Resource Leveling Optimization Using Different Objective Functions on Building Project

Artya Irvania[1], Alwafi Pujiraharjo[2], Agus Suharyanto[2]

[1]Civil Engineering Department, University Brawijaya, Malang, INDONESIA
[2]Lecture of Civil Engineering Department, University Brawijaya, Malang, INDONESIA

E-mail: artyairvania11@gmail.com

| Submitted: June 27, 2023 | Revised: June 28, 2023 | Accepted: January 10, 2024 |

| Published: January 12, 2024 |

ABSTRACT

One of the problems that often occur in allocating labor is fluctuations arising from the uneven allocation of labor, so resource leveling optimization is needed to avoid these problems. This study investigates the impact of five objective functions to determine which objective function can produce an efficient labor histogram and determine the effect of resource leveling on changes in labor cost fluctuations based on case studies. The research was conducted using the symbiotic organisms search (SOS) algorithm. The results of this study show that objective function 4 (the minimum amount of the sum of the squared deviations in the use of resources between time intervals) is more effective than other objective functions by producing the most significant average increase in fitness value of 61.64% and can produce a smoother labor allocation histogram compared to other objective functions. Resource leveling also affects cost fluctuations, with a decrease in efficiency of 47%, so that it can improve project implementation efficiency and effectiveness.

Keywords: fluctuation; optimization; labor; resource leveling; SOS.

INTRODUCTION

Allocating and managing labor resources is a significant challenge in project execution because, if not planned properly, it will result in increased costs, decreased profit margins, decreased quality, and delays in project completion. Therefore, the success of project implementation depends not only on quality and quantity but also on the proper allocation of resources (Yahya & Abma, 2022). One problem that often occurs on projects is fluctuations caused by uneven labor allocation. For example, on certain days, labor may have no tasks, while on other days, much labor is needed only for a short time, causing the labor demand graph to fluctuate (Loleh et al., 2022).

One technique to handle and avoid fluctuations is resource leveling. Resource leveling is a method used to reduce the mismatch between labor requirements and the type of labor desired (Mahendra et al., 2022). Many researchers have studied meta-heuristic approaches to find more reliable optimization alternatives for solving resource leveling problems (Prayogo & Kusuma, 2019). Researchers have studied this problem extensively, so several meta-heuristic algorithms have been developed to address resource leveling. Some of the frequently used meta-heuristic methods include Ant Colony Optimization (ACO) by (Huang et al., 2015), Differential Evolution (DE) by (Tran et al., 2016), Genetic Algorithm (GA) by (Li et al., 2018), Particle Swarm Optimization (PSO) by (Zhang & Yang, 2018), and Symbiotic Organisms Search (SOS) by (Prayogo & Kusuma, 2019). However, according to research by (Cheng et al., 2016), meta-heuristic algorithms such as DE, GA, and PSO are less effective because they are not entirely free from some existing constraints, meaning that these algorithms rely too much on parameter tuning, where if the settings on the parameter tuning are not correct, it will increase the time for computation until finding the optimal solution to the problem.

Prayogo & Kusuma (2019) conducted research comparing the performance of SOS with PSO with nine optimization criteria using a case study from Sears (2008). The results obtained by SOS are superior to PSO by producing better solutions in eight of the nine objective functions used; only one objective function produces the same fitness value as PSO. Objective function 8 (minimum sum of the squared deviations in resource utilization between time intervals) provided the most significant

pISSN 2302-4240
eISSN 2655-2086
Volume 13, Issue 1, February 2024, pp.182-191
DOI: http://dx.doi.org/10.32832/astonjadro.v13i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

average increase in fitness value of 58.14%. In connection with that, this research wants to continue the research of Prayogo & Kusuma (2019) by using the SOS algorithm to simulate the five best objective functions produced by the research. This research is applied to a construction project with different objects and types of projects, namely a dormitory building construction project in Sidoarjo. In addition, this research contributes to analyzing the effect of resource leveling on labor costs, where previous research only focused on performance and impact without explicitly considering the cost aspect. By including cost analysis, this research can provide a more comprehensive understanding of the effectiveness of the SOS method in resource leveling on construction projects.

