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2-LEVEL CONSTRUCTION PLANNING MODEL WITH A LOCAL CASE STUDY

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Abstract: *Two basic approaches underlie construction project management practices: Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). CPM widely used in the construction industry is criticized for its lacks of planning of repetitive or linear construction projects that contain the same or similar number of units such as mass housing. In this paper, a new 2-level location-based planning model (2-LCPM) has been presented to be used in the planning of construction projects consisting of repetitive activities and which is thought to eliminate the deficiencies of the existing models. It was designed at two levels: globally and locally. It provides a schedule with minimum delay to the planner at the global level while provides resource continuity at the local level. 2-LCPM was programmed in Go language and tested with a real case study by using Postman platform and SQL database. As a result, 2-LCPM is presented a new plan with increased resource continuity which are 5.32 %, 3.645% and 2.455% respectively, besides gives the same project complete time which is 15 months.*

Keywords: *Location-Based Project Planning, Construction Project Management, Resource Continuity*

JEL classification: *B41, C02, J22, L74, M11, M54, O21*

1. Introduction

2-LCPM has the feature of a web-based domestic program designed specifically for mass housing construction projects in our country, which is easy to use and offers reliable results.

The contributions of 2-LCPM to the literature are as follows: First, the problem of ‘not reflecting the relations between activities" of MS Project software (Jongeling and Olofsson 2007; Kenley 2005) has been solved. Activity priority relations have been placed in the model itself. Secondly, 2-LCPM is able to provide the user with a 15-month completion time, as well as providing planning to ensure resource continuity between locations and between floors in the same location. This implies that 2-LCPM includes both activity-based and location-based planning approaches.

The content of "Project Management" in the broad sense or "Construction Project Management" within the scope of the sector is a long-standing phenomenon that has not changed much compared to today. As a first step towards improving performance, SME managers need to determine their level of knowledge regarding projects and project management concepts (Daniela, 2015).

However, for an effective project management, it is necessary to be able to choose the management tools that are most suitable for the structure of the sector, the company and of course the project and to apply these tools effectively. Especially the construction industry has its own characteristics. Some of these features are; The fact that most construction projects contain high levels of variability and uncertainty, the construction process is far from automation, the project involves sharp commitment times and severe penalties are encountered if these times are not followed, and there are many and different suppliers in the management and logistics network. These characteristics affect the planning, implementation and control stages of the project life cycle both individually and collectively. For this

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reason, project management requires special methods and models that are prepared in a way that can reflect the characteristics of the sector and then the project accurately and fully, from general to specific. In this way, projects will be planned and controlled more accurately.

In the literature of construction project management, the critical path method is one of the most effective planning and control tools used for many years (Bansal and Pal 2009; Kastor and Sirakoulis 2009) and its importance has increased recently (Galloway 2006; Benjaoran et al. 2015) also with complex projects (Shah and Dawood 2011, Jongeling and Olofsson 2007) by using a software compatible with CPM such as Microsoft Project or Primavera (Hegazy and Menesi 2010; Bragadin and Kähkönen 2016). However, the effect of CPM on projects consisting of repetitive or linear activities (Harris and Ioannou 1998; Hegazy and Kamarah 2008) has been criticized and it has been found that CPM has deficiencies on workflow (Arditi et al 2002), work team balancing (Russel and Wong 1993; Hamzeh et al. 2015) and labor, material, and equipment continuity (Mattila and Pardk 2003; Benjaoran et al. 2015). As known from the literature, ensuring workflow is a key element for a successful scheduling and provides many benefits to planning in general like: avoiding risks in the production process (Kenley and Seppänen 2010), reduction in mobilization and demobilization, fewer production problems (Seppänen 2009), reduction in the time to complete an activity as the number of repetitions increases (Wright 1936), and a reduction in labor demand (Anagnostopoulos and Koulinas 2010). In addition, the lack of workflow and work team balance between locations are stated as the most common deficiency of CPM (Arditi et al 2002; (Russel and Wong 1993; Hamzeh et al. 2015). Repetitive activities in CPM are usually completed with different production rates in different periods (Arditi et al 2002). This causes blockages in the workflow as it requires fast activity in each location to wait for the previous activity. Similarly, despite the completion of previous activities, due to disruptions in the supply chain, consequently, the next activity is not ready which also disrupts the scheduling workflow and prevents the project from being completed within the planned time (Koskela et al. 2014). Moreover, the CPM only focuses on the project duration (Kim and Ballard 2010) and the scheduling process generally neglects the workflow analysis.

