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Evaluating a novel smart algorithm to manage RCC dam's construction via a nonlinear analysis

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Abstract: Roller compact concrete (RCC) dams are constructed by controlling the speed of production, pouring, transferring, and curing of dam concrete. This phenomenon underscores the importance of scheduling and control time planning which is the basis used to control upon the project process. Up to now, there has never been a linear scheduling method in dam construction. In this study, a new approach was introduced to planning and scheduling RCC dams. Also a novel, intelligent model to schedule a RCC dam with LOB, LSM technique proposed providing an overall algorithm. The main objective of this paper is to introduce a generalized and simplified model for scheduling RCC dams. The authors suggest a novel approach as a flow chart and prove it with LOB, LSM methods. This is useful for RCC dam scheduling and planning all around the world. This model is able to recognize an incorrect or unreliable input number, later requiring the user to check the parameter or fix the sensors (thermometer). In addition, an effective criteria is defined: the LJQI (Lift Join Quality Index), checking the quality of the built lift. The model is expected to helps decision makers to efficiently set a schedule within a limited time.

Key words: *Novel smart algorithm; Nonlinear analysis; RCC Dam's; Project process; Model*

1. Introduction

Roller Compacted Concrete (RCC) has been rapidly developing over the past 40 years and is now commonly used for mass concreting operations typically in a Gravity Dam application. With a widely varied methodology of design theories and project specific considerations, RCC is not only extremely practical from a constructability standpoint; it is also, along with other advantages, very cost effective (Warren, 2012). The realization that homogeneity across RCC lift joints and the development of lift joint bond, tensile resistance and shear strength approaching that of the RCC itself will only be achieved with joint surfaces if they are covered by the next lift within the initial set time of the RCC, has been instrumental in giving designers confidence to develop RCC gravity dams to heights now approaching 300m. Where cold joints do occur they are treated in the same manner as with CVC, green cut to expose aggregate surfaces and treated with a bedding mortar (Forbes, 2008).

The roller-compacted concrete (RCC) technique has achieved significant time and cost savings compared to conventional methods of concrete placement and consolidation. International interest in RCC dam design and construction continues to increase and new techniques for design and construction are being developed, particularly to accommodate higher dams. Seeking better ways to prove the quality and safety of RCC dams and to reduce their costs and effects on the local environmental is essential as the RCC dams become more costly and time-consuming structure (Forbes, 2003). The significant advantage with in the development of RCC dam construction is the fact that the diversion schemes can be significantly reduced in size with further cost savings and reducing the overall construction schedule as the RCC dams can be overtopped during flood stages without any significant damage to the main structure as opposed to their earthen counterparts (Warren, 2012). Thermal analysis of roller compacted concrete (RCC) dam's plays an important role in their design and construction. For a given roller compacted concrete dam, changing the placing schedule can optimize the locations of maximum temperature zones (Jaafar et al, 2007). The time span between the beginnings of mixing materials until the time of finishing compacting is one of the parameters affecting the RCC properties (Karimpour, 2010). Activities that repeat from unit to unit create a very important need for a construction schedule that facilitates the uninterrupted flow of resources (i.e., work crews) from one unit to the next, because it is often this requirement that establishes activity starting times and determines the overall project duration. Hence, uninterrupted resource utilization becomes an extremely important issue. The scheduling problem posed by multiunit projects with repeating activities is akin to the minimization of the project duration subject to resource continuity constraints as well as

