Civil Engineering and Architecture 10(3): 836-857, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100308

Construction Operations Practices and Operations Research Tool Application in a Hypothetical Construction Project

Jimmy Adora Nebrida[1,2,*], Ronald Orale[2]

[1]Civil Engineering Division, Bahrain Training Institute, Ministry of Education, Kingdom of Bahrain
[2]Graduate School, Samar State University, Philippines

Received December 13, 2021; Revised March 4, 2022; Accepted March 27, 2022

Cite This Paper in the following Citation Styles

***(a):** [1] Jimmy Adora Nebrida, Ronald Orale , "Construction Operations Practices and Operations Research Tool Application in a Hypothetical Construction Project," Civil Engineering and Architecture, Vol. 10, No. 3, pp. 836-857, 2022. DOI: 10.13189/cea.2022.100308.*

***(b):** Jimmy Adora Nebrida, Ronald Orale (2022). Construction Operations Practices and Operations Research Tool Application in a Hypothetical Construction Project. Civil Engineering and Architecture, 10(3), 836-857. DOI: 10.13189/cea.2022.100308.*

Abstract This study aimed to assess the construction operations practices of three contractors; apply the construction operations practices for each company to a hypothetical construction project; and use an operation research tool in the hypothetical construction project. The results showed that the majority of contractors have similar organizational delivery systems with functional departments such as business development, finance, human resources, and construction operations, and they fall into the PCAB group. According to respondents, efficiency in resource use, avoidance of non-conformance works, elimination of wastes or non-value-added activities, value engineering, bulk order discounts, listing of different suppliers, double shifting of work scheme, prioritizing activities suitable for weather conditions, delegating work packages to subcontractors, resequencing the project schedule, application of value engineering are all important factors in optimizing project costs. The study concludes that operations research methods are important in project management, particularly in terms of reducing construction costs and increasing project profit. The findings indicated how the operations research tool, in conjunction with the QM for Windows application, made determining project schedule priorities to manage large and complicated project operations appear simple.

Keywords Construction Operations, Management Practices, Operations Research, Construction Amidst COVID-19 Pandemic

1. Introduction

The Philippine construction industry is a major contributor to the country's economy, with a gross added value of 336 billion Philippines Pesos in 2020. This includes total building expenditures from both the private and public sectors that were disrupted during the pandemic [1]. The construction sector has declined to 9.8% in 2020 due to health protocols implemented amidst pandemic [2]. In the recent report, the local construction industry is expected to improve from the slump in 2020 as the government rises its major infrastructure projects, which will support the small and medium contractors which are the ones commonly affected by this pandemic [3].

Construction management plays a significant role in the achievement of good performance of the project which specifically in minimizing project cost. In any project development, such as a construction project, cost is the most important factor to consider [4]. Construction projects are time consuming by which the total project development consists of different stages requires specialized services, and from initial stage to project completion will demand a lot of necessary factors like the technical and financial resources and set of professionals to perform the tasks. Construction project is unique, meaning no two jobs are the same but it still follows through a construction process that tends to be consistent from mobilization up to the project closing [5].

Every construction company's most frequent goal is to reduce construction waste, and achieving this goal necessitates the application of specific skills and strategies. Delay is one of the constructions wastes that have an impact on project operations. Time and expense overruns, conflicts, arbitration, litigation, breach of contract, total abandonment, and delays to other projects are some of the effects of delays [6]. To address these issues, there is a need for sufficient knowledge and tools of operations research to be used for construction operations such as PERT CPM using manual and computer aided software. In the construction operation, operational activities and management principles are important in the construction stage, which could be seen from the concept of management that issues in the construction sites are the reasons for lack of economic success for contractors. In addition, there is an increasing number of construction companies embracing the lean principle of construction, which aims to minimize waste by producing repetitive work and foreseeing results in a controllable environment like in fabrication houses or factories [7].

Minimizing the expenses will maximize the project cost in the operations through appropriate tools of operations research applicable to construction projects. The operations research has an impressive impact in various organizations such as in manufacturing industry, which contributes to the increase of productivity of economies of various countries [8]. The operation research tools like PERT CPM are commonly used tools applied in construction projects. Evaluation of different construction companies in terms of its construction practices would help in coming up with the method on how a project would minimize its construction wastage, thus increasing its productivity and project profit.

