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Dynamic Planning of Construction Site

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Abstract

Dynamic planning of a construction site is an unexplored part of a project execution process, according to its absence in literature. The aims of this study are first to highlight this issue basically in linear construction projects and secondly to explore its value through practical applications. For this purpose, factors that influence the selection of the construction site location and then the costs resulting from this selection are examined. The location which maximizes the production rate is investigated. The location must simultaneously minimize the non-productive time/cost and adhere to project's technical specifications. According to the project's time schedule, the "ideal" site location is explored at time intervals taking into account the work progress. The optimization method that is presented aims to minimize the cost that arises from the site non-productive time/cost and site relocation cost as part of the total construction cost. The validity of the model is tested in two real case studies. The first study investigates a vertical axe to Egnatia Odos Motorway (5.5km) and the second regards a section of Egnatia Odos Motorway in North Greece (15km). The results show that for the second project the relocation is required, with a profit of 100.000 €, whereas for the first one, relocation has no profit for the contractor. The concluding remark is that during the planning phase of linear projects, a study of dynamic site location should be performed in order to investigate whether there is a profit for the constructor from the relocation of site or not. This profit could cover expenses of financing according to the project cash flows.

Keywords: Dynamic site planning, relocation profit, optimization, cash flows.

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1. Introduction

Dynamic planning of a construction site is as an innovative idea not only targeting potential reduction of operating costs, but also pursuing increased safety levels during the construction phase of a project. However, the implementation of this process is a very challenging task due to the large number of different parameters involved in the selection of an appropriate initial location of the construction site. At the same time investigation of the potential benefits of its relocation must be performed according to the changing needs that arise from project progress. An optimization method is proposed with respect to the total operating costs by quantifying the combined effect of the cost factors involved in dynamic site planning.

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Thus far, studies on dynamic planning of construction site have been mostly focused on the effective placement of site layouts within the construction site and on their possible relocation after some time. What is ignored, is the effect of the construction site location on the total operating cost. This concept has been demonstrated through different methodologies with remarkable success, yet without considering the effect of a possible relocation of the construction site itself on the total cost of construction, safety and project duration. Cheng and O'Connor [1] developed an automatic site layout system called "Arcsite" to determine suitable areas for locating temporary site layouts in construction site. Some years later, Xu [2] demonstrated that dynamic layout planning is capable of minimizing the total operating cost and, at the same time, maximizing the safety measures on the construction site, proposing a fuzzy random multi-objective decision-making model to specify the parameters. Elbeltagi [3] presented a methodology for site layout planning, which combines the effect of safety, productivity, construction site area and the interrelationships between the necessary facilities on the total operating costs.

This paper investigates how relocation of the construction site in its entirety affects the total cost of a project. This unexplored idea despite the fact that seems relevant to the aforementioned researches, it is completely different; this research focus on the relocation of the whole construction site and not on the relocation of construction layouts into a specific construction site. In projects with several possible site locations, the focus is set on identifying the "ideal" one; being the most profitable acceptable location according to certain requirements. Therefore, criteria are formulated to determine acceptable locations for construction site and cost parameters of pertinence to the proposed methodology are discussed. Then, the "ideal" location, with respect to a specific sub-period of the construction process, is determined through the solution of an optimization process that minimizes the operating costs of the project. Eventually, the procedure is repeated for several non-overlapping sub-periods to obtain the "ideal scenario" for the entire construction period. The methodology is applied to two different road projects that have been already constructed to evaluate its potential for gaining significant cost savings.

2. Methodology

2.1. Location criteria

According to Building Regulation [4], there are several restrictions regarding the available locations for site construction. These restrictions include factors such as [5, 6, 7]:

- Availability of free spaces to host construction's site layouts [8].
- Existing electricity grid, water supply and sewage, to satisfy the demands of the site and the personnel.
- Ground morphology and quality. Some ground soils are not suitable for hosting a construction site [9].
- Environmental factors such as temperature, moisture, sun, rain.
- Ground slope. Slopes that are more than 17% [4], are considered unsuitable because of the high grade of resistance in the movement of the equipment that means higher transportation cost and waste of time.
- Legislative regulatory factors such as the use of land, biodiversity, archeology.
- The distance from public buildings such as hospitals, schools.