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technical precedence constraints. The uninterrupted deployment of resources is not a problem addressed by the critical path method (CPM), nor by its resource-oriented extensions, such as time-cost trade-off, limited resource allocation, and resource leveling (Robert and Photios, 1998). Although the popular scheduling methods, such as the Gantt chart and its variations the Linked Gantt chart and the critical path method (CPM), are really beneficial to the construction industry, these methods are inadequate when applied to scheduling linear construction projects (Cheng, 2005). Due to repetitive construction processes required in multiple units or locations, repetitive construction projects are not scheduled by using the critical path method (CPM) (Kenley and Seppanen, 2009). Instead, LSM is used for repetitive construction projects (Shim et al, 2012). LSM is one method of construction project scheduling and is also called the Line of Balance (LOB) or Repetitive Scheduling method (Kenley & Seppanen, 2009). Since LSM can visually plot repetitive operations, it helps contractors schedule continuous workflow. The main benefits of LSM include simple graphical presentation and easy understanding of the progress of each activity and when, where and what activities are being performed at any given time (Kemmer et al., 2009). Tang and et al. used LSM as the basis to examine the issue of schedule control for linear projects (such as railway construction) which are constrained by fixed duration. A progress control model, a CSP-based scheduling model, and a schedule control system were proposed (Tang et al, 2014). The Line of Balance (LOB) and its variations were developed to search for a better solution for projects with repeating activities such as highway projects, tunnel construction, high rise building, pipe line projects and even utility projects (Cheng, 2005). The line of balance (LOB) and its variations are more appropriate for linear construction because of their presentation of productivity and project progress corresponding to true location. However, most of LOB studies focus on the activities of a linear project (Cheng, 2005). Recent studies show that the major reason that a construction industry has been slow to adopt LOB scheduling was the lack of supporting software. With advancements in construction related technologies, theories, and ideas, the need for more effective and efficient scheduling and management tools has grown correspondingly. A review of literature and search for available software models reveals very few attempts to produce a well-supported, advanced, and user-friendly LOB scheduling software model for the construction industry. For the past three decades, numerous researchers have identified the various intrinsic advantages of the Line of Balance scheduling technique (LOB) in comparison to the CPM (Chrzanowski and Johnston, 1986) (Spencer and Lewis, 2005) (Yamin and Harmenlink, 2001) (Jongeling and Olofsson, 2007) (Trofin, 2004) (Arditi et al. 2002). Literature shows that LOB schedules are better understood and more easily updated, facilitate better resource optimization, provide improved visual management, and are more capable in scheduling construction projects with a repetitive nature. Jogeling and Olofsson (2007) in their studies explained their advocacy of LOB scheduling and claimed that the technique has not been widely adopted in the construction industry “mainly due to the strong tradition of activity-based planning and the absence of software packages that support location-based planning” (Jogeling and Olofsson, 2007). Line of Balance scheduling is a location-based scheduling technique. When compared to the activity-based CPM, LOB provides a more practical scheduling method in implementing Building Information Modeling technologies. Jongeling and Olofsson (2007) stated that “location-based scheduling provides a promising alternative to activity-based planning approaches for planning of work-flow with 4D CAD. RSM is a scheduling methodology that simplifies and generalizes various multiunit scheduling procedures previously proposed by several authors and known by a number of different names. It applies to both vertical and horizontal projects containing either discrete or continuous activities. An RSM schedule is presented graphically as an X-Y plot of a series of production lines, each of which represent a repetitive activity. names that have been used include: “Line of Balance” (O’Brien 1969; Carr and Meyer 1974; Halpin and Woodhead 1976; Harris and Evans 1977); “Construction Planning Technique” (Peer 1974; Selinger 1980); “Vertical Production Method” (O’Brien 1975; Barrie and Paulson 1978); “Time-Location Matrix Model” (Birrell 1980); “Time Space Scheduling Method” (Stradal and Cacha 1982); “Disturbance Scheduling” (Whiteman and Irwig 1988); or “Horizontal and Vertical Logic Scheduling for Multistory Projects” (Thabet and Beliveau 1994).For highways, pipelines, tunnels, etc., where progress is measured in terms of horizontal length, the names used have included: “Time Versus Distance Diagrams” (Gorman 1972);“Linear Balance Charts” (Barrie and Paulson 1978); “Velocity Diagrams” (Dressler 1980), or “Linear Scheduling Method” (Johnston 1981; Chrzanowski and Johnston 1986; Russell and Casselton 1988) (Shim et al, 2012). This study will try to introduce a software model on the utilization of LOB scheduling, and evaluate the advantages, benefits, limitations, and implications of applying this scheduling technique in the construction industry through LOB software model. Fayek Aziz and et al., (2014) evaluated the development of smart optimization model in order to support the balance between time, cost and quality simultaneously for mega construction projects. The model was designed to search for the optimal resource utilization plans that minimize construction time and cost while maximizing its quality, and also to make development in three main tasks (Fayek Aziz, 2014).