Operation research tools will contribute to the improvement of operations management for construction projects by which these services have already performed in some other disciplines. Since it is already used scientifically with other disciplines, the project managers or civil engineers will be provided with better solutions to the issues of construction projects which are derived from the evolutions of construction practices, experience and empirical studies [9]. It is for these reasons that this study will look into the depth of construction operations to develop answers on the issues faced in construction projects, especially on minimizing construction costs, thus improving profits. This study will further present the utilization of construction practices and operations research tools in a hypothetical construction project.

1.1. Objectives

This study aimed to find out the construction operations practices of three companies. Specifically, it aimed:

(1) To assess the construction operations practices of three contractors in terms of organizational structure, construction operations, health and safety, and strategy in minimizing cost.
(2) To apply the construction operations practices for each company to a hypothetical construction project.
(3) To use an operation research tool in the hypothetical construction project.

1.2. Conceptual Framework

This study is based on the idea that the performance of the project is maximized when its construction objectives in terms of approved cost are achieved. The idea is to determine the construction operations practices in terms of minimizing project cost of three identified contractors on their respective projects. The information is determined through interview from a civil engineer employed by the contractor. The construction operations practice of three contractors will be applied to a hypothetical construction project which will identify their performance in minimizing the cost of the hypothetical construction project.

To reinforce this concept, a paradigm is shown in figure 1.

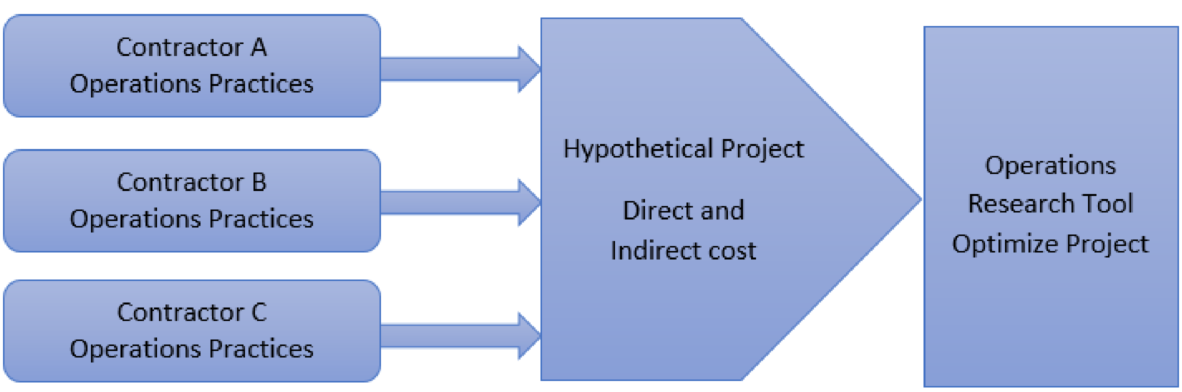


Figure 1. Paradigm of the study

2. Methodology

2.1. Research Design

This study used qualitative research in determining the construction operations practices of different contractors for a construction project which specifically aims to minimize the cost of a hypothetical construction project using strategies of minimizing cost and operations research tools. Qualitative research is a method of research which explores real life situation focused on phenomenon using in depth data collection about detailed views of the participants, collects comprehensive responses from them in the form of words or images, then analyzes the data for description and themes [10]. The study used an interview guide with major concerns and a series of open – ended questions about the cost of the construction project.

The subjects of interview are the civil engineers who are representative of each of the three contractors. To get a diverse of construction operations practices, contractors are identified from cities and provinces, and with different categories from PCAB. The operations practices determined in the interview were utilized in a hypothetical construction project to optimize the construction project.

2.2. Research Instrument

Data gathering made use of an interview with a series of open-ended questions related to the cost of the construction project. The instrument was validated before being used for actual interview. All identified corrections were edited by the researcher before being used for actual interview. The interview questions covered aspects of projects such as planning and quantity survey, health and safety, execution and monitoring, and quality control.

