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Evaluation of Different Scheduling Techniques Used for Infrastructure Projects

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Abstract: In the last ten years, Decision Support System has been used for many applications such as evaluation, prediction, selection, and optimization purpose. The main objective of this study is to design and develop a Decision Support System (DSS) to assist project contractors in selecting the most appropriate scheduling technique as they start a new infrastructure project, having considered the appropriate factors necessary for taking such decision. Project contractors are keen to choose an appropriate selection for infrastructure projects because of their positive effect on project success. The research primarily focuses on early planning for infrastructure projects before starting the construction phase and specifically examines network-based techniques such and graphical-based techniques. A Decision Support System developed in this paper is simple to use and allows the contractor to consider all decision-relevant factors. Its practical application will benefit the contractor's decision making in the selection of proper scheduling technique for their infrastructure projects.

Keywords: Decision Support System; Network based techniques; Graphical based techniques; Critical Path Method (CPM); Line of Balance (LOB); Infrastructure Projects.

Introduction

Construction is a risky undertaking that necessitates meticulous planning and scheduling. The successful execution of construction activities depends on effective planning and scheduling, even though various internal and external factors can influence the schedule. Scheduling is essential in all areas of life and functions as a work timetable. It provides guidance to managers, outlining the necessary resources and predicting the progression of activities throughout the project's duration. By adhering to a well-designed schedule, managers can navigate the right path to achieve their goals [1]. Infrastructure capital projects are vital for economic revitalization and are key to driving growth in the construction sector. Despite their importance, many of these projects fail to achieve their objectives mainly because of inadequate initial planning [2]. Scheduling in the field of construction is crucial as it sets time and sequence of the various stages, the linkage between one activity to another to achieve the project deadline [3]. The schedule is the elaboration of project planning into the sequence of steps to carry out the work to achieve the target. The schedule has included a time factor. There are several scheduling methods in construction, such as Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Precedence Diagramming Method (PDM), Line of Balance (LOB) and Ranked Position Weight Method [4]. According to [5], effective project planning and scheduling significantly increases the likelihood of completing the project on time and within cost thus reducing the negative effects on the return on investment. Project teams can use the most appropriate scheduling technique to increase the likelihood of project success [6].

The limited implementation of DSS software in Egypt until very recently that could aid contractors to select the most appropriate scheduling technique in their infrastructure projects which fulfill their requirements may lead to the failure of these projects.

The research gap for the current study is the lack of a comprehensive decision support system (DSS) to assist in selecting the most suitable scheduling technique for infrastructure construction projects. Also, a lack of comprehensive analysis across a wide range of scheduling techniques and tools specifically tailored for infrastructure construction projects.

The solution of this problem was by using DSS software that depends on the importance of the main factors affecting scheduling technique selection.

This research aims to bridge this gap by developing a decision support system that incorporates the highest important factors such as project size, complexity, resource availability, site conditions, and project objectives to assist project managers in selecting the most suitable scheduling technique. 34 main factors that influence the selection of the proper scheduling technique used in infrastructure projects were collected from literature, site visits, and stakeholder interviews during the construction of a sample of these projects. An online questionnaire was prepared and data analyzed using IBM SPSS version 20. Hence, the relative importance of these factors is investigated then arranged.

The research objectives are as follows:

1. Identify the different factors affect the selection of the scheduling technique importance for infrastructure construction projects.
2. Estimate the relative importance impact selection factors.
3. Design and develop a DSS to assist the project contractors in selecting the most appropriate scheduling technique and tool that can be used for a unique type of infrastructure construction projects.

Research Methodology

To achieve the previous stated objectives, the following methodology is considered and presented in Figure 1.

1. Conducting a detailed literature review in the field of project planning and scheduling techniques then identifying the common factors affect the selection of the proper scheduling technique used for infrastructure projects.
2. Carrying out a field survey for investigating the importance of factors affect the selection of scheduling technique.
3. Analyzing data and calculating the relative importance (RII) of 34 factors that affect the scheduling technique selection in construction projects.
5. Developing a DSS model to be used as helpful tool for the contractor's decision maker to select the most appropriate scheduling technique used for their infrastructure projects.

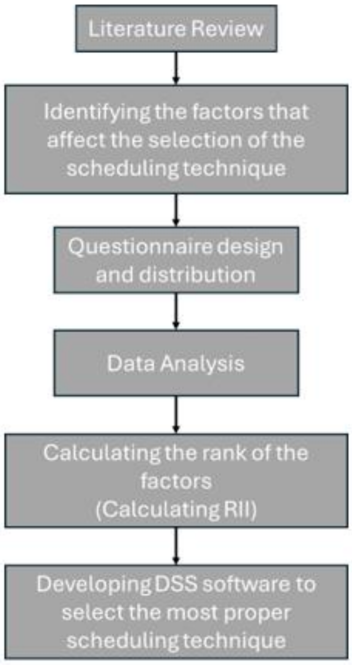

Fig 1: Research Methodology Framework

Literature Review

Most of literature review concentrated on the early planning stage in construction projects using two scheduling techniques: Network based techniques and Graphical based techniques. Critical Path Method (CPM) belongs to network-based techniques, while Line of Balance (LOB) falls under graphical-based techniques.

