = \frac{1}{2} \times \sum_{1}^{m} (X_i - r)^2 + \frac{1}{2} \times \sum_{1}^{m} (W_i + r)^2$$

What are the preferred values for these two functions? is the question that has to be answered. The solution is straightforward: for the resource histogram to improve, M1 must be bigger than M2. The MOM's central tenet is that a more levelled histogram will be formed by placing the lowest moment value near the resource histogram's x-axis. The resource histogram is said to be more levelled if M1, the value of the moment before shifting, is bigger than M2, the value of the moment after shifting. This led to the development of a function known as the improvement function (If), which was motivated by the idea that M1 must be greater than M2. The following equation displays the improvement function (3).

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

The following are represented by each variable:
- M is the minimum number of days that the activity is shifted or the duration of the activity; - Xi is the daily resource sum for the current time frame over which resources will be subtracted; - Wi is the daily resource sum for the future time frame over which resources will be added; - R is the daily resource rate for the activity.

Also, this function ought to be used for all optional actions found in the earlier case study in this paper.

The function that determines whether or not the resource histogram is improving is depicted below. The number obtained by using this function spans from 1.1 to 1.3, and the lower the value, the more evenly distributed the final resource histogram will be. The following are represented by the variables in this equation:

- n is the overall project's day count.
- r = total resources required for the entire project.

$$\frac{n \times r^2}{\sum r}$$

This procedure has to be repeated after applying MOM to the case study's non-critical activities until no more positive values were obtained after using the improvement function.

3.1. Model Creation

Any construction project should be scheduled using the appropriate scheduling techniques. For instance, if a bridge needs to be built, the Line of Balance (LOB) method will be the most effective way to schedule that project because it is a linear method used for linear projects like bridges and roads. Although the project in this case study was not linear, the Critical Path Method (CPM) was selected for scheduling. Moreover, CPM will result in the project being completed in the smallest amount of time possible because it does not view resources as a restriction, maybe just viewing time.

Initially, a table should be used to present the project's details. The table shows the name of each activity, the time needed to complete the task, the number of workers required to complete the job, the preferred and latest start dates for the activity, as well as the relationships between the activities. We can build a Primavera model to keep a resource histogram for this project using the data from the table.

3.2. Model Primavera

To get the resource histogram using the Primavera model, there are numerous steps to do. We began by placing each activity and determining the original time frame needed for each activity. Second, relationships between activities will occur; these relationships can take a variety of shapes, including start to finish (SF), start to start (FS), and finish to finish (SS) (FF). The relationships between all activities in this case study were presented as SS.

3.3. Modelling Verification

A solved example utilising the generated minimal moment model is provided, and a comparison between the two outputs will take place, in order to ensure that the model produced to handle the resource levelling problem using the minimum moment approach is operating appropriately. To ensure that the model created works properly, the example in Table 1 should be solved. Whereas Fig. 5 displays the ultimate outcome, which is regarded as the model response. The improvement factor, which is 1.1392 as shown in the picture, is thought to be precisely levelled since it is so near to 1.1.