Taking into account these constraints, locations not fulfilling at least one of the requirements are not suitable for construction sites and therefore, they should be excluded from the following mathematical equation.

2.2. Cost parameters/factors

The following cost parameters/factors could lead to the "ideal" site location by minimizing the overall operating cost. For this research, the parameters that have been taken into account are listed below:

- Transport costs of workers and machinery. If the distance between the construction site and the workplace is long, then the transportation cost is higher. Especially for construction sites, where the transportation is intense, it is a crucial parameter.

- Duration of transportation for work. If the duration of transportation from the construction site to the workplace is long, then the production rate drops.
- Effect of acceptable slopes on the total cost. For steep slopes above 10% but below 17%, a modulation of the ground would be necessary.
- The influence of the morphology and the quality of the ground on the total cost. In case the ground is not suitable to host heavy facilities, soil reinforcement should be applied.
- Accessibility of construction site by trucks hauling material deliveries, fire trucks, ambulances.
- Accessibility from the construction site to the working site. In case there is no access, temporary site roads should be constructed.
- Preference of the decision maker. It is calculated as the total saving that the contractor would like to achieve in order to proceed the relocation of the construction site (it was taken equal to zero for this analysis).

2.3. The optimization equation

Five factors are embedded in the optimization equation for minimizing the total operating cost. The first refers to the transportation cost of the machinery from the construction site to the working site (and vice versa), while the second refers to the unproductive time due to workers transportations. The rest of the factors include costs related to ground formation, slope levelling and construction of the road network, as shown below:

$$TC(i,tp) = min \left\{ \begin{aligned} & fuel\ consumption \times fuel\ cost \times \sum_x \left(|x-i| \times transportation_{x,tp} \right) \\ & + \frac{hourly\ wage}{machinery\ speed} \times \sum_x \left(|x-i| \times transportation_{x,tp} \right) + GRcost_i + Sl_i + RC_i \end{aligned} \right\} \qquad (1)$$

where

i chainage of the controlled “ideal” location (m) and

x the chainages of the work sites in which the project is divided (m).

tp the time period, for which the quantities are taken into the calculation.

$Transportation_{x,tp}$ the total number of necessary transportations from the construction site (i) to the work site (x) for the machinery (trucks, excavator, concrete mixer) to execute a task, within the examined time period. This factor is the result of the quantities (m^3) for every task divided with the capacity (m^3) of the trucks.

fuel consumption the fuel consumption of each machine (lt/km).

fuel cost the cost of the necessary fuel that is used for the function of the machines, to execute the demanded tasks in the examined time period (€/lt).

hourly wage the average wage that the workers are paid per hour of work (€/h).

machinery speed the managed speed that each machine can achieve (km/h).

$GRcost_i$ the cost that is necessary in case that ground reinforcement is demanded (€).

Sl_i the cost that is necessary in case that slope leveling is demanded (€).

RC_i the cost for the construction of the road service network (€).

2.4. The “ideal scenario”

To identify the “ideal scenario” for the construction site of a project, the project manager should define the accuracy that would like to have in the analysis. This could be determined by setting a minimum time period in which the project manager would accept to proceed the relocation of the construction site and the density of the chainages in which the project is divided.

Specifically, in this research, the time period for a possible relocation is set 6 months or 1 semester and its multiples, and the total quantities of the materials (e.g. Concrete, steel, sewers) are divided in work sites with chainages increasing per 100 meters. In this way, it is possible to calculate the "ideal" location of the construction site not only for every semester (1, 2, 3.. N), but also for the combination of non-overlapping semesters [1+2, 1+2+3, 2+3, N+ (N+1)]. In addition, the total cost for each case is compared. Apparently, the "ideal scenario" is the one with the minimum total cost. The methodology is depicted step by step in Table 1.