Network scheduling techniques are employed to effectively plan and schedule large projects, aiming to minimize issues like delays and interruptions by identifying critical factors and coordinating different components of the overall job. These techniques enable control at various stages of the project, facilitating completion before the scheduled time and cost reduction. Several techniques are utilized for network scheduling, with the main ones being [7, 8]:

1. Critical Path Method (CPM)
2. Project Evaluation and Review Technique (PERT)
3. Bar/Gantt chart.

Project planners are looking forward to achieve the cost-effective and convenient method to represent project plans and simulate various planning scenarios. Network programming techniques such as Project Evaluation and

Review Technique (PERT) and Critical Path Method (CPM) have been widely used in project planning for several decades. Network-based techniques provide a mathematical modeling system that has shown some success. However, upon closer examination, these techniques require significant effort from the planner. The planner needs to identify the work objectives, determine the appropriate level of detail for each task, and understand how to interpret the model's results [9].

PERT and CPM are two network-based project management methods that illustrate the flow and sequence of activities and events within a project. The main distinction between CPM and PERT lies in their focus and approach. PERT is typically employed when the time required for each activity is uncertain, relying on probabilistic models. On the other hand, CPM is based on the knowledge and experience gained from past projects, using a deterministic model for project execution. PERT primarily emphasizes time planning and control, while CPM focuses on activity management. In PERT, three-time estimates are utilized to account for uncertain activity durations, whereas CPM typically uses a single time estimate [3, 10].

CPM provides planned schedule to assist the project team and forms the basis for checking project schedule performance by comparing actual with planned task progress. CPM is a means of evaluating how long will each task take before one can finish the entire project [11]. It plans and controls a large number of activities that have complex dependencies on design and construction issues requiring time and cost functions. The time estimate used in CPM denotes the normal time, and links to the trade-off between completion time and the costs of the project. However, CPM can be defined as a sequence of project network activities that add up to the longest duration. Its sequence regulates the least time possible to complete the project [4, 12].

PERT is also known as Back Research Technique. This technique uses time as a variable in planning, scheduling, organizing, coordinating and controlling of uncertain activities along with performance specification [3].

The Gantt chart is a widely utilized tool in project planning and control. According to a survey involving 750 project managers, the Gantt chart ranked as the fourth most frequently used tool out of a total of 70 tools and techniques associated with project management [13]. Indeed, the decision maker can hardly imagine project management practice or training without it. Project management scholars and practitioners are all familiar with the Gantt chart, and many have used it to plan and control a project or personal complex tasks. Thus, the Gantt chart is part of the common language amongst the members of project management community [14].

Alternate graphical methods have been provided a simplistic formulation to maintain crew work continuity for repeated activities through sequential units of such projects [15].

LOB scheduling technique is a linear scheduling method commonly used in construction projects that involve repetitive sequences of tasks, similar to continuous manufacturing processes. Although LOB has not been extensively adopted by the U.S. construction industry due to the popularity of network techniques like CPM, it has found applications in resource scheduling and coordination of subcontractors, highway pavement construction, modeling production activities for multi-facility projects, and transportation projects [16].

LOB offers several advantages in the context of construction projects such as: enables project managers to assess whether they can meet the schedule by analyzing the ongoing progress of the project, helps identify process bottlenecks, enabling project managers to focus on critical areas causing delays or slippage, assists in avoiding hiring and procurement problems by optimizing the flow of labor and materials during construction, and ensures a smooth flow of crews from one unit to another, minimizing conflicts and reducing idle time for workers and equipment. The primary objectives of the LOB technique are to minimize the number of workstations, minimize cycle time, maximize workload smoothness, and maximize work relatedness. It aims to achieve an efficient and balanced workflow while optimizing resource utilization in construction projects [10, 16].

Choosing the optimal scheduling technique can significantly enhance project efficiency by minimizing delays, reducing resource conflicts, and optimizing resource utilization. A DSS can analyze and compare different scheduling techniques, considering factors such as project duration, critical paths, and resource allocation, to identify the most efficient approach. This leads to improved project timelines and cost-effectiveness [17].

The project planning & scheduling helps to cover the full scope as per contract into a plan which benefits the project by reducing the time, cost and risk on the project. This phase is a vital step in conducting the construction work smoothly [18].

Danfulani et al. (2023) conducted a study on applying CPM in scheduling a building construction, using Mosul Estate as a case study. The research indicated that implementing CPM reduce the project completion time from 32 to 27 weeks, potentially saving costs and time. The study recommended utilizing CPM in building construction projects before initiation, suggesting that allocating more resources to the critical path can help prevent delays and reduce labor costs [19].

The literature indicated that construction planners have historically achieved significant success by employing LOB scheduling for projects with repetitive features. Additionally, LSM is particularly effective when used in projects such as pipelines, highways, railroads, and utility projects [20].