Table 1: Solved Illustration

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

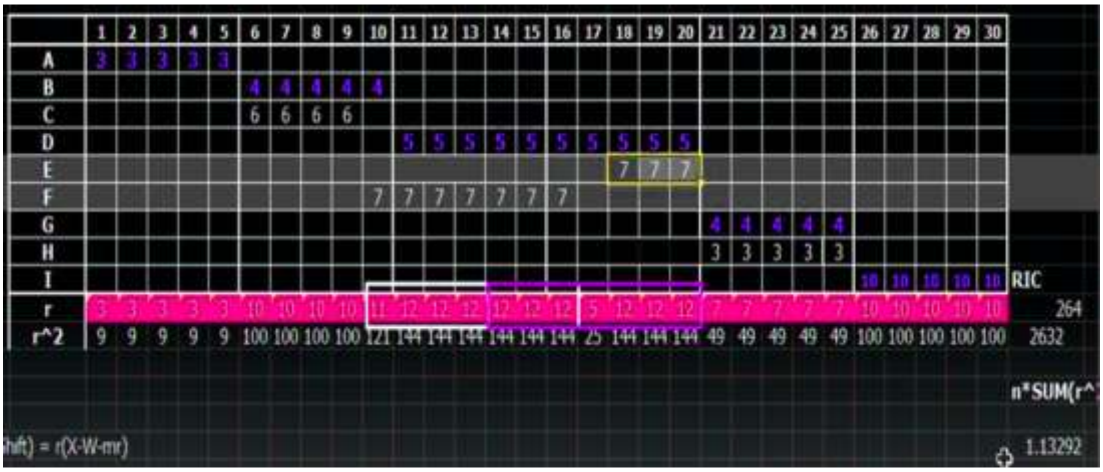

Figure 5: Solution

4
. Analysis and Discussion
4.1. Case Study

To compare the outcomes, Table 2 shows the case study that was resolved using SOS and will be resolved once again using MOM.