The interview was done using zoom us meeting and google meet applications. Also, recording of the interview session was done for data collection. The researcher ensured that all necessary activities in the conduct of the study were properly undertaken such as sending communication letters, consent forms, scheduled interviews, and its confidentiality. After each interview session, the raw data was transcribed and analyzed with the use of maxQDA software. In using this software, analysis begins with coding to sort and organize data. The second step is axial coding to analyze the questions based on the initial coding made. Lastly, selective coding helps to narrow down the selected code.

The data collected from respondents were applied on the hypothetical project using QM windows software, an operations research tool which helps optimize project performance by identifying critical path of activities and generates tables of network precedence and Gantt chart of activities. The percentage cost allocation from the data received from the respondents who are company representatives will be used in the hypothetical construction project.

3. Results and Discussion

The findings of the study are based on the subjects' narratives, which highlight the organizations' construction operations in terms of organizational structure used, construction operations, health and safety, and strategy to minimize project cost. It revealed the study's subjects' introspective phenomenological experience.

Construction Operations practices for Company A

Organizational Structure. The company is a partnership between a local and an international construction firm. The project is a government-funded railway construction that will be financed by an international financial institution. At the job site, there is a project management group that serves as consultants and represents the government agency. PCAB has granted the local firm category AAAA accreditation. Category AAAA can join single largest project above PhP 225 million [11]. There are three departments in the company which include civil, building includes architectural and MEP. "The business is a joint venture between local and international companies. JICA is the funder, and the government is the employer." (COMPANY A, Pos. 9]

Construction Operation. The project cost is PhP 55 billion for package A of a railroad project. The departments included in the construction operations are health and safety, environment, quality assurance and quality control, design engineering team, construction team, public relations and road right of way, administration, and commercial for contracts, cost and planning. The project has an expected actual profit of approximately 15% of the project cost. The project cost is one of the most important factors in the operation of construction in the industry and rarely projects are completed according to the estimated budget [12]. The following information is the percentage allocation of works taken from bill of quantities as mentioned by the civil engineer:

Table 1. Company A Project Cost Breakdown, Planned vs Actual

Description	% of cost, Planned	% of cost, Actual
General Requirements • Mobilization, 85% • Mobilization program, site office, operating and maintenance expenses, provision of motor vehicle, etc., 15%	4%	7%
Works • Materials, 50% • Labor, 40% • Equipment, 10%	70%	75%
Overhead and Profit (OHP)	26%	11%
Total Project Cost (55 billion PHP)	100%	93%

In Table 1 above, the civil engineer cited that the cost increases from 4% to 7% for the general requirements due to additional cost incurred by delays attributable to contractors such as site office extension, temporary facilities, insurances, equipment, and vehicles. In the study of Hasan, delay is one of the constructions wastes which affect the operations of the projects. His study revealed that causes of delays as well as frequency of delay's effects the projects which were identified and classified by responsibility into six groups related to contractor, owner, consultant, services and utilities, government regulations, and external environment [6]. Furthermore, due to price escalation, defective works and products, resource mismanagement, and inadequate supervision, work planned for material, labor, and equipment grows from 70% to 75%. However, the actual cost of overhead and profit falls from 26% to 11%, resulting in a 7% increase in project profit.

Health and Safety. The civil engineer stressed out that health and safety have a substantial effect in the construction operations. Injuries and fatal accidents affect the working days of the project operations since labor in construction operations is associated with high risk of injuries which is an important element in the production efficiency [13]. On the construction site, there was a deadly accident in which an equipment spotter died. The company declared a 5-day work stoppage due to claims from sub-contractors that could not be reimbursed by the government, resulting in a loss to the project around 0.04% of project cost. "Work was immediately suspended for 5 days by the company" (COMPANY A, Pos. 40).

Strategy on how to minimize cost. The civil engineer cited that efficient use of resources like avoiding non – conformance of works is one strategy used in minimizing cost. Lean construction was also observed, such as on-time delivery and the Just-in-Time (JIT) method of lean construction. Lean production is the eliminating of wastes or anything that does not add value to the project [14]. The general concept of cost minimization is based on the construction practices which are mostly related to material suppliers, sub-contractors, and plant and equipment providers [15].