The literature shows a lack of a comprehensive decision support system (DSS) specifically designed to assist contractor's decision maker in selecting the most suitable scheduling technique for infrastructure construction projects. Also, a lack of comprehensive comparative analysis across a wide range of scheduling techniques and tools specifically tailored for infrastructure construction projects. Managing a construction project schedule can be tough for many construction business owners. The schedule needs to be accurate for the short-term and adaptable for the long-term [21].

Most of literature on scheduling techniques primarily focuses on general project management or construction projects as a whole, rather than specifically targeting infrastructure construction projects [22, 23, 24, 25, 26, 27]. Scheduling is crucial for project planning and greatly impacts the project's success [7]. For these reasons, there is a need for a research study introduce a detailed assessments of the effectiveness, limitations, and applicability of various scheduling methods and software tools in the context of infrastructure projects and to develop a DSS that takes into account the specific requirements, constraints, and challenges associated with infrastructure construction projects. This research aims to bridge this gap by developing a decision support system that incorporates relevant factors such as project size, complexity, resource availability, site conditions, and project objectives to assist project managers in selecting the most suitable scheduling technique.

Factors affecting the selection of scheduling technique

A review was carried out to identify the different factors that may affect the selection of the proper scheduling technique that can be used in planning of construction projects. Yang (2015) revealed that the most important factors affecting on the selection of the proper project scheduling technique are the project's size, the complexity of the project, level of activities repetition, familiarity/well known technique, and expertise available for the chosen approach [25]. Yamin and Harmelink (2001) compared CPM and LSM by outlining essential attributes required in scheduling tools for effective management at both higher organizational levels and project-specific levels. Their study revealed that the most important factors affecting on the selection of the proper project scheduling technique are the project's size, extensive utilization in other similar projects, level of activities repetition, number of activities, type of sequence logic (hard logic or soft logic), familiarity/Well known technique, ease of use, facilitates project communication and understanding between project participants in the planning phase to reach out the project baseline, ease of determination of the critical path, aid in reduction of uncertainty/risk, aid in achieving better understanding of objectives, unawareness of the specialized capabilities and functionality of the method, ability to perform quantitative and qualitative calculations, easy for planners to understand the impact of resource variation on milestones and completion dates, ease of use and updating, facilitates project communication and understanding in the controlling phase to reach out a realistic update, good reporting / visualizing, and clear understanding of any delays and changes that have occurred when compared to the baseline schedule [22]. Mattila, & Park (2003) discussed basic linear scheduling techniques and then the calculation of critical activities of basic linear scheduling elements using the two methods. Their study revealed that the most important factors affecting on the selection of the proper project scheduling technique are the project's size, ease of determination of the critical path, and ease of Resources leveling [23]. Galloway (2006) summarized significant research conducted in the construction industry regarding the utilization of CPM scheduling. The researcher revealed that the most important factor affecting on the selection of the proper project scheduling technique is ease of extension of time analysis [24]. Through interviews with the experts, the questionnaire was reviewed by experts who had the opportunity to suggest edits or add new questions to ensure their appropriateness and relevance Finally, thirty-four factors were identified and categorized into ten groups (group No. 1 includes project related attribute factors (five factors), group No. 2 includes contractual related attributes factor (one factor), group No. 3 includes activities/tasks related attributes factors (three factors), group No. 4 includes scheduling technique related attributes factors (eight factors), group No. 5 includes staffing related attributes factors (three factors), group No. 6 includes resource management related attributes factors (three factors), group No. 7 includes cost management related attributes factors (two factors), group No. 8 includes controlling and monitoring related attributes factors (seven factors), group No. 9 includes recovery and revised plans related attributes factor (one factor), and group No. 10 includes claims and extension of time related attributes factor (one factor). These factors are shown in Table 1 below.

Table 1: Factors affecting the selection of the proper project scheduling technique in previous articles

ID	Factor	Yang, 2015 [25]	Yamin and Harmelink, 2001 [22]	Mattila & Park, 2003 [23]	Galloway, 2006 [24]	Survey
	Project related attributes (group 1)					
C01	The project's size	√	√	√	-	-
C02	The complexity of the project	√	-	-	-	-
C03	Extensive utilization in other similar projects	-	√	-	-	-
C04	The project's duration	-	-	-	-	√
C05	Nature of the project (roads, short crossing bridges, long corridor bridges, via ducts, open cut tunnels, TBM tunnels, pressure pipes networks, slope pipes networks, … etc.)	-	-	-	-	√
	Contractual related attributes (group 2)					
C06	The contract stated to use a specific scheduling technique	-	-	-	-	√
	Activities/Tasks related attributes (group 3)					
C07	Level of activities repetition	√	√	-	-	-
C08	Number of activities	-	√	-	-	-
C09	Type of sequence logic (hard logic or soft logic)	-	√	-	-	-
	Scheduling technique related attributes (group 4)					
C10	Familiarity/Well known technique	√	-	-	-	-
C11	Ease of use	-	√	-	-	-
C12	Facilitates project communication and understanding between project participants in the planning phase to reach out the project baseline	-	√	-	-	-
C13	Ease of determination of the critical path	-	√	√	-	-
C14	Aid in reduction of uncertainty/risk	-	√	-	-	-
C15	Aid in achieving better understanding of objectives	-	√	-	-	
C16	Applying scheduling optimization	-	-	-	-	√
C17	Flexibility to change the construction sequence	-	-	-	-	√
	Staffing related attributes (group 5)					
C18	Expertise available for the chosen approach	√	-	-	-	-
C19	Unawareness of the specialized capabilities and functionality of the method	-	√	-	-	-
C20	Required more staffing	-	-	-	-	√
	Resource management related attributes (group 6)					
C21	Ability to perform quantitative and qualitative calculations	-	√	-	-	-
C22	Easy for planners to understand the impact of resource variation on milestones and completion dates	-	√	-	-	-
C23	Ease of Resources leveling	-	-	√	-	-