Regarding the consideration of workflow analysis linear, repetitive, and location-based scheduling systems (LBMS) have been used in the construction industry for a long time (Kenley and Seppänen 2010; Lucko et al. 2014; Seppänen et al. 2014). LBMS has adopted an approach that follows the resource movement flowing from one work package to another and tries to maximize it. Here, the purpose is to follow the resource usage; to reduce waste and risk, increase transparency, as well as improve flow and the planner's ability to predict project dynamics (Kenley and Seppänen 2010). Both CPM and LBMS methods are based on activity network structure. While the CPM network falls short of reflecting on the scheduling process, which consists of a large number of activities and the relationships between these activities (Kenley 2005), it is accepted that similar activities are performed by the same / very similar resources at locations in LBMS ((Kenley and Seppänen 2010). This study focuses on the workflow and resource continuity shortcomings of CPM for the projects with repetitive activities. It has been tested with a local mass housing project and after seeing those shortcomings and delays, 2-LCPM has been presented to eliminate the deficiencies and to get a more accurate plan.

2. Methodology

2-LCPM has been designed as a 3D construction project planning system with X, Y, and Z coordinates. In residential projects, the construction progresses simultaneously on the floor -on the horizontal plane - and between the floors - on the vertical plane -. In mass housing projects, other residences in different locations are added to the construction after a certain period of time – the diagonal plane-. The project manager should plan and monitor the ongoing construction at multiple locations and manage them. For this reason, two different levels of planning are designed in 2-LCPM: local level planning (LLP) and global level planning (GLP). Within the scope of LLP, the construction process has been considered as it continues in the X and Y coordinates in a specific location while the different locations are designed with the Z coordinate of the method within the scope of GLP.

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2.1. Global Level Planning (GLP)

GLP is established to plan the relationship between locations as a diagonal (z coordinate) relationship. It is designed as the top-level plan of 2-LCPM. In planning, firstly, it aims to divide the complex / long project into short parts based on location (thus planning and tracking will be easier) and then to make an integrated plan of these parts according to the constraints and features that will affect the planning of each location. Under the GLP, all project locations will be interconnected according to the constraints set by the planner and the uncertainty the project has or might have. 2-LCPM does this division and reconnection by running Model 1. This division must be planned under some constraints or for a specific objective like obtaining minimum complete time, minimum delay etc. In this study, we aimed to make a plan outlining the sequencing of locations that will allow the project to be complete with minimum delay. Model 1 is presented below. Notations can be found in (Erdinç 2020).

Parameters:
M: A big value (for example: 1000), P_l: Process time of location l, T_l: Delivery time of location l, N: Activity set (0 ve n+1 are dummy activities.), D: Activity durations set , $Q_{k,i}$: Activity amount set
Decision variables:
y_{ij} = 1, if location i before location j
0, other situation i, j
S_l: Start time of location l
u_i^+: Positive residual variable
u_i^-: Negative artificial variable

$Z = \min \Sigma u_i^+$
subject to
1- $y_{ij} + y_{ji} \leq 1, \forall (i, j) \in N \times N, i < j$
2- $y_{ip} \geq y_{ij} + y_{jp} - 1, \forall i, j, p \in N, i \neq j \neq p$
3- $M*(1- y_{ij}) + (S_j - -S_i) \geq P_i, \forall i, j$
4- $M*(y_{ij}) + (- S_j + S_i) \geq P_j, \forall i, j$
5- $S_l + P_l - u_l + + u_l - = T_l \; \forall l$
$y_{ij} \in \{0,1\}$ ve $S_l, u_i^+, u_i^- \geq 0$

2.2.Local Level Planning (LLP)

LLP considers a specific location at a specific time and makes its calculations within that location by using the information determined in the pre-planning phase. In this study, for example, it creates the activity network of the valid location, and it calculates the activity rate parameters with Eq.1, and the complete time for that location. The 2-LCPM primarily performs the first GLP process by running Model 1 and gives two results: the schedule that minimizes the total delay that needs to be tracked, and the starting times for each location sequence in the schedule. As long as the implementation can adhere to this location's sequence and start times found, the project will be completed without delay both on the basis of locations and overall. The activity rate parameters *(Vi)* are the main tracking tools of this model, and they express the completed amount per unit time for each activity (Equation 1). Index: q: activity amount, d: activity durations and i: activity numbers.

$$v_{1,i} = q_{1,i} / d_{1,i} \qquad (1)$$

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In the next step, resource assignment should be made to provide the parameters. Once an enough resource is found, it is assigned to that location and activity is started.