On issues of delays during pandemic, the company's response is to stop the work for 2.5 months until IATF is allowed to resume the construction activities. In this case, all schedules have been moved and restructured, and the contractor is claiming time and expense as additional payment owing to a change in legislation because of the government's general quarantine protocols. Such claims arise from contractors' maintenance of materials and equipment, for which they are authorized to claim an extension under the contract. The construction industry has been affected by the pandemic by which decisions were made that restricted people for movement and developments of the projects were postponed [16].

Construction Operations practices for Company B

Organizational Structure. According to the civil engineer**,** the company is PCAB-accredited as category A with design and build project procurement. The business development department, finance department, human resource department, and operation department are the four departments that make up the company. According to the principle of departmentalization, department has to be grouped according to specialization and similarity of tasks as it will provide the best way of managing organizations [17].

Business development department includes planning and design, such as architectural planners and structural engineers, which are outsourced on a contract basis and account for about 2% of the project cost. Consultancy group is applied and effective to small companies in an external project management delivery system where there is insufficiency of staff or need for specialization [18]. While human resource and finance department has an estimated budget of 1% of the project cost for each department.

The project cost is PhP 259 M for a housing project. The project cost includes land acquisition, site development, and payment for mobilization. While construction cost includes estimated direct cost plus 8% OCM, 8% profit, 1% mobilization. Direct cost includes labor and materials by which material cost is around 60 – 65% which could go to 60% after value engineering. The labor cost is 20 – 25% in region and 25 – 30% in the National Capital Region.

Construction Operation. There are 5 engineers on the site composed of project manager, assistant project manager, project supervisor, safety officer/Engineer and administrative staff which are all licensed engineers. The safety officer is also accredited by NEBOSH (National Examination Board in Occupational Safety and Health). NEBOSH is an internationally recognized qualification which helps the competence of safety professionals in achieving health, safety and environmental qualification requirement [19].

Health and Safety. One of the departments in construction operation, which has an allocation of around 0.25% - 0.50% from the OCM of the construction cost intended for the salary and personal protective equipment (PPE). Health and safety issues are minimal with some minor accidents and have no effects on the project cost. Health and safety issues are common in the industry which most participants have agreed on this claim by which it is recommended that practical guidelines should be developed and implemented in construction sites [20]. "The accidents that happened have no effects on cost and the work was not suspended" (COMPANY A, Pos. 21)"

Project Supervision and Quality Control. The cost for execution and monitoring of construction activities is 1.5 – 2% of the construction cost which is also taken from OCM. While Quality control is 1% of the construction cost and taken from OCM.

Strategy on how to minimize cost. The list of different suppliers is identified at the start of the building stage for approval by the management group that represents the owner. Following the approval of the suppliers, the company will conduct a bidding procedure based on the approved materials required as specified in the project drawings and specifications. Competitive bidding is important in the economy in allocating resources [21] which is a factor in minimizing the cost of the project.

During construction activities of different site works, some construction works are carried out by sub-contractors. "Normally, a subcontractor is used for implementation. There is an administrative part as well as a subcontractor. (COMPANY A, Pos. 44)"

Table 2 below shows the summary of the percentage allocation of works taken from bill of quantities as mentioned by the civil engineer.

In Table 2, the civil engineer cited that the material cost decreases from 58% to 50.12% due to savings from value engineering and discount from suppliers for bulk orders. Likewise, the labor and equipment also decrease from 25% to 19.5% due to savings from sub contractors' works, value engineering and for maintaining 30% labor cost for low-cost housing. In totality, the profit increases from 8% to 21.38%. Value engineering is a powerful tool in construction industry which provides significant savings and quality improvement [22].