	Cost management related attributes (group 7)					
C24	Cost allocation and distribution	-	-	-	-	√
C25	Cost control	-	-	-	-	√
	Controlling and monitoring related attributes (group 8)					
C26	Ease of use and updating	-	√	-	-	-
C27	Facilitates project communication and understanding in the controlling phase to reach out a realistic update	-	√	-	-	-
C28	Ease of handling out of sequence activities	-	-	-	-	√
C29	Good reporting / visualizing	-	√	-	-	-
C30	Clear understanding of any delays and changes that have occurred when compared to the baseline schedule	-	√	-	-	-
C31	Reliable earned value calculations	-	-	-	-	√
C32	Reliable forecasting	-	-	-	-	√
	Recovery and revised plans related attributes (group 9)					
C33	Ease of handling a recovery or revised plan	-	-	-	-	√
	Claims and extension of time related attributes (group 10)					
C34	Ease of extension of time analysis	-	-	-	√	√

Questionnaire Design

The designed questionnaire aims to investigate the importance of 34 factors that affect the selection of scheduling technique for infrastructure construction projects. The questionnaire structure consists of five parts. The first part consists of respondents' demographics and their experience, the second part consists of six questions about the respondent's point of view for the best technique achieves the required criteria for infrastructure construction projects, and the third part consists of 34 questions concerning the degree of importance of 34 factors that affect the scheduling technique selection in infrastructure projects. A five-point Likert scale was adopted for this study [28]. The values ranged from 1 Strongly Disagree to 5 Strongly Agree. The five-point rating scale was preferred due to its ability to sufficiently capture experts' opinions for detailed evaluation [29]. The fourth part of questionnaire consists of 34 questions concerning the impact of these factors on the selection of Network based Technique (Critical Path Method) as an optimal choice. The available choices were from 1 to 9 where 9 means this factor strongly affecting on the selection of CPM and 1 means this factor moderately affecting in the selection of CPM or LSM. The fifth part of questionnaire consists of 34 questions concerning the impact of these factors on the selection of LSM as an optimal choice. The available choices were from 1 to 9 where 9 means this factor strongly affecting on the selection of LSM and 1 means this factor moderately affecting in the selection of LSM or CPM.

The terms used in the questionnaires were accurately defined to avoid any ambiguity or confusion in respondents' interpretations.

Sample Size

According to Cochran's sample size formula and Cochran's (1977) correction formula [30] that calculates the required sample for the distributed questionnaire, the sample size was 112 from specialized engineers from contractors, consultants, and owners worked at infrastructure projects in Egypt.

Cochran's sample size formula in equation (1) is used to calculate desired survey sample size [30].

$$n_0 = \frac{(t)^2(s)^2}{(d)^2} \ldots\ldots\ldots\ldots\ldots (1)$$

-Equation (1) [30]

Where t = value for selected alpha level of 0.025 in each tail = 1.96

s = estimate of standard deviation in the population = 1.167

d = acceptable margin of error for mean being estimated = number of points on primary scale x acceptable margin of error = 7 x 0.03= 0.21

n0 = sample size needed prior to correction = 119 (surpasses 5% of the population (1755*.05=88).

Cochran's (1977) correction formula specified in equation (2) should be used to calculate the final sample size [30].

$$n = \frac{n_0}{(1 + \frac{n_0}{\text{Population}})} \ldots\ldots\ldots\ldots\ldots (2)$$

- Equation (2) [30]

Rounded up, Equation (2) indicates that 112 participants are needed to have 95% confidence that sample estimates are within ±5% of the population value. The equation variables are defined as follows:

n0 = sample size needed prior to correction = 119

Population= 1755

n = corrected sample size =112

Data Collection

A review was carried out to identify the different factors that may affect the selection of the proper scheduling technique that can be used in planning of infrastructure construction projects. A questionnaire was created to gather opinions from experts, including contractors, consultants, and owners' engineers, regarding the importance of each one of the 34 factors in selecting the most proper project scheduling technique for infrastructure construction projects. The questionnaire questions were reviewed by university experts and expert's engineers from contractors, consultants, owner who had extensive experience in planning of infrastructure projects through a pilot study. The experts have the chance to edit these questions or add any new question if it was necessary. A Pilot study is conducted to improve the internal validity of the questionnaire. At the end, a final version of the questionnaire is ready to achieve the research aims with a high degree of success. The questionnaire was distributed directly through an online Google Form to the experts. The questionnaire was sent to a sample of 112 specialized engineers from contractors, consultants, and owners who had a minimum of 10 years of experience in project planning and scheduling techniques of infrastructure construction projects across various public and private sectors. A total of 100 contractors, consultants, and owners' engineers responded to the questionnaire, resulting in a response rate of approximately 91%.