Based on the empirical studies above, this research uses the SOS algorithm, which still needs to be applied in handling resource leveling. The advantage of the SOS algorithm is that it does not require particular parameters like most other meta-heuristic algorithms and can exploit well through mutualism and commensalism (Ezugwu & Prayogo, 2019). This study aims to determine which objective function can provide the most significant average increase to produce an efficient labor histogram to see the effect of resource leveling on changes in fluctuations in labor costs on the project. The research is expected to be applied easily, practically, and accurately in overcoming the problem of resource leveling on the project; for that, the researcher proposes this research topic.

RESEARCH METHODS

Materials

The research was conducted on a medium-scale building project, namely a dormitory building in Sidoarjo. The data used are project plan data, including Time Schedule, Labor Schedule, and Analysis of The Unit Price of Work (AHSP). The main tools needed for this research are Microsoft Project 2013 and MATLAB 2022 trial version.

Methods

1) Resource Leveling

Table 1. Objective Function on Resource Leveling

Objective Function	Optimization Criteria	Equality	Notation Description
1	The minimum amount of absolute deviation in daily resource usage	$Z = \min \sum_{i=1}^{T} \lvert Rdev_i \rvert$	min = minimize i = day under consideration T = project duration $Rdev_i$ = deviation between required resources on a day i and i+1
2	Minimum number of days only with incremental resource usage from the previous day	$Z = \min \sum_{i=1}^{T} \lvert Rinc_i \rvert$	min = minimize i = day under consideration T = project duration $Rink_i$ = increase between required resources on a day i and i+1
3	Minimum amount of maximum deviation in daily resource usage	$Z = \min\left[\max \lvert Rdev_i \rvert\right]$	min = minimize max = maximum i = day under consideration $Rdev_i$ = deviation between required resources on a day I and i+1
4	The minimum sum of the squared deviation in daily resource usage	$Z = \min \sum_{i=1}^{T} \left(Rdev_i\right)^2$	min = minimize i = day under consideration T = project duration $Rdev_i$ = deviation between required resources on day i and i+1
5	The minimum sum of the squares of the deviation between daily resource usage and average daily resource usage	$Z = \min \sum_{i=1}^{T} \left(R_i - A_{rr}\right)^2$	min = minimize i = day under consideration T = project duration R_i = resources needed on a day i A_{rr} = average resource usage

Source: (Prayogo & Kusuma, 2019)

The selection of an appropriate objective function in resource leveling is essential to understand the efficient use of different types of resources. Different objective functions and resource leveling models cannot provide constant use of resources in every construction project, so the purpose of resource leveling is to create uniform use of resources or distribute them according to the type of resources, needs, and characteristics of the project (Damci & Polat, 2014). According to Damci (2016), project managers considering only one objective function should realize that resource distribution is not only determined by that objective function. Project complexity factors, such as the number of activities, the float of each activity, and the dependency relationship between activities, also affect the distribution of resources. By considering all these aspects, the project manager can choose the most favorable schedule in terms of resource distribution. Therefore, choosing the proper objective function is essential to achieve this. This study used the five best objective functions generated by Prayogo & Kusuma (2019) research, shown in Table 1.

2) Symbiotic Organisms Search (SOS)

The SOS algorithm was first introduced by Cheng & Prayogo (2014). The SOS algorithm is based on the interaction pattern between organisms in nature that depend on each other for survival, and this inspired the algorithm to use symbiosis to find the optimal solution to the optimization problem (Cheng & Prayogo, 2014). The SOS algorithm adopts three search phases that follow the symbiotic interaction patterns of mutualism, commensalism, and parasitism. In finding the optimal solution, the algorithm moves the population of solutions from a possible search space to a more optimal one. Each solution in the population is an organism with a fitness value representing its survival advantage in the new environment (Prayogo et al., 2018). The three phases used in SOS are described as follows:

a) Mutualism Phase

In this phase, X_j organisms are randomly selected from the ecosystem to interact with X_i organisms aiming to establish a mutually beneficial relationship. X_i is a vector of (i) organisms from the ecosystem, while X_j is a vector of (j) organisms from the ecosystem (where i ≠ j). X_{best} represents the best organism in the ecosystem. If the fitness value of X_{inew} is better than X_i, then X_i will be replaced by X_{inew}, as well as X_j and X_{jnew}. During the mutualism phase, the organism X_i interacts with X_j through Equations (2-1) and (2-2).