Zirdan RCC dam was selected as a case study in this research. The verification process was done on Kinta RCC dam reports. The Zirdan dam is modeled via a proper FEM method. The model outputs give the actual temperature, the thermal stresses of each made, and then allows for managing the best time for the production of an RCC layer.

2. Research method

2.1. Thermal equation

The Fourier equation governed the thermal generation and temperature distribution for two dimensional and isotropic solid environments is expressed by the following formula:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial \mathrm{T}}{\partial \mathrm{x}}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial \mathrm{T}}{\partial \mathrm{y}}\right) + Q = \rho c \frac{\partial T}{\partial t} \qquad (1)$$

Where T is the concrete temperature, k_x and k_y are the concrete conductivity coefficients in x- and y-directions, respectively, Q is the rate of heat of hydration introduced per volume, q is the material density, and c is the concrete specific heat.

Two main types of boundary conditions are Drichlet and Cauchy boundary, which can be written as: (Sergerlind, 1984; Hinton and Owen, 1981)

$$T = T_p$$

$$k_x \frac{\partial \mathrm{T}}{\partial \mathrm{x}} l_x + k_Y \frac{\partial \mathrm{T}}{\partial \mathrm{Y}} l_Y + q = h\,(T_S - T_f) \qquad (2)$$

Where Tp is the known values of the nodal points of the temperatures on the boundaries; q is flowing heat from surface; h is the film coefficient; Ts is unknown temperatures at the boundary nodal points; T_f is the ambient temperature; *lx* and *ly* are the direction cosines of the normal to the surface under consideration (Sergerlind, 1984; Hinton and Owen, 1981)

2.2. The major steps of the novel model

2.2.1. Recognizing the activities

Each activity is the smallest part of the WBS (work breakdown structure) that cannot be broken down anymore. Based on lag time and critical activities, we first separate the main activities from others.

2.2.2. Expressing the relations between activities

Repetitive construction projects are typically scheduled by the Linear Scheduling Method (LSM) due to repetitive construction processes in multiple units or locations. Workflow between subcontractors in repetitive construction projects affects project performance. Thus, selection of appropriate size workflow has been of interest to contractors (Shim et al., 2012).

The unit or location is a critical component of LSM and represents a numerical sequence of repetitive operations. For example, in the case of multi-unit residential building construction projects, each residential unit (or apartment) can be the base for scheduling and measuring progress. This means that contractors can schedule and monitor construction operations based on each residential unit. While LSM is a practical and easy tool for scheduling repetitive construction projects, it is based on a selected unit of workflow (i.e., each unit in a multi-unit residential project) (Kenley and Seppanen, 2009). On the other hand, understanding the impact of batch size on project performance and incorporating it into scheduling can improve project performance.

Batching production means making products in lots, not by pieces (Alves and Tommelein, 2003). Batching production related management is of interest in the manufacturing industry because the setup costs of work stations can be reduced by decreasing the number of setups and batching production. Some construction processes are considered as batching production. Therefore, it is recommended that repetitive construction projects are scheduled along with consideration of batch size (Shim et al., 2012).

It has been reported by several researchers and practitioners that using a small batch size has advantages over bigger batch sizes: 1) faster project delivery, 2) cost reduction and 3) reduction in rework and defects (Ward and Mc Elwee, 2007). While small batch size can lead to early completion of the project and reduced costs, as mentioned above, at the project level, a batch size preferred by one subcontractor may be different from a batch size preferred by another subcontractor, depending on their production rates and other job conditions (Shim et al., 2012).