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

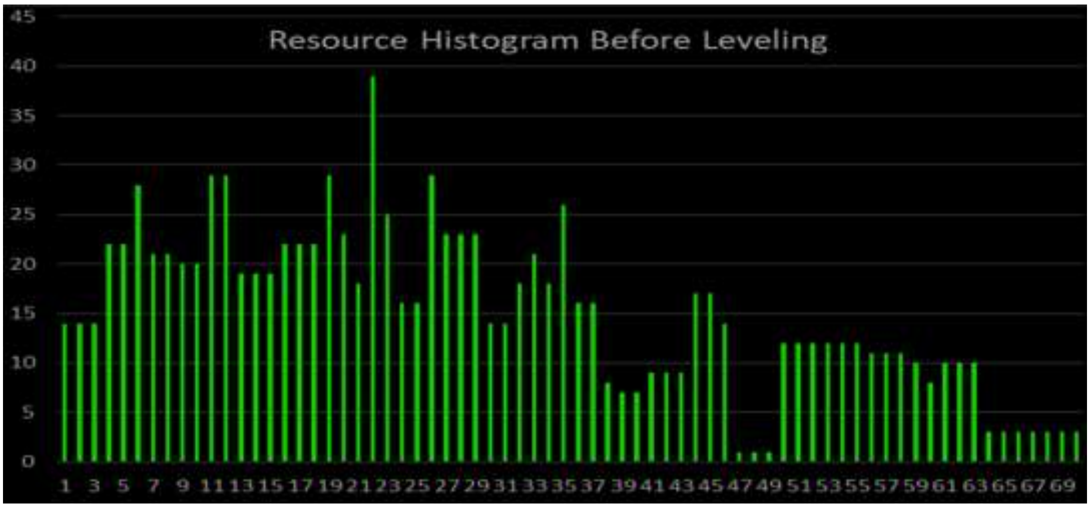

Figure 6: Before levelling, the resource histogram

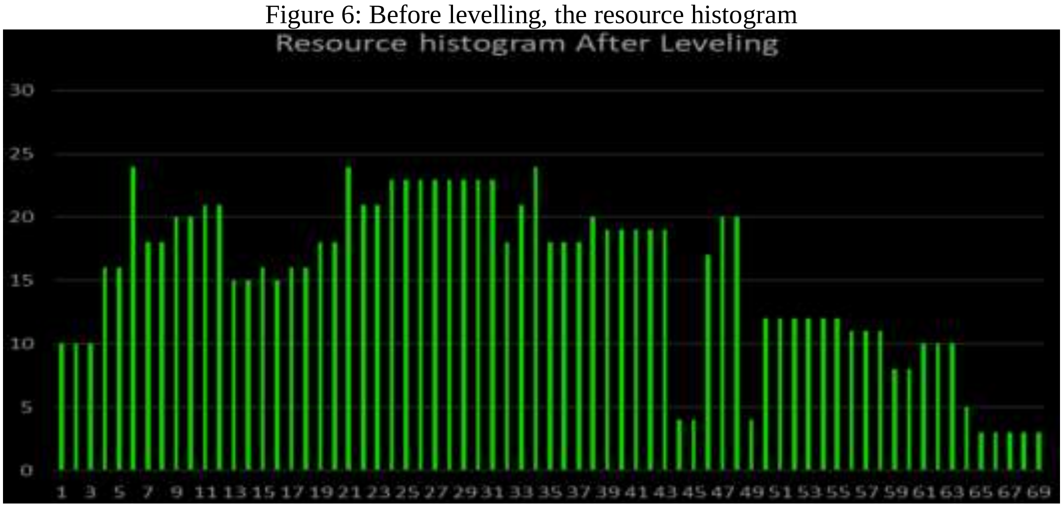

Figure 7: Histogram of Resources Following Leveling

It is quite easy to know or determine that the resource histograms hold less fluctuations than before levelling by comparing these histograms of resources with one another in terms of fluctuations. Moreover, fewer workers are needed every day than they were before to levelling. For instance, the number of labourers needed on day 22 of the project before levelling was 39, whereas on that day but after levelling the number of labourers required was 24, and that is a great change that enables the company to decrease the amount of labourers needed by 15 labourers, indicating that not only stability has been reached in the field but also a significant cost reduction has resulted.

The issue of whether this levelled resource histogram is the best option for levelling the resource histogram accessible in this case study must be posed, on the other hand, at this point. Furthermore, there are several techniques utilised to level resource histograms for every building project in order to keep the site stable. Symbiotic Organisms Search will be utilised as the methodology to compare MOM solutions (SOS). By relocating non-critical operations along their total floats, SOS also levels resource histograms. Yet, SOS produces nine distinct resource histograms since it employs nine distinct functions, each of which operates on a separate variable.

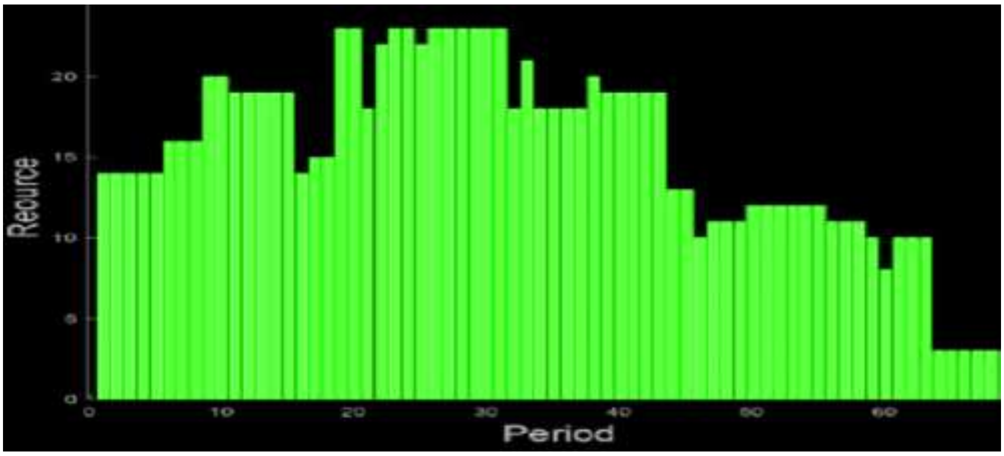

Figure 8: Resource Histogram with SOS Leveling

In order to make it clear to project managers and experts which method is more effective to use when it comes to resource-leveling, the results were maintained by levelling the resource histogram using the minimum moment method will be compared with the best-shaped resource histogram that was maintained by solving the same case study using SOS.

Figure 9: Resource Histogram with MOM Leveling

4.2. Evaluation of MOM vs. SOS outcomes

Figure 8 shows the resource histogram after using MOM to level resources, whereas Figure 9 shows the optimal resource histogram after utilising SOS to level resources. The highest peak in each resource histogram will be used for comparison first. These two figures demonstrate that the greatest peak, or the largest daily resource demand, is the same for both resource histograms, with a value of 24 workers per day. Yet, the SOS resource histogram reveals that it requires 24 workers per day for 9 days, but the MOM resource histogram only requires 24 workers per day for 3 days. As a consequence, MOM is more effective in reducing the number of workers required each day when outcomes are compared based on respective peaks of labour demand. Second, the variations shown in each histogram's findings from SOS and MOM must be compared to one another. The resource histogram fluctuations have obviously been greatly reduced after applying resource-leveling using SOS and MOM, however SOS findings indicate that the fluctuations have been reduced even more than by using MOM. The SOS histogram shows that on day 43, resource demand decreased from 19 workers per day to 14 labourers per day, but on the same day, resource demand decreased from 19 labourers per day to 4 labourers per day in the MOM resource histogram. Additionally, the resource histogram created by SOS shows that 12 labourers are needed daily in total, and that number remained the same on day 50. In contrast, the resource histogram created by MOM shows that 20 labourers are needed daily on day 48, but that number has decreased to 4 labourers on day 50. SOS has thus demonstrated that it creates a resource histogram with less amount of fluctuations than MOM resource histogram by comparing the two histograms to each other utilising the fluctuations accessible in both of these resource histograms. As a result, stability at the site will be maintained by applying SOS to any construction project since SOS generates a resource histogram with less amount of variation.