Relative importance of factors

After determination of factors affecting the selection of optimal scheduling technique, questionnaires were designed in order to collect information about the impact of these factors. Additionally, the results of the questionnaires were analyzed using the Likert scale with the assistance of SPSS software. This allowed for the calculation of the data's validity. The Cronbach's Alpha coefficient, calculated using SPSS, was found to be 0.88. This high value indicates that the collected data from the questionnaires and interviews possess a high level of validity.
The resu'ts of the analyzed collected data in this stage have been shown in Table 4. Also, the relative weight of each one of these factors is calculated and presented in this table.
By using equation 3 below, Factor's Impact is calculated as follows:

Factor's Impact = (SA*5+A*4+N*3+D*2+SD*1)/{(SA+A+N+D+SD)*5}---Equation (3) [31,32]

Where: SA means Strongly Agree, A means Agree, N means Neutral, D means Disagree, and SD means Strongly Disagree.

Also, by using equation 4 below, relative importance of any factor is calculated as follows:

Relative importance of any factor = $\frac{Factor's\ Impact\ \%}{\text{Total Impact \%}}$ --------- Equation (4) [31, 32]

For example: C02 impact = (55*5 + 23*4 + 11*3 + 8*2 + 3*1) / (100*5) = 82.2%

Relative weight of CO2 = 0.822 / 26.042 = 0.0316

Data Analysis

Table 4: Impact and relative weight of each factor on the selection of the proper project scheduling technique

No.	Factor	Impact %	Relative weight (X)
C05	Nature of the project.	87.5	0.0336
C30	Clear understanding of any delays and changes that have occurred when compared to the baseline schedule.	86.0	0.0330
C34	Ease of extension of time analysis.	85.2	0.0327
C06	The contract stated a specific scheduling technique.	84.4	0.0324
C26	Ease of use and updating.	83.8	0.0322
C27	Facilitates project communication and understanding in the controlling phase to reach out a realistic update.	83.8	0.0322
C33	Ease of handling a recovery or revised plan.	82.7	0.0317
C02	The complexity of the project.	82.2	0.0316
C32	Reliable forecasting.	81.4	0.0312

C29	**Good reporting / visualizing.**	**81.1**	**0.0311**
C28	Ease of handling out of sequence activities.	79.8	0.0306
C22	Easy for planners to understand the impact of resource variation on milestones and completion dates.	79.7	0.0306
C31	Reliable earned value calculations.	79.0	0.0303
C07	Level of activities repetition.	78.6	0.0302
C18	Expertise/Qualifications available for the chosen approach.	78.4	0.0301
C24	Cost allocation and distribution.	78.1	0.0300
C12	Facilitates project communication and understanding between project participants in the planning phase to reach out the project baseline.	77.6	0.0298
C25	Cost control.	77.3	0.0297
C13	Ease of determination of the critical path.	76.1	0.0292
C21	Ability to perform quantitative and qualitative calculations.	76.0	0.0292
C01	The project's size.	75.7	0.0291
C10	Familiarity/Well known technique.	75.7	0.0291
C16	Applying scheduling optimization.	75.2	0.0289
C11	Ease of use.	72.8	0.0279
C15	Aid in achieving better understanding of objectives.	71.8	0.0276
C23	Ease of Resources leveling.	71.2	0.0273
C03	Extensive utilization in other similar projects.	70.1	0.0269
C09	Type of sequence logic (hard logic or soft logic).	69.8	0.0268
C04	The project's duration.	69.2	0.0266
C17	Flexibility to change the construction sequence.	68.6	0.0263
C14	Aid in reduction of uncertainty/risk	67.6	0.0259
C08	Number of activities	66.5	0.0255
C19	Unawareness of the specialized capabilities and functionality of the method	65.5	0.0251
C20	Required more staffing	55.8	0.0214
Σ		2604.2	1

Table 5: the average score for each factor (-ve indicates for LSM while +ve indicates for CPM)

No	Factor	Option 1	Score for option 1 (Y)	Option 2	Score for option 2 (Y)
C01	[Mega / large project]	Yes	**3**	No	**-3**
C02	[Unique / complex project]	Yes	**2**	No	**-2**
C03	[Extensive utilization in other similar projects in your firm]	Yes	**2**	No	**-2**
C04	[Long project duration]	Yes	**2**	No	**-2**
C05	[For roads projects]	Yes	**-4**	No	**4**
	[For short crossing bridges]	Yes	**1**	No	**1**
	[for long corridor bridges]	Yes	**-3**	No	**3**