In addition to batch size, buffer is another important factor to be considered in repetitive construction projects. Buffer is defined as “the additional absorbable allowance provided to absorb any disturbance between two activities or tasks as a component of the logical connection between two activities” (Horman and Kenley, 1998). Using a small batch size leads to small amounts of up-front work-in-process inventory; and, a small amount of work-in-process inventory may cause lost production or idle workers due to an insufficient amount of work-in-process inventory. Therefore, it is recommended to allocate a buffer along with a small batch size (Ward and Mc Elwee, 2007; Nielsen and Thomassen, 2004).

2.2.3. Main activities

From WBS (Work Breakdown Structure), we found seven main activities that are important in taking part in all RCC dams.

These seven main activities are as followed:

1- Producing RCC in batching plant:

Batching plant is used to produce the RCC concrete near the site. There are several important issues that have to be considered here. One of these is the production rate, which is dependent on its component’s (water, ingredients, cement) production. The location of the dam, as well as the climate zone and temperature of the season, is all factor that need to be considered when determining whether or not we need pre-cooling or past-cooling.

It is crucial to match the RCC layer production rate to the batching plant's, so that no leftover concrete would remain unused and passed its useful lifespan. Generally, the optimum time for using concrete is less than 30 minutes; however in RCC dams, this time is variable. This is due to several factors: the slump of RCC being zero and less cement being used in RCC compared to conventional concrete. Some of this cement is replaced by natural and artificial pozzolans. The other important issue that must be considered is the probability of a dysfunctional batching plant, which corrupts that coherence of construction. There has to be a plan in place for spurs as needed.

2- Making the substructure:

Pouring the cement mortar helps build a substructure which is used as glue to stick two layers together. One of the factors to consider is the height of the mortar in each layer and its examination.

3- Conveying the concrete to the site:

There are different machines and equipment that can be used in transforming the RCC concrete to the site. Usually, a conveyer belt is used for this purpose. However, one has to also consider the variable velocities and capacities of various conveyor belts. Another factor is the exact distance between the batching plant and potential layer under construction, protecting the concrete during its transport, while maintaining its physical characteristics.

4- Spreading and pouring:

In this section, we have to consider spreading the machine's velocity and the effect of the height coefficient on it. The height coefficient is a function of the total height of the structure and the height and area of each corresponding layer. The spreading velocity is a function of the layer itself and the adjacent conditions (i.e. climate).

5- Evening the plain field using rollers for compaction:

Factors to be considered are the length of the rollers, the quantity used, and the velocity of their action.

6- Making intersections or joints:

The factors to be considered are the distance between each joint, the number of joints in each layer, the velocity of the machine used in making the intersections, and the length of each layer.

7- Curing the poured RCC layer:

There are various methods available to cure concrete, and the appropriate one must be selected, considering the desired curing velocity.

2.2.4. Time scheduling

Scheduling for the next layer is related to how quickly each step could be accomplished. That would result in either a warm, cold, or hot joint.

The various kinds of joints that occur at the site are:

- A hot joint: this joint is formed when the inner layer hasn't set yet.
- A cold joint: this joint occurs when the subsequent layer is poured upon a completely hardened layer.
- A warm joint: this joint exists when the subsequent layer is formed appropriately, which is when aggregate movement from the top to the bottom layer is not possible.

Since we are only interested in achieving a warm joint, we need to idealize our scheduling to eliminate the existence of the other two joints.

Usually, scheduling is prior to the start of project, and control comes during the project's time span. We suggested an LOB, LSM scheduling model for the Zirdan RCC dam, which is comparable with the generalized scheduling by CPM. The schedule of Zirdan RCC dam already exists. usually concrete temperature change is observed by burying thermometer during construction, concrete temperature data is collected (Zhen-xian & Yu-qing, 2012). We found the exact relation between time and temperature, and then arrived 3 different equations in three various periods by interpolation.

This information was used to complete our model through combining it with LJQI (Lift Joint Quality Index) factor. The LJQI factor is useful for checking the quality of the poured layer.