For instance, supposing for scenario X, one relocation of the construction site at the end of Nth semester is examined. For the first time period which last from the beginning of the project until Nth semester, the construction site is established at the available location 'a', which is the "ideal" location for that period. The operating cost for that period and for that "ideal" location would be 'A' €. In addition, the relocation of the construction site is taking place. The relocation cost arises from the facilities that are used in the construction site, named 'R'. For the second time period, which last from the beginning of (N+1)th semester until the end of the project, the construction site is established at the available location 'b', which is the "ideal" location for that period. The operating cost for that period and for that "ideal" location would be 'B'. User Target (€) is the amount that the user would like to achieve in order to proceed the relocation of the construction site. In this way, for scenario X, it is possible to calculate the total operating cost 'X' that is the sum (A + R + B + user target).

The decision about the relocation of the construction site, is taken after comparing scenario X with the "ideal scenario". The "ideal scenario" is the one with the minimum total operating cost TC. At the first repetition of the methodology, the "ideal scenario" is the "ideal" location of the entire project, without relocation.

Table 1:Methodology for relocation of the construction site

Scenario X	**Site in chainage**	**Cost**
1st +2nd +… + N	a	A €
(N+1) +…+ Last	b	B €
Relocation cost		R €
Total scenario cost		**(A+B+R+ user target*) = X €**
Saving or charge of the basic scenario		**(TC(i)-X) = Y €**

*in the analysis that equals to zero

The result of this comparison after the subtraction [TC ("ideal scenario") –X] = Y, indicates whether the relocation provides a profit to constructor or not.

If Y > 0, then the relocation is profitable, if Y < 0, then the relocation is not profitable.