	[for via ducts and open cut tunnels]	Yes	**-2**	No	**2**
	[for TBM tunnels]	Yes	**-4**	No	**4**
	[for pressure pipes networks]	Yes	**-3**	No	**3**
	[for slope pipes networks]	Yes	**-3**	No	**3**
C06	[The contract stated to use a specific scheduling technique]	Yes	**3**	No	**1**
C07	[High level of activities repetition]	Yes	**-3**	No	**3**
C08	[lots number of activities]	Yes	**1**	No	**1**
C09	[Type of sequence logic is hard logic]	Yes	**1**	No	**1**
	[Type of sequence logic is soft logic]	Yes	**1**	No	**1**
C10	[Familiarity/ Well known technique]	Yes	**3**	No	**-3**
C11	[Ease of use]	Yes	**2**	No	**-2**
C12	[Facilitates project communication and understanding between project participants in the planning phase reach out the project baseline]	Yes	**1**	No	**1**
C13	[Ease of determination of the critical path]	Yes	**4**	No	**1**
C14	[Aid in reduction of uncertainty/risk]	Yes	**2**	No	**1**
C15	[Aid in achieving better understanding of objectives]	Yes	**2**	No	**1**
C16	[Ability of applying scheduling optimization]	Yes	**1**	No	**1**
C17	[Flexibility to change the construction sequence]	Yes	**2**	No	**-2**
C18	[Expertise available for the chosen approach]	Yes	**2**	No	**-2**
C19	[Unawareness of the specialized capabilities and functionality of the method]	Yes	**1**	No	**1**
C20	[Required more staffing]	Yes	**1**	No	**1**
C21	[Ability to perform quantitative and qualitative calculations for resources]	Yes	**2**	No	**-2**
No	**Factor**	**Option 1**	**Score for option 1**	**Option 2**	**Score for option 2**
C22	[Easy for planners to understand the impact of resource variation on milestones and completion dates]	Yes	**2**	No	**-2**
C23	[Ease of Resources leveling]	Yes	**1**	No	**1**
C24	[Better in cost allocation and distribution]	Yes	**2**	No	**-2**
C25	[Better in cost control]	Yes	**2**	No	**-2**
C26	[Ease of use and updating]	Yes	**2**	No	**-2**
C27	[Facilitates project communication and understanding in the controlling phase to reach out a realistic update]	Yes	**2**	No	**-2**
C28	[Ease of handling out of sequence activities]	Yes	**2**	No	**-2**

C29	[Good reporting / visualizing]	Yes	**-3**	No	**3**
C30	[Clear understanding of any delays and changes that have occurred when compared to the baseline schedule]	Yes	**2**	No	**-2**
C31	[Reliable earned value calculations]	Yes	**2**	No	**-2**
C32	[Reliable forecasting]	Yes	**2**	No	**-2**
C33	[Ease of handling a recovery or revised plan]	Yes	**2**	No	**-2**
C34	[Ease of extension of time analysis]	Yes	**3**	No	**-3**

The main ten factors to be considered on the selection of the proper project scheduling technique are shown in the top of Table 4. The chosen factors are all the factors with impact factor more than 80%.

In the fourth part of the questionnaire, each one of the respondents who fills out the questionnaire puts a score from 1 to 9 for each factor with the CPM method and puts another score from 1 to 9 only with the other method LSM. The goal of this is to come up with an average value from 1 to 9 for each method. The model is based on the idea that whoever uses it answers a set of optional questions for each criterion. The model, from the user's choice, will take the number saved inside it for this choice (for example, it will be 2 for LSM). Then, multiplies it by the RII for the nature of the project. Thus, it gives you a score based on answers that you move towards LSM by a specific value and so on for each question. So, the final result is that you move towards Network Based Techniques (CPM) by a certain score and towards Graphical Based Techniques (LSM) by a certain score. The higher score is the most appropriate method for the project scheduling.

The analysis of this section of the questionnaire was conducted by calculating the average, which involved summing all the responses and dividing them by the number of respondents. To obtain the average for both methods, the scores for LSM were recorded as negative, while those for CPM were recorded as positive. This approach yielded a final average score (Y) for each factor, which was used in the model. The final average scores are presented in Table 5.

This approach resulted in final average scores for each factor (Y), which were incorporated into the model. The final average scores are presented in Table 5. As indicated in this table, the lowest score is 1 and the highest is 9, with negative values indicating a preference for LSM and positive values indicating a preference for CPM. The close alignment of these results with those derived from previous studies reinforces the respondents' understanding of the factors and methods involved. Furthermore, it is evident that many of the factors may have been evaluated in isolation in earlier research. This study aims to examine all factors collectively and quantitatively, rather than relying solely on experience or conjecture. For instance, the factor of Ease of Use, ranked fifth after calculating the RII (X) as shown in Table 4, is significant and has been addressed in previous studies, as illustrated in Comparative Table 2. Prior research consistently concluded that the CPM method is more widely used and easier to implement than the LSM method. In Table 5, if a respondent answers "Yes," the score will be 2 towards the CPM method. This underscores the correlation between the results obtained from the questionnaire and those from prior studies, enhancing the credibility of the findings and reflecting their consistency with existing literature. As shown in the results of this table, there is a significant equivalence, and the numerical results align with the expectations presented in Table 2 derived from the literature review. Thus, the numerical results are more accurate and consistent with previous studies.