Table 2. Company B Project Cost Breakdown, Planned vs Actual

DESCRIPTION		% of cost, Planned		% of cost, Actual	
	General Requirements				
1	Business Development (Planning and Design)		2%		2%
2	Land acquisition		10%		10%
3	Construction Cost	100%	85%	100%	85%
	A. Materials	58.0%		50.12%	
	B. Labor and equipment	25.0%		19.50%	
	C. Mobilization & demobilization	1.0%		1.0%	
	D. OCM	8.0%		8.0%	
	D.1 Overhead	5.0%		5.0%	
	Operation/supervision	2.0%		2.0%	
	QA/QC	1.0%		1.0%	
	Safety	0.5%		0.5%	
	Human resources	1.0%		1.0%	
	others	0.5%		0.5%	
	D.2 Contingencies	1.2%		1.2%	
	D.3 Miscellaneous	1.8%		1.8%	
	Site office and warehouse	0.8%		0.8%	
	Utilities	0.5%		0.5%	
	PPEs	0.3%		0.3%	
	Consumables	0.2%		0.2%	
	E. Profit	8.0%		21.38%	
4	PROJECT MANAGEMENT		3%		3%
	Total Project Cost		100%		100%

Construction Operations for Company C

Organizational Structure. The company is PCAB category AAA accredited, according to the civil engineer. The project consists of a road network and two bridges, with a total cost of PhP 997,000,000.00. It is being financed by an international financial institution, with the main contractor being based outside of the Philippines. All engineers employed are licensed by the Philippine Regulation Commission (PRC). PCAB category AAA allows the contractor to deliver project costing above PhP 225 Million [11].

Construction Operation. There are four departments in the construction operation responsible for the implementation of activities like health and safety, quantity survey, quality control and operation department. Generally, a construction company contains basic functions like HR, purchasing, project, engineering, financial, and marketing department [23].

The items below are the percentage allocation of the project.

Table 3. Company A Project Cost Breakdown in %

Description		% of cost
Construction Survey and Staking		0.05%
Bridge Survey and Staking		0.19%
Miscellaneous survey		0.10%
Occupational Safety and Health Program		0.23%
Environmental Management and Monitoring		0.31%
Detailed Engineering Design		16.00%
Profit		12.00%
Civil Works		71.10%
Tax	12.00%	
OCM	5.00%	
Materials	40.00%	
Labor	35.00%	
Equipment	8.00%	
	100.00%	
Total		100.00%

Health and Safety. The civil engineer raised concerns about health and safety in this project, which had two incidents but no fatalities. Although the foreman who was involved in the accident was given official leave with pay, the accident had no financial impact on the project because it had a minor impact on the cost. The health and safety officers were able to successfully administer the program, resulting in a decrease in the number of accidents. Health and safety procedure is a process that provides protection to workers against accidents, hazards and health issues [24].

Strategy on how to minimize cost. The civil engineer emphasized that bad weather conditions, such as a high frequency of rain throughout the year, cause significant delays in construction activities. One of the most impactful factors in the construction projects is the weather conditions like temperatures, precipitation, and high winds which can lead to decrease productivity by affecting the schedule of the construction activities [25]. "Only about three months out of a year are sunny days! (COMPANY C, Pos. 24)"

As a response to the delays, the company prioritizes work that is appropriate for the current weather circumstances, such as concrete work on sunny days and riprap on rainy days. The company would plan some rainy-day activities, such as fabrication and installation of barriers. In terms of financial impact, the company requests a weather-related extension. In order to keep up with the schedule, they also developed a double-shifting work system.

On the effect of the pandemic, the project manager designed for shifting of working hours for a month but was stopped, claiming that staff do not even meet frequently in the construction site. "Because the workers don't even meet at the building site, the project manager stopped the shift in work hours (Civil Engineer, Pos. 22)".

In addition to the strategy of minimizing cost, the company assigns some work to subcontractors in order to keep up with the schedule.

3.2. Hypothetical Construction Project and Operations Research Tool Application

A hypothetical project is utilized to apply the construction operations practice in case studies from companies A, B, and C. The hypothetical projected direct cost is PhP 558,505,755.60. The unit costs for each item of work in this hypothetical project were obtained from a real project and used to estimate the construction operations of companies A, B, and C. The relevant percentage allocation from case studies was used to demonstrate distinct figures in the hypothetical project corresponding to a company in the case study.