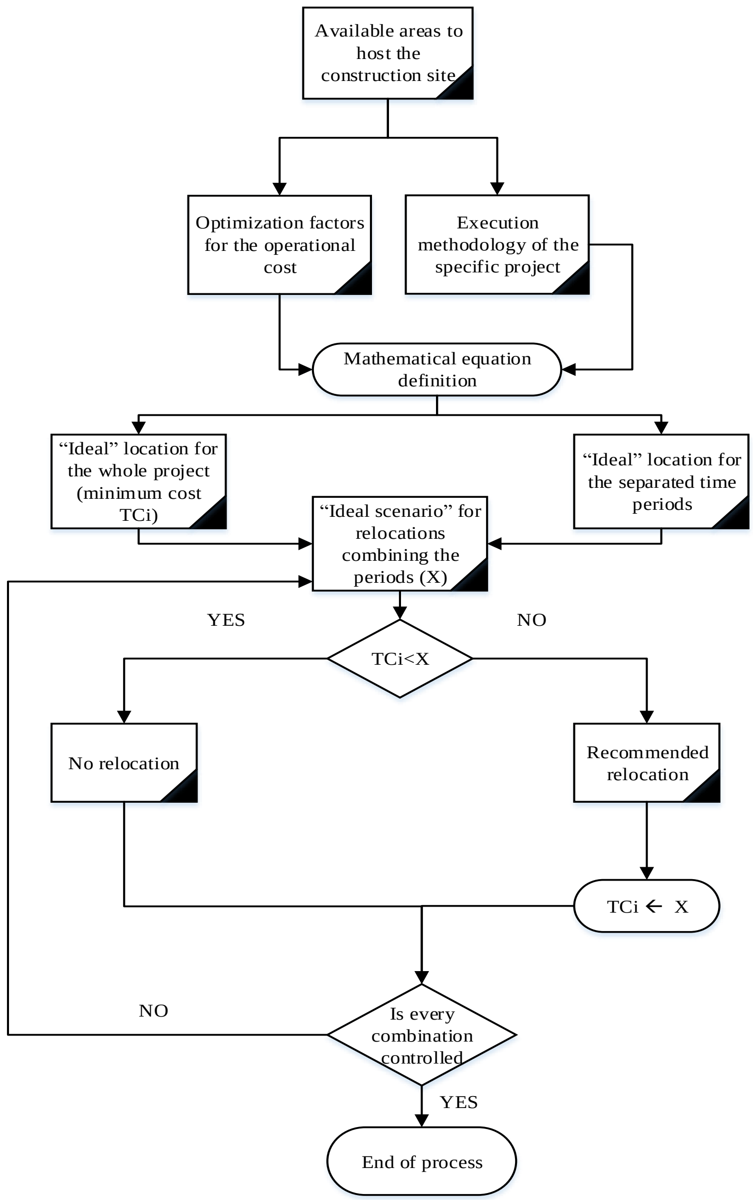

Figure 1: Methodology flowchart

The "ideal scenario" may include 2 or more relocations, so all the combinations of non-overlapping time periods should be controlled. The overall methodology is depicted in Figure 1. The process stops when no additional reduction on total operating cost of the project can be reached.

3. Applications and discussion

3.1. Case studies

The proposed methodology has been implemented into two road projects; the first project is a small vertical axe of Egnatia Odos Motorway in North Greece with a length of 5.5 km and a total cost of 25,000,000.00 €. The construction duration lasted three years from 2015 to 2018. The second project is a part of Egnatia Odos Motorway 15 km long and a total cost of 127,000,000.00 €, the construction phase of this project lasted also 3 years from 2004 to 2007. The available data for these projects was the topographic diagram, the horizontal alignment, the table of quantities of excavation and embankments, the table of technical works, the time schedule and the mechanical equipment needed for each work. The quantities of material were calculated for every 100 meters and the project duration was divided in semesters. All the data was saved in Microsoft Excel spreadsheets. For the optimization of equation (1) Evolver 7.5.2 of Palisade excel add-in tool was used. The ideal location for each scenario was then calculated.

According to the proposed methodology a cost saving of approximately 100,000.00 € was derived for the second case study. The relocation cost depends on the number and the size of site layouts. According to project managers for a typical linear project this cost might range from 30,000 € to 34,000 €.

Case study 1

According the project manager for the first project the machinery was transported from the construction site to the worksite, the products of excavation were not used for embankments, and the aggregates were stored in silos at the construction site. Thus, there were transportations from the construction site to work site. The mathematical equation resulted in that no relocation was needed and that the total operating cost for the "ideal" location was 104.507,36 €, whereas the cost of relocation was accordingly very high (Table 2).

Table 2 presents the total operating costs calculations, according to the examined location of the construction site. The first column depicts the number of the relocations that takes place in each scenario, whereas the second column shows the time period that the construction site would be established in the examined location. The fourth column indicates the operating cost of each scenario, and finally the last column calculates the profit or loss of each scenario compared to the "ideal scenario". This is essentially an application of the mathematical equation (1). That is, TC (1550, 1-6) = 142.044,10 € for the entire project. TC (i=3050, 1-3) = 39.127,72 € for the quantities of first to third semester. For the fourth to sixth semester, the ideal location is 2050. TC (i=2050, 4-6) = 83.604,51 €. So the total cost for this scenario is: TC (3050, 1-3) +TC (2050, 4-6) +Relocation Cost = 147.232,24 €, 42.724,87 € higher than the previous "ideal scenario".