It was demonstrated by comparing the outcomes of MOM and SOS that, in accordance with the peaks of both resource histograms (the quantity of resources needed each day), SOS's peaks have led to a significant amount of overusing MOM. On the other hand, it was demonstrated by comparing the findings to one another in accordance with the fluctuations present in each resource histogram that the MOM resource histogram has significantly more fluctuations than the SOS resource histogram. SOS should thus be used instead of MOM since it will help to maintain site stability more effectively.

5. Conclusion

Resource levelling is the method used to reduce the variations shown in the resource histogram, maintaining more field stability. There are hundreds of ways to apply resource levelling to each building project, as was discussed in the literature study. Nevertheless, the Minimal Moment approach, a novel heuristic strategy used to tackle resource levelling issues by distributing the non-critical activities among their total floats, was the major emphasis of this work. Also, a comparison was made between the minimal moment approach and the symbiotic organisms search, another levelling technique that, when used on any building project, produces nine separate resource histograms. The comparative outcome demonstrated that SOS is a more effective method for resource leveling.

6. References

Arditi, D., Tokdemir, O. B., & Suh, K. (2002). Challenges in line-of-balance scheduling. Journal of Construction Engineering and Management, 128(6), 545–556.

Cheng, M.-Y., & Prayogo, D. (2014). Symbiotic organisms search: a new metaheuristic optimization algorithm. Computers & Structures, 139, 98–112.

Christodoulou, S. E., Ellinas, G., & Michaelidou-Kamenou, A. (2010). Minimum moment method for resource leveling using entropy maximization. Journal of Construction Engineering and Management, 136(5), 518–527.

Christodoulou, S., Ellinas, G., & Aslani, P. (2009). Entropy-based scheduling of resource-constrained construction projects. Automation in Construction, 18(7), 919–928.

Halpin, D. W., & Riggs, L. S. (1992). Planning and analysis of construction operations. John Wiley & Sons.

Harris, R. B. (1990). Packing method for resource leveling (PACK). Journal of Construction Engineering and Management, 116(2), 331–350.

Hegazy, T., & Kassab, M. (2003). Resource optimization using combined simulation and genetic algorithms. Journal of Construction Engineering and Management, 129(6), 698–705.

Khabiri, M. M. (2016). The Application of Factor Analysis to Determine the Parameters of Planning Work-Zone in the Road Repair and Maintenance. International Journal of Sustainable Construction Engineering and Technology, 7(1), 1–10.

Koulinas, G. K., & Anagnostopoulos, K. P. (2013). A new tabu search-based hyper-heuristic algorithm for solving construction leveling problems with limited resource availabilities. Automation in Construction, 31, 169–175.

Kumar, V., Shahpur, S., Maneeth, P. D., & Brijbhushan, S. (2017). Analysis of academic building by planning, scheduling & resource allocation using oracle® primavera p6. International Journal of Scientific Research in Science and Technology (IJSRST),(3), 6, 518–527.

Mattila, K. G., & Abraham, D. M. (1998). Resource leveling of linear schedules using integer linear programming. Journal of Construction Engineering and Management, 124(3), 232–244.

Mendoza, C. E. (1995). Resource planning and resource allocation in the construction industry. FLORIDA UNIV GAINESVILLE.

Möhring, R. H. (1984). Minimizing costs of resource requirements in project networks subject to a fixed completion time. Operations Research, 32(1), 89–120.

Prayogo, D., & Kusuma, C. T. (2019). Optimization of resource leveling problem under multiple objective criteria using a symbiotic organisms search. Civil Engineering Dimension, 21(1), 43–51