$$X_{inew} = X_i + rand\ (0,1) * (X_{best} – (X_i + X_j)/2 * (1 + round\ (rand\ (0,1) \quad (2\text{-}1)$$

$$X_{jnew} = X_j + rand\ (0,1) * (X_{best} – (X_i + X_j)/2 * (1 + round\ (rand\ (0,1))) \quad (2\text{-}2)$$

b) Commensalism Phase

In this phase, organism X_j is randomly selected from the ecosystem to interact with organism X_i. The two organisms establish a relationship in which X_i seeks to increase its profits, while organism X_j gains or loses nothing from the relationship. X_{best} represents the best organism in the ecosystem. If X_{inew}'s fitness value is better than X_i's, then X_i will be replaced by X_{inew}. X_i interacts with X_j through Equation (2-3) during commensalism.

$$X_{inew} = X_i + rand(-1,1) * (X_{best} –Xj) \quad (2\text{-}3)$$

c) Parasitism Phase

Xi organisms, like the anopheles mosquito, have a role in creating artificial parasites ($X_{parasite}$). X_j is randomly selected from the ecosystem and used as the host of $X_{parasite}$ (then, $X_{parasite}$ tries to replace X_j in the ecosystem). If the fitness value of $X_{parasite}$ is better than X_j, then X_j will be replaced by $X_{parasite}$. If the result is otherwise, X_j will remain in the ecosystem, and $X_{parasite}$ will die.

A. Data Analysis

Table 2. SOS Parameters

Control	Parameters
Ecosize	944
MaxIt	2000

ASTONJADRO
pISSN 2302-4240
eISSN 2655-2086
Volume 13, Issue 1, February 2024, pp.182-191
DOI: http://dx.doi.org/10.32832/astonjadro.v13i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Table 3. Project Information Data

ID	Duration (Weeks)	Resource (Persons)	ES	LS	ID	Duration (Weeks)	Resource (Persons)	ES	LS
1	0	0	0	0	60	1	4	13	25
2	3	31	2	2	61	1	4	13	25
3	1	10	1	1	62	1	4	12	24
4	3	4	2	2	63	1	24	15	25
5	2	0	2	24	64	1	32	14	14
6	1	33	5	5	65	1	66	15	15
7	1	34	6	6	66	1	12	15	15
8	1	18	8	8	67	1	14	15	15
9	1	8	6	6	68	1	42	15	15
10	4	77	7	22	69	2	266	21	24
11	1	56	15	25	70	3	53	11	12
12	2	8	10	10	71	3	55	12	13
13	2	11	10	10	72	3	39	13	14
14	2	18	10	10	73	2	5	13	24
15	2	21	10	10	74	2	16	14	24
16	2	12	11	24	75	2	6	14	24
17	2	20	10	23	76	1	40	15	25
18	2	36	11	24	77	2	82	14	14
19	2	8	12	24	78	2	87	15	15
20	2	8	11	23	79	2	58	15	15
21	2	8	12	24	80	2	5	15	24
22	2	20	12	12	81	2	16	15	19
23	2	22	11	24	82	2	6	15	24
24	2	41	12	12	83	2	21	15	24
25	1	35	13	14	84	2	14	15	15
26	2	34	12	13	85	1	144	16	22
27	1	96	13	14	86	1	61	17	25
28	1	30	13	13	87	1	87	17	25
29	2	22	12	12	88	2	8	18	24
30	1	98	13	13	89	2	4	18	24
31	1	27	14	15	90	2	68	17	21
32	1	38	13	25	91	2	13	19	24
33	1	71	14	15	92	2	45	19	24
34	1	24	14	25	93	2	10	20	24
35	1	11	14	25	94	2	4	20	24
36	1	4	12	25	95	2	8	22	24
37	1	4	11	25	96	1	35	22	23
38	1	5	11	24	97	3	34	10	23
39	1	4	14	25	98	3	36	11	23
40	1	4	13	24	99	1	37	14	25
41	1	4	13	24	100	1	127	14	25
42	1	24	13	22	101	3	21	21	23
43	1	24	12	21	102	3	11	22	23
44	1	24	11	20	103	3	6	18	23
45	1	24	13	25	104	1	29	20	25
46	1	24	12	24	105	1	21	23	25
47	1	24	11	23	106	1	58	24	25
48	1	24	12	12	107	3	19	22	23
49	1	36	11	11	108	3	25	23	23
50	1	90	12	12	109	1	8	16	25
51	2	15	13	24	110	1	41	21	25
52	1	30	12	25	111	1	34	22	25
53	1	44	11	23	112	1	31	22	25
54	1	116	12	25	113	3	22	17	17
55	1	12	12	25	114	1	63	18	18
56	1	6	12	25	115	1	43	18	18
57	1	25	12	25	116	1	7	18	25
58	1	31	12	25	117	2	9	20	24
59	1	127	11	23	118	3	6	23	23