A Lift Joint Quality Index score card has been developed which assigns both positive and negative points to factors such as surface segregation, lift maturity, type of delivery systems used, curing, etc.

LJQI is derived from the sum of the following factors:

- Joint quality depends on concrete's ingredients segregation
- Rainfalls effect on joint quality
- Curing methods quantitative and qualitative influence
- Levelness of the joint layer
- Effects of various transportation means on the joint quality
- The stages of concrete maturation and the visible characteristics of the joint

Table 1: LJQI Factor

LJQI> +1	Great
-1 <LJQI < +1	Good
-3 <LJQI < -1	Average
-6 <LJQI <-3	Poor
LJQI < -6	Worst

Generally, we have to schedule the dam in the way to minimize its coincidence with warm months (June and August).

Practical Points:

1. Make the CVC performance velocity compatible with RCC's performance velocity
2. Where the location of the hydraulic equipments lie
3. Pre scheduling the initial activities to prepare the dam site
4. Resource allocation and leveling should be considered in the overall theme

3. Numerical tests

Zirdan RCC Dam is the 3rd RCC dam in Iran which is completed and impounded in early 2012. It is located in South east of Iran, in a semi dry area over a wild / heavy flooded river. The height of the dam is 64.5 m and the crest length is 350 m. The project was selected as one of the best concrete projects of 2011 in Iran by Iran Concrete Institute. Since the technology of RCC dams is comparatively new in Iran and many countries, some cases and experiences applied in this project were quite new in Iran, and changed the methods to simplify the works and/or reduce the costs (Jafarbegloo and Hajialikhani, 2006).

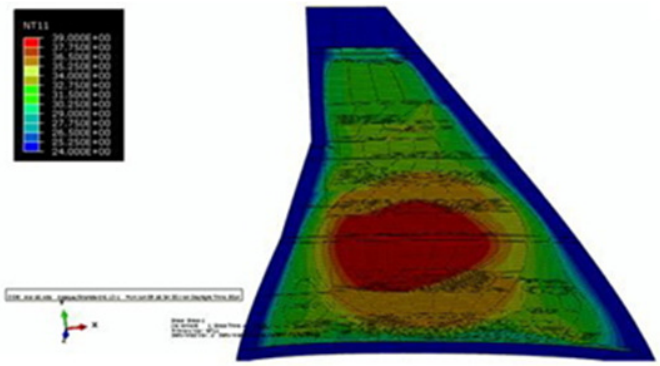

Fig. 1: Abaqus Model Results

Due to hot climate of Zirdan district, chemical admixtures should be used to prolong workability and reduce the cementations content and so help prevent thermal problems (Sadri and Araghian, 2009). Within each case study, parameters shall carefully be evaluated and decisions about their variation may rely not only on engineering expertise but also on available laboratory and field data.

Fig. 2: Flowchart for Introduced Software

Of course, if such a study is to be performed during the design phase of the dam project, decisions about those statistical distributions will mostly be supported by the experts' experience and most likely be much conservative (Gaspar et al., 2014).

4. Data analysis and test results

4-1- Demonstrate using conveyer machines for RCC transportation, 37 layers poured, inappropriate temperature on 1st and 11th day of construction and invalid LJQI on 8th, 9th layers.

4-2- Demonstrate using a low capacity belt conveyor to transform RCC, 30 layers poured, inappropriate temperature on 10th layer, no invalid LJQI.

4-3- Demonstrate using 2 high capacity belt conveyors to transform RCC, 15 layers poured, and inappropriate temperature on 10th layer, no in varied LJQI, less RCC lifted on 3rd layer placing hydraulic equipment. This status is possible if we had wrong input, but by using the smart algorithm this precaution is ignorable.