Table 2: Analytically calculation of the total cost for the first project

Relocation	Time period	Ideal location	Operating cost	Relocation cost	Total cost	Profit/Loss
0	1st to 6th	1550	142.044,10 €	- €	142.044,10 €	- **37.536,73 €**
0	1st to 6th	Ideal =2650	104.507,36 €	- €	104.507,36 €	- €
0	1st to 6th	3550	122.580,05 €	- €	122.580,05 €	- **18.072,68 €**
1	1st to 3rd	Ideal =3050	39.127,72 €	24.500,00 €	147.232,24 €	- **42.724,87 €**
	4th to 6th	Ideal =2050	83.604,51 €			
1	1st to 4th	Ideal =3050	95.602,17 €	24.500,00 €	168.100,25 €	- **63.592,88 €**
	5th to 6th	Ideal =2050	47.998,08 €			
	1st to 2nd	Ideal =4250	4.555,69 €			
2	3rd to 4th	Ideal =2950	56.773,51 €	49.000,00 €	158.327,29 €	- **53.819,92 €**
	5th to 6th	Ideal =2050	47.998,08 €			

Case study 2

According the project manager for the second project machinery was stored on the work site, the products of the excavation were used for the embankments, the materials were delivered by trucks and the concrete was produced on site. The total duration of the project was 3 years (6 semesters) and the chainages were from 8+550 to 23+350. The available locations which could host the construction site were 9 (17 if only the slope parameter was taken into account, 41 if only the existing road network was taken into account). The total cost for the “ideal” location (i=14+850) of construction site without relocation is calculated 1.129.475,59 €. In this case, following the actual methodology of execution chosen by the constructor, the “ideal scenario” results in one relocation of the construction site (i1=14+650, i2=19+450) and the total savings are about 97.759,69 €. The relocation for this scenario should take place at the end of 4th semester. Table 3 presents the scenarios investigated.

Table 3: Analytically calculation of the total cost for the second project

Relocation	Time period	Ideal location	Operating cost	Relocation cost	Total cost	Profit/Loss
0	1st to 6th	11650	1.469.784,12 €	- €	1.469.784,12 €	**- 340.308,53 €**
0	1st to 6th	11850	1.436.149,95 €	- €	1.436.149,95 €	**- 306.674,36 €**
0	1st to 6th	14050	1.166.642,71 €	- €	1.166.642,71 €	**- 37.167,12 €**
(Scenario 1) 0	1st to 6th	Ideal =14850	1.129.475,59 €	- €	1.129.475,59 €	**- €**
0	1st to 6th	19450	1.363.944,17 €	- €	1.363.944,17 €	**- 234.468,58 €**
(Scenario 2) 1	1st to 4th	Ideal =14650	835.489,50 €	33.500,00 €	1.031.715,90 €	**97.759,69 €**
	5th to 6th	Ideal =19450	162.726,40 €			
(Scenario 3) 1	1st to 3rd	Ideal =14050	538.520,79 €	33.500,00 €	1.077.709,39 €	**51.766,20 €**
	4th to 6th	Ideal =19450	505.688,60 €			
	1st to 2nd	Ideal =14850	227.522,67 €			
2	3rd	Ideal =11850	289.677,88 €	67.000,00 €	1.089.889,16 €	**39.586,43 €**
	4th to 6th	Ideal =19450	505.688,60 €			
	1st	Ideal =14850	103.764,33 €			
2	2nd to 4th	Ideal =14250	726.713,93 €	67.000,00 €	1.060.204,67 €	**69.270,93 €**
	5th to 6th	Ideal =19450	162.726,40 €			
	1st to 2nd	Ideal =14850	227.522,67 €			
(Scenario 4) 2	3rd to 4th	Ideal =14050	599.960,19 €	67.000,00 €	1.057.209,26 €	**72.266,33 €**
	5th to 6th	Ideal =19450	162.726,40 €			

It is important for the successful completion of a project to safeguard financial viability throughout the construction period [10]. The proposed model of dynamic site relocation could help towards this objective. The cost savings of such a relocation process could cover financing costs. The following figures (1, 2 & 3) graphically present cash flows with cost savings in comparison among scenarios during the construction period by the adoption of a dynamic site relocation.