2.3. Handling Local Level Planning in Detail

LLP is calculated depending on each location. As explained before, mass housing projects proceed simultaneously in X and Y coordinates separately. From the point of view of the activities, while the activities are scheduled on a floor, they should be scheduled between floors at the same time. Therefore, some intermediate actions are needed:

- At the start of the project: l (location) =1, k (floor) =1 (1. location,1. floor plan)

Intermediate processes:

1- $s_{1,i} + d_{1,i} = c_{1,i}$ *(All $c_{1,i}$ values are kept in a set.)* *s: start times and c: complete times*

2- $v_{1,i} = q_{1,i} / d_{1,i}$ *(All $v_{1,i}$ values are kept in a set.)*

- l=1, k=2 (1. location 2. floor plan)

Here, the 1st floor activity speed parameter of the i activity ($v_{1,i}$) is now known. In other words, the planner knows how much he can do from the i activity per unit time using the resources he has! Now the calculated $v_{1,i}$ value is accepted as the parameter when making the 2nd floor plan and used to calculate how long the i activity can be completed on the 2nd floor with the current activity speed (Equation 2). Thus, by maintaining the same activity speeds, it is calculated how long the activities should take on the next floor.

$$d_{2,i} = q_{2,i} / v_{1,i} \quad (2)$$

Intermediate processes:

1- $S_{2,i} + d_{2,i} = c_{2,i}$ *(All $c_{2,i}$ values are kept in a set.)*

2- $V_{2,i} = q_{2,i} / d_{2,i}$ *(All $v_{2,i}$ values are kept in a set.)*

The operations carried out continue along all floors in the planning. Once the activity has been completed on the vertical plane, it starts in the other building which is a different location. Now, a new location page is opened in the 2-LCPM, and it may have new data such as new activity distributions, new resources etc. However, similar activities are scheduled here again based on the activity rates in the previous position.

2.4. Case Study Based on a Real Mass Housing Project

This paper has a mass housing case study project consisting of 3 residential building, 20 pre-planned activities and 11 labor and material resources. Each building has own pre-planned process (Pl) and delivery times (Tl) data. The time data are given as P1=256 days, P2=320 days, P3= 413 days, T1=280 days, T2=350 days and T3=430 days. Table 1 shows us predecessors of each activity and resource requirements accepted for each location.

Table 1: Activities, predecessors, and resource requirements

Activity		Pred.	M	F	EU	MU	DU	C	PW	UL	SL	RW	AT
1		0	2							5		10	2
2		1		2						4	2	12	2
3		1	2							4		20	3
4		2,3			2					2		10	4
5		4				2				2		8	3
6		1						2		2		10	2
7		3					2			2		15	2

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8		1,6				2				2		10	3
9		2,3,8	2							3		20	2
10		7,8,9								2	3	10	2
11		10								2	2	10	3
12		10								2	3	110	2
13		12					3			3		150	3
14		13									4	110	2
15		14						3		3		10	3
16		15							3	3		20	2
17		16							3	3		15	3
18		17			2					2		20	2
19		18				2				2		15	4
20		19									4	200	4
	Resource total amounts		9	9	6	6	9	5	9	35	30	1000	100

The original plan was an output of MS Excel and MS Project joint works and in this study, it has been replanned via 2-LCPM. Within the scope of LLP, the planner must provide the following data. These data are the inputs of the method: Activity list (the list of activities that planned for each location), activity times list (duration of activities), priority relationships between activities (relationship from start to start or finish to start), resource list (the list of resources to be used in each location), resource usage amount (the amount of resource usage for each activity in each location).

Table 1 shows the total of 11 types of resources that have been considered in 2 main types (labor (R1) and material (R2)), and these are as follows: R1: Mason (M), Formen (F), Skilled labor (SL), Electrician (EU), Mechanical worker (MU), Drywall worker (DW), Carpenter (C), Paint worker (PW), Unskilled labor (UL), and R2: Raw materials (RM) and Raw material application tool (AT). In the plan prepared by using both MS Excel and MS Project, it shows what the activities are, duration of activities and the time of project completion with a frequent wasted time (Erdinç, 2020). The planner does not consider the project based on location. On the other hand, the 2-LCPM performs the planning process in steps via two algorithms in a clearer vision and deeper insight. For that firstly, GLP constraints should be determined by a project manager. In this study, GLP constraints were determined as follows: Location scheduling / sequencing with the smallest delay in the project, The type and amount of resource needs for each activity in each location of the project, Resource total amounts, The decision to start / not start the activity with a waiting period in a different location. As 2-LCPM implementation of this example, firstly, the location schedule with minimum delay is obtained based on Model 1. 2-LCPM is programmed in Golang language. Instead of creating interfaces, SQL is used to feed the application. The result of Model 1 is: Z = 8, $u_1^+ = 0.00$, $u_2^+ = 0.00$, $u_3^+ = 8.00$, $S_1 = 0.00$, $S_2 = 13.00$, $S_3 = 25.00$, $y_{12} = 1.00$, $y_{13} = 1.00$, $y_{23} = 1.00$, $u_1^- = 15.00$, $u_2^- = 17.00$. The optimum solution of GLP is 8 days' delay and locations are scheduled as 1-2-3 with starting times of each of them as $S_1= 0$, $S_2=13$ and $S_3=25$ respectively.