4-4- Demonstrate using conveyer machines (50 trucks with 16 m^2) for RCC transportation, 30 layers poured, inappropriate temperature on 6th and 7th day of construction and invalid LJQI on 16th, 22th layers

4-5- demonstrate using conveyer machines (5 trucks with 16 m^2) for RCC transportation, 30 layers poured, inappropriate temperature on 6th and 7th day of construction and invalid LJQI on 16th, 22th layers

4-6- Demonstrate using 2 high capacity belt conveyor to transform RCC, 30 layers poured, inappropriate temperature on 6th and 7th day of construction and invalid LJQI on 16th, 22th layers.

The Mann-Whitney test (using spss21 software) was used to evaluate results. Table (1) illustrates;

1-Comparing lob scheduling models using a belt conveyor, versus 10 conveyor machines (1, 2)

2-Comparing lob scheduling models using 5 belt conveyors, versus 50 conveyor machines (4, 6)

3-Comparing lob scheduling models using 2 belt conveyors, versus 5 conveyor machines (4, 5)

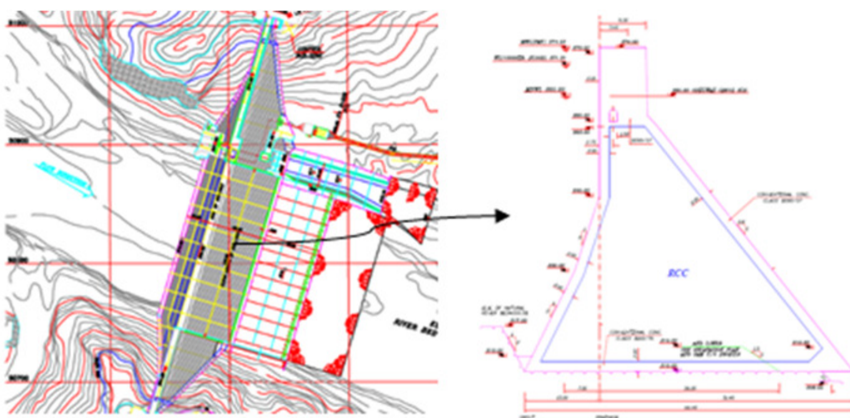

Fig. 3: Plan and Profile for Zirdan Dam

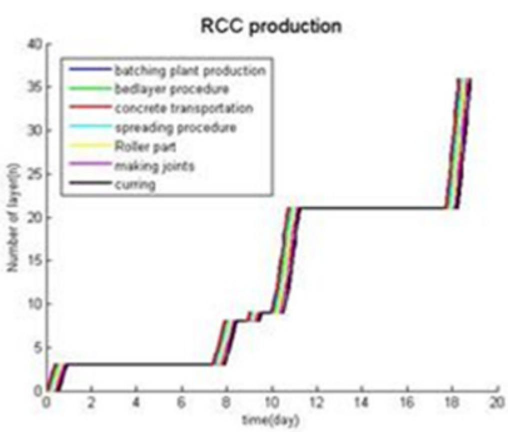

Fig. 4: Method 1

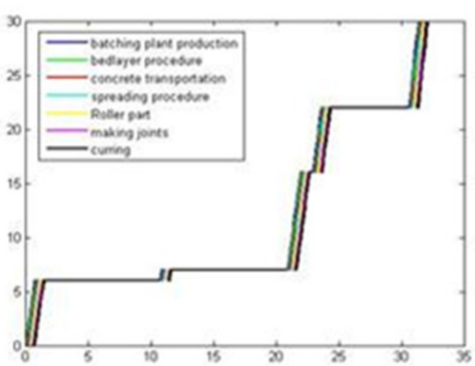

Fig. 5: Method 2

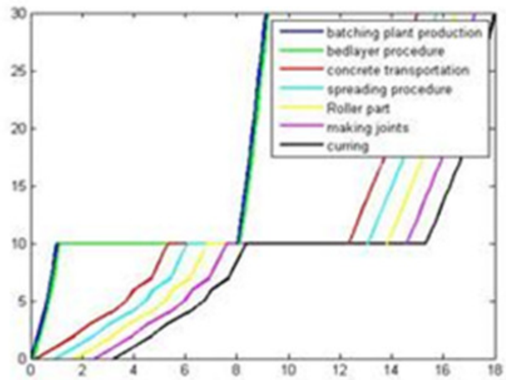

Fig. 6: Method 3

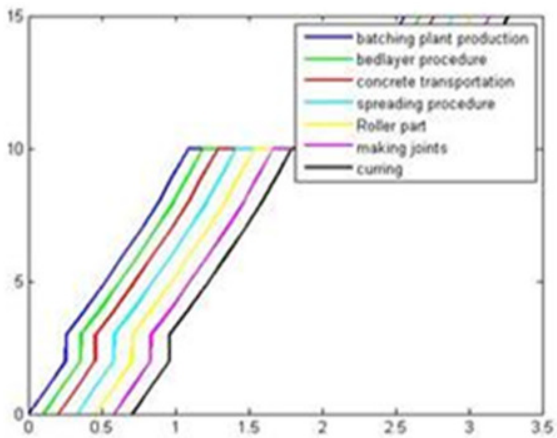

Fig. 7: Method 4

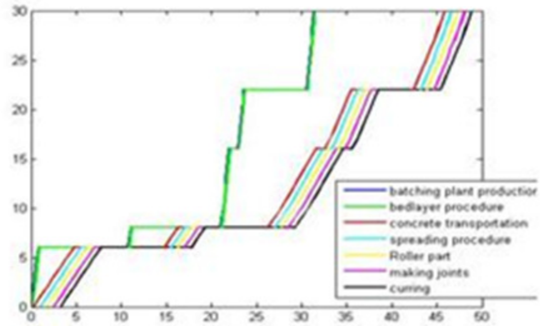

Fig. 8: Method 5

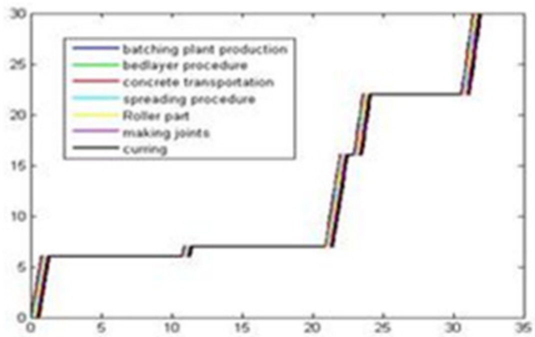

Fig. 9: Method 6

Table 2 shows a high level of similarity in the results between case studies (1 and 2) and (5 and7). These results are satisfactory because the Exacts sig equals 1.

Table 2: Mann-Whitney Test Results

Output result	Parameter			
	Mann-Whitney U	Wilcoxon W	Z	P value
1, 2	40.000	85.000	-.044	1.000b
4, 6	45.000	100.000	-.379	.739b
4, 5	21.500	76.500	-2.155	.029b

a. Not corrected for ties.

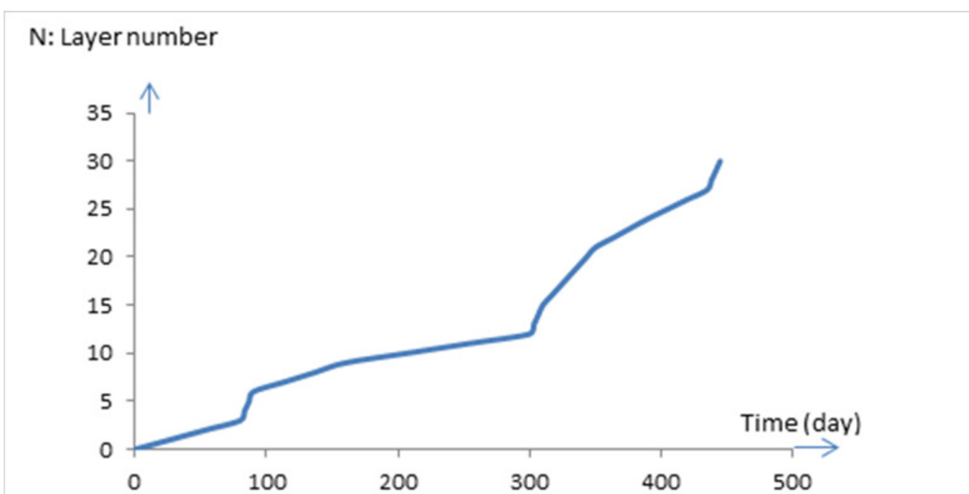

Fig. 10: The real state modeled schedule which used CPM (preformed in Zirdan) through 30 layers