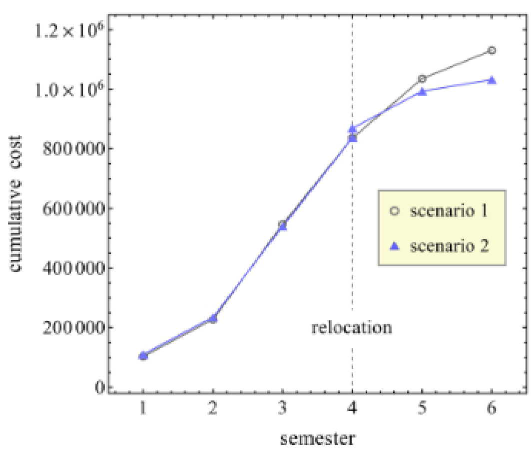

Figure 2: Operating cost cash flows scenario 1 vs scenario 2

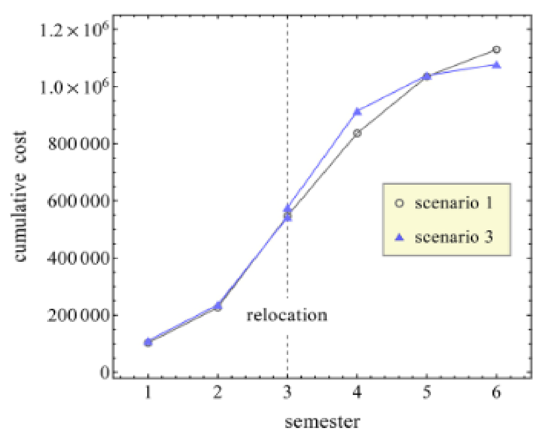

Figure 3: Operating cost cash flows scenario 1 vs scenario 3

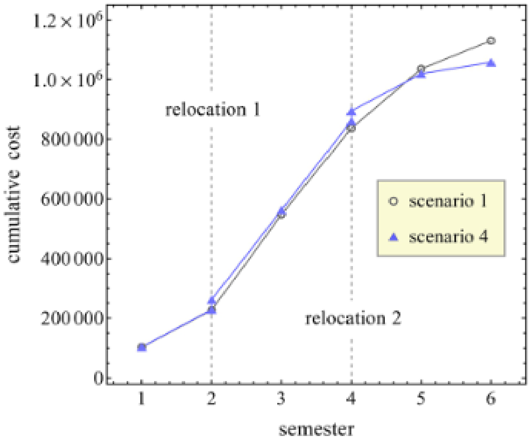

Figure 4: Operating cost cash flows scenario 1 vs scenario 4

Cost savings are developed after the relocation of the construction site, and especially at the 5th and 6th semester. This is explained from the fact that during the fifth and sixth semester the main tasks were executed at the last part of the road, which is from chainage 18+450 to 23+350.

3.2. Sensitivity Analysis

The methodology is sensitive to the way that the constructor chooses to execute the project. The sensitivity of identifying the ideal scenario for the location of the construction site could be clarified by the following hypothesis.

<u>Case 1:</u> It is examined the implementation of another execution methodology in the project, which include the division of the whole project in two parts, the first part from chainage 8550 to chainage 15550, and the second part from chainage 15650 to chainage 23350. In Table 4, it is presented two scenarios of this case. In scenario 1, after the completion of the first part, and the relocation of the construction site, the works on the second part start. In scenario 2, the first stage includes the execution of the earthworks and the relative technical works at the first part of the project, the second stage the execution of the earthworks and the relative technical works at the second part of the project and the third stage the execution of the asphalt pavement at the first and second part continuously. These scenarios are compared with the scenario 1 §3.1/case study 2 with total operating cost 1.129.475,59 €. Scenario 1 creates a profit of 532.881,89€.