Decision Support Systems (DSS)

Decision support systems (DSS) are interactive computer-based information systems designed to assist decision makers in utilizing data and models to solve semi-structured or unstructured decision problems. DSS provide support for decision-making processes by providing access to relevant data, tools for analysis and modeling, and facilitating the exploration of alternative solutions. They are particularly useful in addressing complex decision scenarios that do not have well-defined procedures or solutions. DSS help decision makers navigate through such problems and make informed decisions based on available information and analysis [33].

The developed Decision Support System (DSS)

The Decision Support System (DSS) is selected as a comprehensive and versatile decision-making model in this study. The DSS employed is multi-objective and knowledge-driven, aiming to provide suggestions and recommendations to contractors. It is designed to be utilized by Contractor's planners and discission maker for infrastructure construction projects. The questionnaire results are incorporated and stored in the DSS software package, enabling the determination of weight values for various options in relation to the factors being considered. These results are the relative importance weight of each one of 34 factors affecting the selection of the most appropriate project scheduling technique.

Classification Limits for infrastructure projects

Classification limits of infrastructure projects according to their type, size, duration, and difficulty are summarized in Table 6 below.

Table 6: Classification of Infrastructure Projects according to their type, size, duration, and difficulty)

		Classification
1	**Project Type**	Unique (Seawater desalination plant, Lift station, ……….)
		Short crossing bridges
		Via ducts and open cut tunnels
		Roads
		TBM tunnels
		Slope pipes networks
		Pressure pipes networks
		Long corridor bridges
2	**Project Size**	Small (construction cost is less than 50 Million LE)
		Medium (construction cost = 50-500 Million LE)
		Big (construction cost is more than 500 Million LE)
3	**Project Duration**	Small (construction time is less than 6 months)
		Medium (construction time = 6-12 months)
		Big (construction time is more than 12 months)
4	**Project difficulty (No. of activities)**	Less than 50
		50-200
		More than 200

Developed Model for studying scheduling techniques

1. Model Name: Decision Support System to Select the Most Appropriate Scheduling Technique.
2. Input the Available Choices
   (1) CPM (2) LSM
3. The program has based on the calculated relative importance weight (RII) (X) for 34 factors according to the analysis of the questionnaire results.
4. Afterward, the program will multiply each RII (X) by each score (Y). In the fourth part of the questionnaire, each one of the respondents who fills out the questionnaire puts a score from 1 to 9 for each factor with the CPM method and puts another score from 1 to 9 only with the other method LSM. The goal of this is to come up with an average value from 1 to 9 for each method. The model is based on the idea that whoever uses it answers a set of optional questions for each criterion. The model, from the user's choice, will take the number saved inside it for this choice (Y) (for example, it will be 2 for LSM). Then, multiplies it by the RII (X) for the nature of the project. Thus, it gives you a score (Z1) based on your answer that you move towards LSM by a specific value and so on for each question
5. Then, the summation (Z) for each column under each one of the two alternative scheduling techniques will appear at the end of this window. The column with the highest summation value indicates the most proper scheduling techniques.
   $Z = X1*Y1 + X2*Y2 + \ldots\ldots\ldots$
6. So, the final result is that you move towards CPM by a certain score and towards LSM by a certain score. The higher score (Z) is the most appropriate method for the project scheduling.

Input Data

The input data is the answers for the 34 questions.

Output Data

The output data is the recommended scheduling tool to be used for planning of an infrastructure project.

Description and Characteristics for the Proposed Decision Support System

Model description

The proposed DSS model is designed to help project contractors or the decision makers in selecting the most appropriate scheduling technique for their construction projects. For the DSS model to be an efficient and useful one, it should be user friendly to allow the user to move from a step to another smoothly and in an organized manner.

To create a new decision for a new project, the procedures in program will be as follows:

1. Initiate Project Creation: Begin by selecting the option to create a new project.
2. Input User Information: Enter the personal details of the user, then proceed by clicking "Next."
3. Enter Owner Information (if any): Fill in the owner's details and click "Next" to continue.
4. Provide Contractor Information (if any): Input the contractor's information and click "Next" to advance.
5. Scheduling Techniques Evaluation: A new window will display a table featuring two scheduling techniques. The program will assign a relative importance percentage (weight) to each of the 34 factors based on questionnaire results. The user will then respond to these 34 questions, allowing the

model to compute a score for each factor under both techniques. The program will multiply the Relative Importance Index (RII) (X) by each score (Y), and the summed totals (Z) for each scheduling technique will be displayed in the corresponding columns.
Z = X1*Y1 + X2*Y2 + ……….