This study used a quantitative descriptive research method. The data used consists of 118 activities and lasts 25 weeks. The completion of this research begins with a scheduling analysis using the precedence diagram method (PDM) with the help of Microsoft Project 2013 to produce Early (ES) and Late Start (LS), which are used in the resource leveling optimization process. The optimization process was repeated 30 times with 2000 iterations using MATLAB 2022 trial version software to obtain accurate and consistent results for each objective function. Table 2 presents the parameter of the SOS algorithm used in this study. The project details are shown in Table 3.

RESULT AND DISCUSSION

Impact of The Objective Functions on Resource Leveling

In this section, to determine the impact of the five objective functions on resource leveling, it is necessary to analyze the evaluation results by calculating the increase in fitness value. The fitness value of the objective function before leveling is used as the basis for comparison. Meanwhile, to determine which objective function can provide the most significant improvement, each resource leveling result of the five objective functions needs to be assessed based on other objective functions. The fitness value of each objective function is calculated using the work activity start time generated by the SOS algorithm.

Table 4 shows that some objective functions experienced increased fitness value after resource-leveling. However, objective functions 1 and 2 decreased after leveling using the results of objective function 5. The decrease indicates that using the results of objective function 5 in the leveling process does not produce the optimal or best solution, so it does not meet the criteria of a particular objective function. However, other objective functions experience an increase in fitness value after leveling with any objective function. Furthermore, to determine which objective function can provide a solution with the most significant improvement of all objective functions, it is necessary to calculate the average increase in fitness value by dividing the fitness value between after and before leveling.

Table 5 shows that each objective function provides different performance improvements. Objective function 4 provides the most significant increase in fitness value after leveling using the results of the objective function itself, which is 93.71%. Objective function 4 also produced the most significant average fitness value improvement of 61.64%, followed by objective functions 1 and 2, with average fitness value improvements of 58.44% and 57.70%, respectively. An objective function should produce an optimal solution and improve the overall quality of the solution population. Based on these results, objective function 4 is more effective than other objective functions. The results of this study are consistent with several previous studies, namely Damci & Polat (2014), Cheng et al. (2016), and Prayogo & Kusuma (2019), where objective function 4 with optimization criteria, minimizing the sum of squared deviations in resource usage between time intervals provides the best improvement in solution performance.