In terms of operations research, the PERT CPM approach was used to help optimize the project cost in the hypothetical project by identifying critical path and demonstrating the sequence of activities. The QM windows application software was used as part of the project presentation to help determine the critical path of activities to reduce project costs. It further shows in the hypothetical each company's percentage allocation of budgets, percentage changes from planned and actual cost, and figures generated by QM windows OR research tool. The PERT CPM method presented includes project cost breakdown, networks precedence table, network diagram and Gantt chart.

Company A

Table 4 shows the substantial increase of 5% from planned to actual direct cost. The primary problem in project costing is estimating labor or direct costs, which is sometimes difficult to do effectively, resulting in variances from early estimates [5]. Based on the operations practice of company A, changes of direct costs are due to price escalation, defective works, mismanagement of resources and poor supervision. Vaardini et al. mentioned in their study on cost overruns in construction projects that planning and implementation, supply of materials and equipment are one of the reasons for cost overruns of the project [26]. The contractor, owner, consultant, services and utilities, government rules, and the external environment all had an impact on the project's performance [28].

Table 4. Company A Hypothetical Project Cost Breakdown, Planned vs Actual

Description	Planned			Actual		
	% of cost	Unit Price	Total	% of cost	Unit Price	Total
General Requirements	4%		31,914,614.61	7%		55,850,575.56
Mobilization of contractors Personnel, Plant & Equipment, 85%						
Mobilization program, site office, etc., 15%						
Direct Works	70%		558,505,755.60	75%		598,399,023.86
Substructures		64,749,617.40			64,749,617.40	
Concrete works		100,571,093.70			100,571,093.70	
Masonry		82,886,309.70			82,886,309.70	
Thermal and moisture protection		30,712,136.70			30,712,136.70	
Metalwork		11,066,356.50			11,066,356.50	
Woodwork		183,754.20			183,754.20	
Doors and windows		53,149,907.40			53,149,907.40	
Finishes		124,051,290.60			124,051,290.60	
Accessories		10,411,800.00			10,411,800.00	
Mechanical engineering installations		30,752,356.80			30,752,356.80	
Electrical engineering installations		49,971,132.60			49,971,132.60	
Overhead and Profit	26%		207,444,994.94	11%		87,765,190.17
Additional profit				7%		55,850,575.56
Total Project Cost	100%		797,865,365.14	100%		797,865,365.14

Table 5. Network Precedence Table

HYPOTHETICAL PROJECT COMPANY A					
		Activity Time	**Activity Cost**	**Predecessor 1**	**Predecessor 2**
A	General Requirements	72	31,914,614.61		
B	Substructures	83	64,749,617.40	A	
C	Concrete works	130	100,571,093.70	B	
D	Masonry	107	82,886,309.70	C	
E	Thermal and moisture protection	40	30,712,136.70	B	
F	Metalwork	14	11,066,356.50	C	
G	Woodwork	5	183,754.20	F	
H	Doors and windows	69	53,149,907.40	G	
I	Finishes	160	124,051,290.60	G	
J	Accessories	13	10,411,800.00	G	H
K	Mechanical engineering installations	40	30,752,356.80	B	
L	Electrical engineering installations	64	49,971,132.60	B	
M	Overhead and Profit		207,444,994.94		

Table 6. Network Precedence Table with ES/EF/LS/LF

	Activity Time	**Activity Cost**	**Early Start**	**Early Finish**	**Late Start**	**Late Finish**	**Slack**
Project	464						
A	72	31,914,614.61	0	72	0	72	0
B	83	64,749,617.40	72	155	72	155	0
C	130	100,571,093.70	155	285	155	285	0
D	107	82,886,309.70	285	392	357	464	72
E	40	30,712,136.70	155	195	424	464	269
F	14	11,066,356.50	285	299	285	299	0
G	5	183,754.20	299	304	299	304	0
H	69	53,149,907.40	304	373	382	451	78
I	160	124,051,290.60	304	464	304	464	0
J	13	10,411,800.00	373	386	451	464	78
K	40	30,752,356.80	155	195	424	464	269
L	64	49,971,132.60	155	219	400	464	245
M	32	207,444,994.94	0	32	432	464	432

Table 5 shows the network precedence table for a hypothetical project containing 13 activities with the corresponding activity time. It involved tasks or work packages which are needed in completing the project. Activities are tasks or jobs that are needed operations in order to complete a certain work package of the project [18].