- Users will have two options at this stage: to view the results by clicking "Get Results," or to return to the previous screen to modify any factor scores by clicking "Back."

6. Results Presentation: Upon selecting "Get Results," a new window will present the user with the most suitable scheduling techniques based on the calculations.

XII. Case Studies and Validity of the system

Finally, the validity of the proposed DSS was tested by practical application via two actual case studies as follows:

Case study No. (1):

Project name: Implementation of roads and pipeline networks for low-cost housing project in New Port Said City.
Owner: Ministry of housing
By applying the Decision Support System software to the project by inputting the following data:
Project type: Roads and Pipeline Networks
Project cost: 415,000,000 EG. Pound
Project Duration: 12 Month
No. of activities: 94
Type of logic (majority): Soft
The user enters the score for each factor in the column under CPM and LSM.
The output report showed that: The most appropriate scheduling technique is "LSM".

Case study No. (2):

Project name: Implementation of a seawater desalination plant in New Port Said City.
Owner: Ministry of housing
By applying the Decision Support System software to the project by inputting the following data:
Project type: Seawater desalination plant
Project cost: 2,340,000,000 EG. Pound
Project Duration: 36 Month
No. of activities: 112
Type of logic (majority): Hard
The user enters the score for each factor in the column under CPM and LSM.
The output report showed that: The most appropriate scheduling technique is "CPM".
Finally, all of these results matched with the actual scheduling technique implemented in these projects, the results of the previous studies done by experts for these types of projects and the same proposed by managers of project with several years of successful work experience in construction projects.

XIII. DISCUSSION

Figure 2 summarized the outputs of the questionnaire analysis about the top ten factors affecting on scheduling technique selection for infrastructure construction projects. The importance weights of 34 factors were determined (Table 4). Nature of the project has the highest score (87.5 %), then Clear understanding of any delays and changes that have occurred when compared to the baseline schedule with (86 %), then ease of extension of time analysis with (85.2%), then the contract stated a specific scheduling technique with (84.4%), then ease of use and updating with (83.8%) and facilitates project communication and understanding in the controlling phase to reach out a realistic update with (83.8%), then ease of handling a recovery or revised plan with (82.7%), then the complexity of the project with (82.2%), then reliable forecasting with (81.4%), and lastly good reporting / visualizing with (81.1 %). This result is consistent with the results in previous studies, but differs in the order of importance of these factors [22,23,24,25] and their impact on selecting the appropriate scheduling technique for infrastructure construction projects.

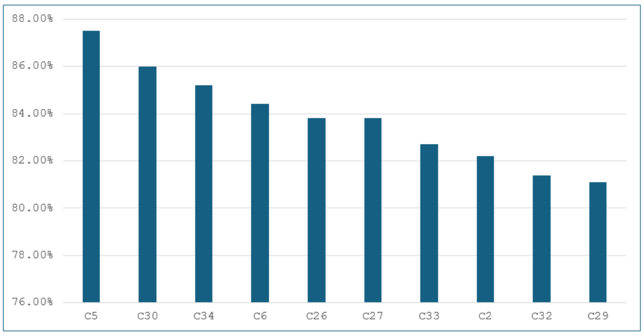

Fig 2. The top ten factors affecting on scheduling technique selection for infrastructure projects

The literature shows a lack of a comprehensive decision support system (DSS) specifically designed to assist contractor's decision maker in selecting the most suitable scheduling technique for infrastructure construction projects [1,3,4,5,6,7,8,22,23,24,25]. Otherwise, this study introduces this DSS software that can be used by employers of different types of infrastructure construction projects as contractual management software in line with selecting the optimal scheduling technique.

XIV. CONCLUSIONS

While no scheduling technique option is perfect, one option may be better suited than another based on the unique requirements of a particular project. The requirements for each infrastructure project should be evaluated to determine which of the various options would mostly likely produce the best outcome for the contractor. Each scheduling technique comes up with its own advantages and disadvantages with the best choice being governed by the requirements of the specific project. In this study, with comprehensive and all-out study of different types of infrastructure construction projects, a number of 34 effective factors were identified and selected in decision making and selection of the proper scheduling technique. In the same direction, relative significance of each one of these factors was obtained using questionnaires distributed among specialized engineers from contractors, consultants, and owners who have though knowledge in related field. In continuation, an analytical approach was used for optimal construction of infrastructure projects and the impact of each factor on scheduling technique selection was calculated. Then, results of questionnaire were inserted and saved in Decision Support System software package, so that weight value of options was obtained in comparison with the factors. It should be noted that this software is used for the optimal construction of several types of infrastructure projects. The answers obtained from software were the same proposed by planning managers of projects with several years of successful work in infrastructure construction projects. It can be mentioned that the proposed software can be adapted easily to changes, so that an option or factor can be removed or added easily and/or adopt some corrections in data of input questionnaire to software. It should be noted that this software can be completed more comprehensively in future studies. Moreover, this software can be used by employers of different types of infrastructure construction projects as contractual management software in line with selecting the optimal scheduling technique.

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