Table 4. Fitness Value of Multiple Objective Functions

Objective Function	Objective Function				
	1	2	3	4	5
1	522	437	192	47116	634020
2	578	434	197	51708	657460
3	934	668	79	53670	670690
4	571	434	104	30479	616230
5	**2601**	**1333**	226	311800	315280
Before Leveling	2343	1187	354	484600	1382100

Table 5. Percentage Increase in Fitness Value After Leveling

Objective Function	Objective Function					Average (%)
	1	2	3	4	5	
1	77.72	63.18	45.76	90.28	54.13	58.44
2	75.33	63.44	44.35	89.33	52.43	57.70
3	60.14	43.72	77.68	88.92	51.47	51.02
4	75.63	63.44	70.62	**93.71**	55.41	**61.64**
5	**-11.01**	**-12.30**	36.16	35.66	77.19	6.23

ASTONJADRO
pISSN 2302-4240
eISSN 2655-2086
Volume 13, Issue 1, February 2024, pp.182-191
DOI: http://dx.doi.org/10.32832/astonjadro.v13i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Labor Histogram After Resource Leveling

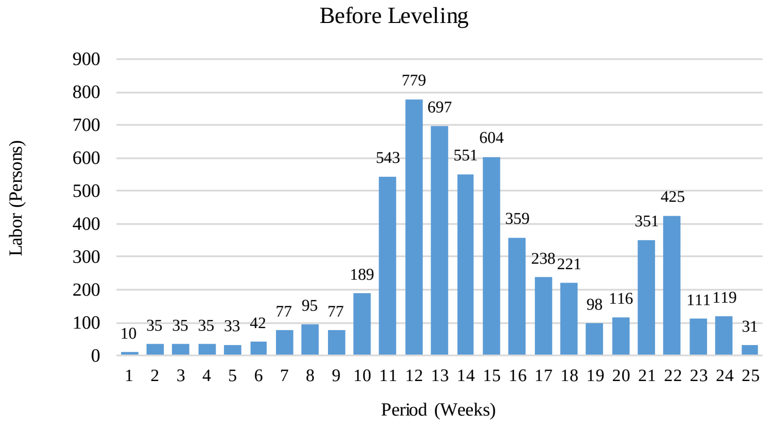

Figure 1. Labor Histogram Before Leveling

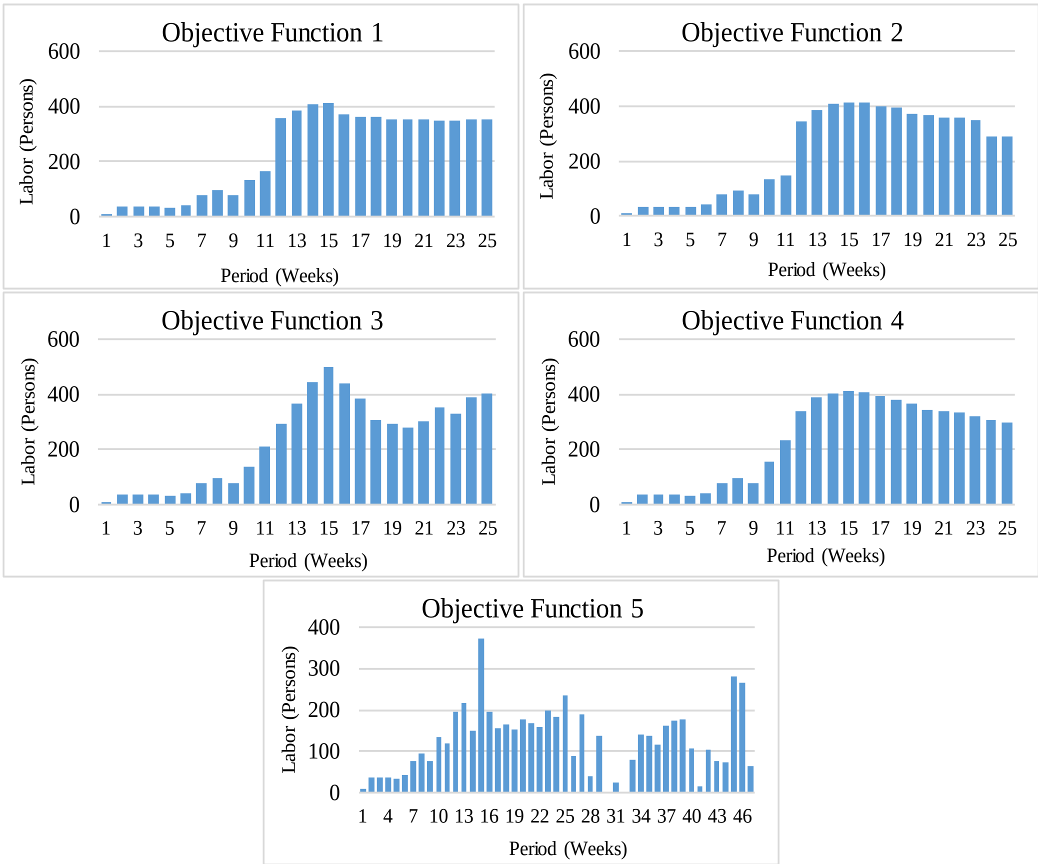

Figure 2. Labor Histogram After Resource Leveling

Figure 2 shows that the labor histogram after leveling using the SOS algorithm looks smoother than before leveling presented in Figure 1. However, in Figure 2, objective function 5 shows a labor histogram that does not meet the constraint function, so the resulting histogram exceeds the predetermined project duration limit. This indicates a mismatch between the objective function and the constraint function used. Regarding Table 4, objective function 5 produces the worst average increase in fitness value, which is 6.23%. In addition, the results of objective function 5 also reduce the performance of solutions to objective functions 1 and 2 with a decrease of -11.01% and -12.30%, respectively, so that the solution generated from objective function 5 cannot be used as a feasible solution. Meanwhile, the other objective functions show that the resulting labor histogram can fulfill the constraint function.