Table 4: Total saving in case of change in methodology execution of the project

Scenario	Relocation	Task accomplished	Ideal location	Operating cost	Relocation cost	Total cost	Profit/Loss
1	1	8550-15550 15650-23350	Ideal =11850 Ideal =19450	258.293,48 € 304.800,23 €	33.500,00 €	596.593,71 €	**532.881,89 €**
2	2	8550-15550 (Earthworks and technical works) 15650-23350 (Earthworks and technical works) 8550-23550 (Asphalt paving)	Ideal =11850 Ideal =19450 Ideal =14850	157.274,60 € 177.154,92 € 463.106,64 €	67.000,00 €	864.536,16 €	**264.939,43 €**

<u>*Case 2*</u>: In case that the area between 15+000 to 23+350 was not available to host the site, then the "ideal scenario" would be without relocation of construction site, and specifically the construction site should be placed in chainage 14850 (scenario 1 §3.1/case study 2) and no profit earned.

<u>*Case 3:*</u> In case that there were no technical works, then the initial cost of no relocation scenario would be 897.115,19 € (scenario 1 §3.1/case study 2) and the total cost of the previous "ideal scenario" 826.891,27 € (scenario 2 §3.1/case study 2). For this hypothesis another scenario would be the ideal that for the relocation at the end of 3rd semester with total profit approximately 92.094,71 (scenario 3 §3.1/case study 2).

Case 4: In case that the machines were stored at the construction site, then for the scenario 1 with no relocation the total cost would be 2.243.701,07 € (scenario 1 §3.1/case study 2), and the "ideal scenario" would be for one relocation at the end of the 3rd semester with total cost 2.098.956,11 (scenario 3 §3.1/case study 2) and total profit of 144.844,95€.

4. Conclusions

A method of identifying the "ideal scenario" for the establishment of construction site was developed and then was applied to two different case studies to evaluate its effectiveness in terms of cost and safety. The results indicate that through the right and individual study of the execution methodology of each project, the constructor could achieve a significant reduction in the operating costs of the construction site, especially in large linear projects. In this way, it is possible for the constructor to cover any financial expenses during the execution period of a project. This research highlighted the areas that are more sensitive to cost increases from the appropriate construction methodology chosen. The relocation cost for a dynamic site organization is affected by the organization of the project team and the availability of resources. If the project is executed in different stages the profit is increasing remarkably.

Possible topics of future research would be in more depth examination of the impact of each factor in the total cost of construction site location. The proposed methodology should be tested in more case studies of linear projects in order to extract concrete results. Finally, this method should be implemented in an on-going project in order to quantify the impact (delay or acceleration of work site's tasks) on project's time schedule.

5. References

[1] Cheng, M.-Y. (2001). GIS-Based Cost Estimates Integrating with Material Layout Planning. Journal of Construction Engineering and Management

[2] Jiuping Xu, Zongmin Li. (2012). Multi-Objective Dynamic Construction Site Layout Planning in Fuzzy Random Environment. In Automation in Construction (pp. 155-169). Elsevier. Retrieved from www.sciencedirect.com.

[3] Elbeltagi, E. (2014). Construction Site Layout Planning: Identifying, Sizing and Locating Temporary Facilities on Construction sites. LAMBERT.

[4] Greek Government. (1989). Building Regulation of Greece. In Article 21.

[5] Lagro, J. (2007). Site analysis. John Wiley & Sons, Inc.

[6] Peurifoy et all. (2011). Construction Planning, Equipment, and Methods. McGraw Hill International Edition.

[7] Petroutsatou, K., & Marinelli, M. (2018). Construction Equipment, Operational Analysis and Economics of Civil Engineering Projects (2nd edition.). Athens, Greece: KRITIKI SA.

[8] Razavialavi et all. (2014). Estimating the Size of Temporary Facilities in Construction Site Layout. In Construction Research Congress 2014 (pp. 70-79).

[9] Kaltsios, A. (2012, 8 18). Improvement and reinforcement of soil. Ktirio, pp. 81-86.

[10] Ashworth, A. (2012). Contractual Procedures in the Construction Industry. Routledge.