After obtaining the start time information of each location, 2-LCPM creates the activity network structure by using the pre-planning information (the priority relations and resource adequacy) to understand the relationship between the activities on both X and Y directions.

As mentioned before, this study aims to ensure continuity of resource usage, in other words, to prevent peaking in resource utilization based on activity or location. That is why 2-LCPM tries to understand the capacity of each activity to work per unit time and to maintain this capacity in every position with the activity speed parameter. Thus, at the end of the project, the situation of encountering

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excess and / or sudden resource usage costs will be eliminated, and the project will become easier to plan and execute. With this feature, it is claimed that 2-LCPM is suitable for mass housing projects. It is very important not to encounter excessive and / or sudden resource usage costs at the end of these projects in particular which are government-funded, and which are offered as social services to buyers with middle- and lower-income levels without making profit. As given in Equation 1, the activity rate defines the amount of work which is done per unit time. Since the completed activities are carried out using the same team and materials along floors, the activity rate is directly proportional to the resource utilization rate**.** In this context, 2-LCPM maximizes the resource utilization rate for each activity along all floors of each location under LLP. LLP tries to maximize this rate depending on q and available resources. Table 2 shows the percentage of resource continuity**.** 2-LCPM assigns the maximum value for all activities of project.

Table 2: Percentage of resource continuity

	Location 1		**Location 2**		**Location 3**	
Activities	MS Excel & MS Project	2-LCPM	MS Excel & MS Project	2-LCPM	MS Excel & MS Project	2-LCPM
1	100	100	100	100	100	100
2	100	100	100	100	100	100
3	100	100	78.8	100	88.2	100
4	69.6	100	100	100	100	100
5	78.8	100	100	100	100	100
6	100	100	89.9	100	89.9	100
7	100	100	100	100	100	100
8	100	100	100	100	100	100
9	100	100	100	100	100	100
10	78.3	100	80.5	100	100	100
11	100	100	100	100	100	100
12	100	100	100	100	100	100
13	66.9	100	77.9	100	72.8	100
14	100	100	100	100	100	100
15	100	100	100	100	100	100
16	100	100	100	100	100	100
17	100	100	100	100	100	100
18	100	100	100	100	100	100
19	100	100	100	100	100	100
20	100	100	100	100	100	100
Average (%)	**94.68**	**100**	**96.355**	**100**	**97.545**	**100**
Increased (%)		**5.32**		**3.645**		**2.455**

3. Conclusions

In this study 2-LCPM is presented. The software of the designed model was completed in Go language and tested using the project data of a local construction company that has been serving in public housing for many years. Instead of creating interfaces, SQL data base is used to feed the example application because SQL is free, understandable, compatible, and makes improving Rest Api patterns easy. Also, Postman platform is used to test Rest Api patterns. The contributions of 2-LCPM to the literature are as follows: First, the problem of ‘not reflecting the relations between activities" of MS Project software (Jongeling and Olofsson 2007; Kenley 2005) has been solved. Activity priority relations have been placed in the model itself. Secondly, 2-LCPM is able to provide the user with a 15-month completion time (Table 3), as well as providing planning to ensure resource continuity between locations and between floors in the same location (Table 3). This implies that 2-LCPM includes both activity-based and location-based planning approaches. Finally, 2-LCPM has the feature of a web-based domestic program designed specifically for mass housing construction projects in our country, which is easy to use and offers reliable results.

Table 3: Complete time

Project id	Method	Complete time
1	MS Excel & MS Project	15 months
	2-LCPM	15 months

Data Availability Statements

Some or all data and models that support the findings of this study are available here (Erdinç 2020) and it can be requested from the corresponding author.

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