Figure 2 also shows that objective function 4 can produce a smoother histogram than other objective functions. These results are consistent with the calculation of the average increase in fitness value, where objective function 4 can produce the best overall increase of 61.64%. Based on this, the objective function that can produce the most efficient labor availability and be a feasible solution is objective function 4, so contractors can consider using objective function 4 in solving resource leveling problems.

The Effect of Resource Leveling on Labor Wage Costs

Table 6. Comparison of Labor Wage Costs Before and After Leveling

Weeks	Before Leveling		After Leveling	
	Resources	Labor wage costs	Resources	Labor wage costs
1	10	Rp. 1.045.600	10	Rp. 1.045.600
2	35	Rp. 3.654.500	35	Rp. 3.654.500
3	35	Rp. 3.654.500	35	Rp. 3.654.500
4	35	Rp. 3.654.500	35	Rp. 3.654.500
5	33	Rp. 3.442.200	33	Rp. 3.442.200
6	42	Rp. 4.386.200	42	Rp. 4.386.200
7	77	Rp. 8.131.400	77	Rp. 8.131.400
8	95	Rp. 10.010.600	95	Rp. 10.010.600
9	77	Rp. 8.131.400	77	Rp. 8.131.400
10	189	Rp. 19.879.200	155	Rp. 16.306.100
11	543	Rp. 56.908.100	235	Rp. 24.629.500
12	**779**	**Rp. 81.637.200**	339	Rp. 35.501.000
13	697	Rp. 73.021.600	388	Rp. 40.623.900
14	551	Rp. 57.691.500	402	Rp. 42.073.500
15	604	Rp. 63.198.800	**414**	**Rp. 43.302.000**
16	359	Rp. 37.549.200	409	Rp. 42.792.800
17	238	Rp. 24.886.100	393	Rp. 41.178.500
18	221	Rp. 23.121.300	383	Rp. 40.126.900
19	98	Rp. 10.258.000	369	Rp. 38.648.800
20	116	Rp. 12.159.900	343	Rp. 35.929.600
21	351	Rp. 36.799.300	339	Rp. 35.548.700
22	425	Rp. 44.548.600	334	Rp. 35.012.800
23	111	Rp. 11.652.900	323	Rp. 33.863.500
24	119	Rp. 12.484.400	309	Rp. 32.401.000
25	31	Rp. 3.257.700	297	Rp. 31.115.200
Total	**5871**	**Rp. 615.164.700**	**5871**	**Rp. 615.164.700**

pISSN 2302-4240
eISSN 2655-2086
Volume 13, Issue 1, February 2024, pp.182-191
DOI: http://dx.doi.org/10.32832/astonjadro.v13i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