Table 3 shows no similarity between graph 1, 2, 3, 4, 5, 6 and graph NO.7. (P.Value =.0002). The proposed LOB, LSM is more satisfying, with less waste of time and money.

5. Discussion:

LOB, LSM diagram is worthy for project management of RCC dams, especially due to the long length of construction time. By separating the direct cost from indirect and hidden costs, these linear methods prevent abuse and jobbery in the term of the project life. It also increases the ability to point out these abusers and follow up accordingly. In a LOB, LSM diagram, the lines of each activity are near each other and area parallel due to the unity of the project. These lines altogether appear as a single unit line and are considered a process graph.

Table 3: The results of the Mann-Whitney test for statistical analyses of Comparing LOB scheduling model versus CPM scheduling (using spss21 software)

Output result	Parameter			
	Mann-Whitney U	Wilcox on W	Z	P value
1	.000	45.000	-3.576	.000[b]
2	.000	45.000	-3.576	.000[b]
3	.000	45.000	-3.576	.000[b]
4	.000	55.000	-3.780	.000[b]
5	.000	55.000	-3.786	.000[b]
6	.000	55.000	-3.781	.000[b]

b. Not corrected for ties

This graph displays the process of financial and/or physical progression of the project, which is comparable with the S diagram. This system is also more compatible and unified with the S Diagram Theory, both of which are aggregative. The suggested LJQI (Lift Joint Quality Index), founded by the Delphi Method, is an effective and scientific criteria that is practical for RCC dams. This criterion converts the quality of the concrete layers to a comparable quantity, enabling their rejection or permission. Using semi nonlinear scheduling approach in Zirdan RCC dams, leads to the decrease in costs, along with the advantage of comfortable planning and scheduling. Additionally, the total work procedure is visible at a glance and is easy to control. The intelligence of the aforementioned model is very helpful in reaching reliable data and diagrams. It warns the user of an out-of-range input and requests re-entering it. This prophylactic model reduces the current errors of input data. By omitting recycling and repeated errors, this system produces results faster in comparison to CPM or current LOB, LSM models. Another example of the suggested model's intelligence is its ability to extinguish the corrupted and ruinous sensors. The additional data amount of this project helps minimize the risks involved. This subsequently allows the stress level of the project manager to be reduced, thus optimizing the end result. These are multiple rewards using the LOB, LSM method for planning and controlling the dam. A simple chart makes it feasible to visualize all the works (parts) and how it is affected by changing the velocity of each activity. This effect could have financial or time precautions. The added emphasis on work velocity with this approach makes it easier to harmonize the various teams, enabling better teamwork and reducing wasted time and energy. This energy includes human resources, materials, and machines. By limiting the wasted time, the costs are minimized. The modified LOB, LSM diagrams are able to more effectively illustrate the activity performance rate than classic methods. These semi non-linear scheduling methods are more beneficial due to their compatibility with RCC's great construction velocity, which is the major indication for usage of RCC's. Finally, by creating a novel approach of smart LOB/LSM for RCC dams, with slight variation, it would be practiced for all kinds of structures. This will subsequently help glorify and expand the applications of smart LOB/LSM. This novel approach makes it easier to compare and control the speed of each subcontractor (contractor). This aids in the selection of the right subcontractor in future projects. The effectiveness of the proposed model was validated using actual data from a real case study (Zirdan RCC dam construction project). The result demonstrated validity of the proposed solution procedure, and its applicability was tested.

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