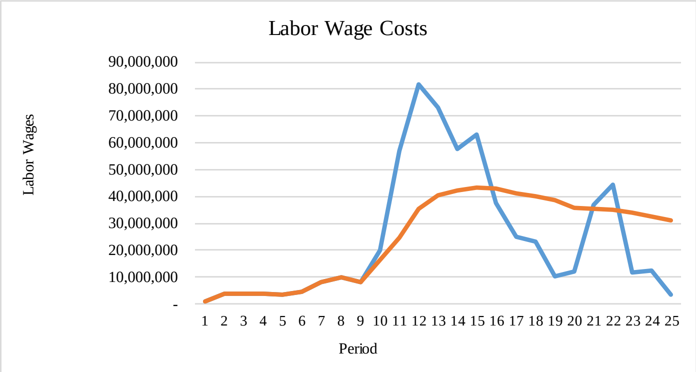

Figure 3. Comparison of Labor Costs Before and After Leveling

Table 6 shows the results of resource leveling, namely after resource-leveling, the total labor cost from week 1 to week 25 is the same as the planned labor cost, namely with a total cost of Rp. 615.164.700,00 and a total workforce of 5.871 people. These results show that the labor required to complete the project has stayed the same. No change after the leveling process can occur if the labor resources available in the planning process are optimal. These results can be supported by the research of Retno et al. (2018) conducted research related to resource leveling using Microsoft Project 2013 by comparing the planned labor cost requirement of 790 people and the realization of 831 people with the results of resource leveling. The results show that after resource leveling the required labor needs are 790 people, which means that the planned labor cost results are the same as the labor costs after leveling because the total number of workers generated before and after leveling is the same. While the realized labor cost when compared to after leveling can reduce the number of workers so that it can save the necessary costs.

However, it should be noted that the results of this optimization result in changes in the labor schedule and the histogram of labor after leveling, which can reduce the fluctuations that occur at this time, so it is necessary to analyze the amount of efficiency and effectiveness during peak costs every week. Tabel 6 shows that the peak labor expenditure before resource leveling occurred in week 12, with an expenditure of Rp. 81.637.200,00. In contrast, after leveling, the peak labor expenditure occurred in week 15 with a peak cost of Rp. 43.302.000,00. These results show that resource leveling can provide a peak cost efficiency of Rp. 38.335.200,00 or 47%.

In addition, resource leveling also has consequences for changes in workload allocation each week. Figure 3 shows that the labor diagram before leveling experienced a sharp increase from week 10 to week 12, with the maximum cost required in that period amounting to Rp. 81.637.200,00. However, after resource-leveling, the workload in week 10 to week 12 decreased so that the maximum cost became Rp. 35.501.000,00, resulting in a 57% decrease in efficiency. Changes also occurred in week 16 to week 20, where the workload before leveling decreased with a maximum cost of Rp. 37.549.200,00. However, after leveling, it shows an increase in workload in that week's range, which means that the contractor needs to prepare a higher cost than the planned cost so that the maximum cost becomes IDR 42,79,800.00 or an increase in the cost of 12%. Based on these results, the resource leveling process has successfully organized and distributed labor resources more evenly. It can reduce sharp fluctuations and imbalances that may have occurred before, thus helping to improve labor cost efficiency.

CONCLUSION

Objective function 4 (the minimum amount of the sum of the squared deviations in the use of resources between time intervals) can produce the best average fitness value increase of 61.64%. The smoothest labor histogram is also produced by objective function 4 to be used as a feasible solution and the best choice. Resource leveling does not affect the total cost of labor, but it can reduce fluctuations in workload allocation by producing a peak cost efficiency of 47%. These results interpret that using resource leveling in construction projects can help companies prepare finances and pay labor wages more efficiently during the project.

This research still uses plan data, so it is necessary to conduct further research using actual data during the project to compare plans and realizations in using labor resources if resource leveling is carried out to show the effectiveness of the SOS algorithm in more depth.

ACKNOWLEDGEMENT

The authors would like to thank Universitas Brawijaya and who have helped in carrying out this research.

REFERENCES

Cheng, M. Y., & Prayogo, D. (2014). Symbiotic Organisms Search: A new metaheuristic optimization algorithm. *Computers and Structures*, *139*, 98–112.

Cheng, M. Y., Tran, D. H., & Hoang, N. D. (2016). Fuzzy clustering chaotic-based differential evolution for resource leveling in construction projects. *Journal of Civil Engineering and Management*, *23*(1), 113–124.

Cheng, M.-Y., Prayogo, D., & Tran, D.-H. (2016). Optimizing Multiple-Resources Leveling in Multiple Projects Using Discrete Symbiotic Organisms Search. *Journal of Computing in Civil Engineering*, *30*(3).

Damci, A., Arditi, D., & Polat, G. (2016). Impacts of different objective functions on resource leveling in Line-of-Balance scheduling. *KSCE Journal of Civil Engineering*, *20*(1), 58–67.

Damci, A., & Polat, G. (2014). Impacts of different objective functions on resource leveling in construction projects: A case study. *Journal of Civil Engineering and Management*, *20*(4), 537–547.

Ezugwu, A. E., & Prayogo, D. (2019). Symbiotic Organisms Search Algorithm: theory, recent advances and applications. *Expert Systems with Applications*, *119*, 184–209.

Huang, H.-H., Huang, C.-H., & Wen, P. (2015). Solving Multi-Resource Constrained Project Scheduling Problem using Ant Colony Optimization. *Journal of Engineering, Project, and Production Management*, *5*(1), 2–12.

Sears, K.S, Sears, G.A., & S. Clough, R.H. (2008). Construction Project Management, a Practical Guide to Field Construction Management. *Publisher John Wiley & Sons Inc*.

Li, H., Xiong, L., Liu, Y., & Li, H. (2018). An effective genetic algorithm for the resource levelling problem with Generalised Precedence Relations. *International Journal of Production Research*, *56*(5), 2054–2075.

Loleh, M. A., Inkirawang, R. L., & Mangare, J. B. (2022). Perataan Sumber Daya Tenaga Kerja Pada Proyek Konstruksi Bangunan Gedung Menggunakan Microsoft Project (Studi Kasus Pembangunan Lanjutan Aula Dan Gedung RKB SMA Negeri 1 Kawangkoan). *Jurnal Sipil Statik*, *10*(1), 47–56.

Mahendra, I. K., Suardika, I. N., & Yuni, N. K. S. E. (2022). *Perbandingan Penjadwalan Proyek Dengan Dan Tanpa Resource Leveling*. *01*(01), 499–507.

Prayogo, D., Cheng, M. Y., Wong, F. T., Tjandra, D., & Tran, D. H. (2018). Optimization model for construction project resource leveling using a novel modified symbiotic organisms search. *Asian Journal of Civil Engineering*, *19*(5), 625–638.

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.

Retno, D. P., Astuti, A., & Tamimi, Z. (2018). Analisa Penggunaan Sumber Daya Manusia Dengan Metode Resource Leveling Pada Pelaksanaan Proyek Konstruksi (Studi Kasus: Proyek Pembangunan Ruang Kelas Baru Ponpes Daarun Nahdah Thawalib Bangkinang). *Jurnal Saintis*, *18*(1), 39–47.

pISSN 2302-4240
eISSN 2655-2086

Volume 13, Issue 1, February 2024, pp.182-191
DOI: http://dx.doi.org/10.32832/astonjadro.v13i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Tran, D.-H., Cheng, M.-Y., & Pham, A.-D. (2016). Using Fuzzy Clustering Chaotic-based Differential Evolution to solve multiple resources leveling in the multiple projects scheduling problem. *Alexandria Engineering Journal,* 55, 1541-1552.

Yahya, A. R., & Abma, V. (2022). Analisis Kebutuhan Tenaga Kerja Dengan Menggunakan Metode Resource Levelling. Avaliable at Researchgate.

Zhang, H., & Yang, Z. (2018). Accelerated Particle Swarm Optimization to Solve Large-Scale Network Plan Optimization of Resource-Leveling with a Fixed Duration. *Mathematical Problems in Engineering, 2018*.