Table 6 shows activities of the project with the corresponding duration, cost, early start and finish, late start and finish, and slack. Slack is the amount of time that an activity can be delayed beyond its finish time without delaying the total project duration [27]. It reveals that the critical path is activities A – B – C – F – G – I, with a total project duration of 464 days. Critical path is the sequence of activities which determine the duration of the project [18]. All activities in the critical path have zero slack which makes this path critical as delays are not permitted.

Figure 2 shows the network diagram showing the predecessor and successor activities. The activities are described in nodes or circles with corresponding duration of activity completion. The red line shows the project's critical path while also describing the total project duration.

Figure 3 shows the Gantt Chart describing all the activities in horizontal bar. Activities A, B, C, F, G, I is the critical path of the project. Bar or Gantt charts present the project schedule plotted in horizontal time scale and is being used traditionally in scheduling for a construction project [5].

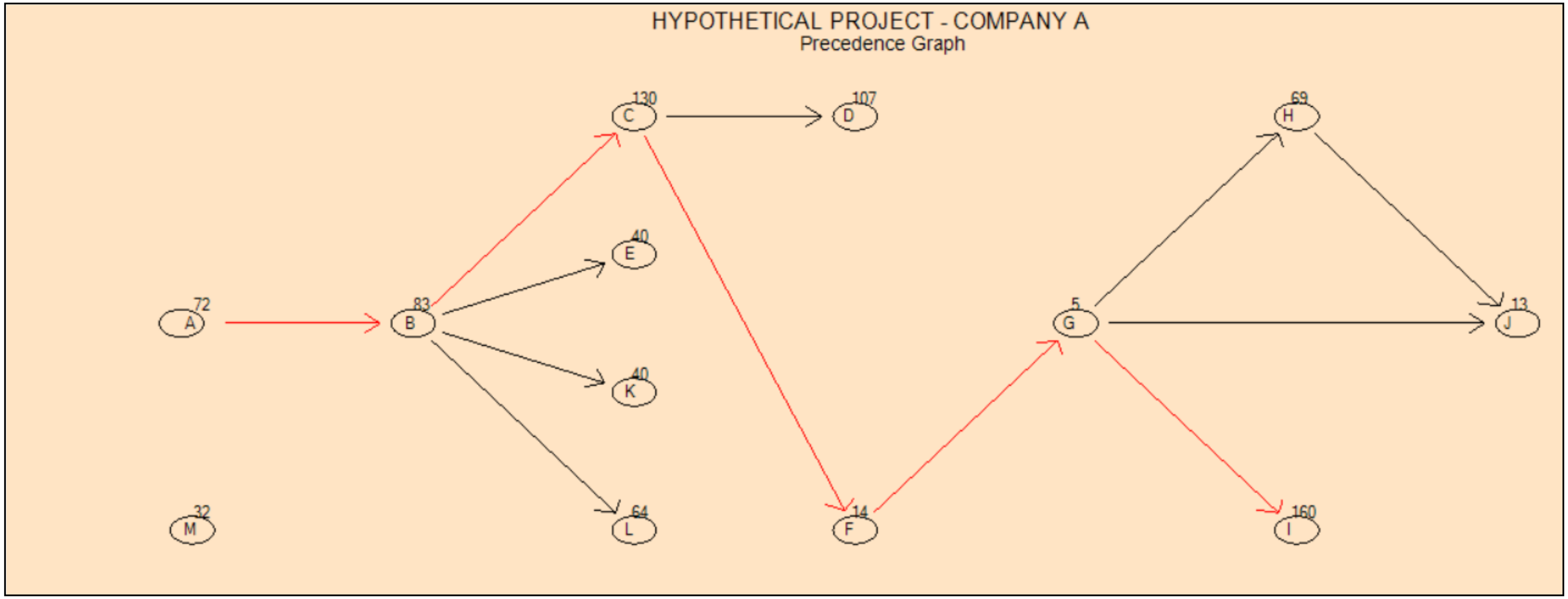


Figure 2. Network Diagram – Company A Hypothetical Project

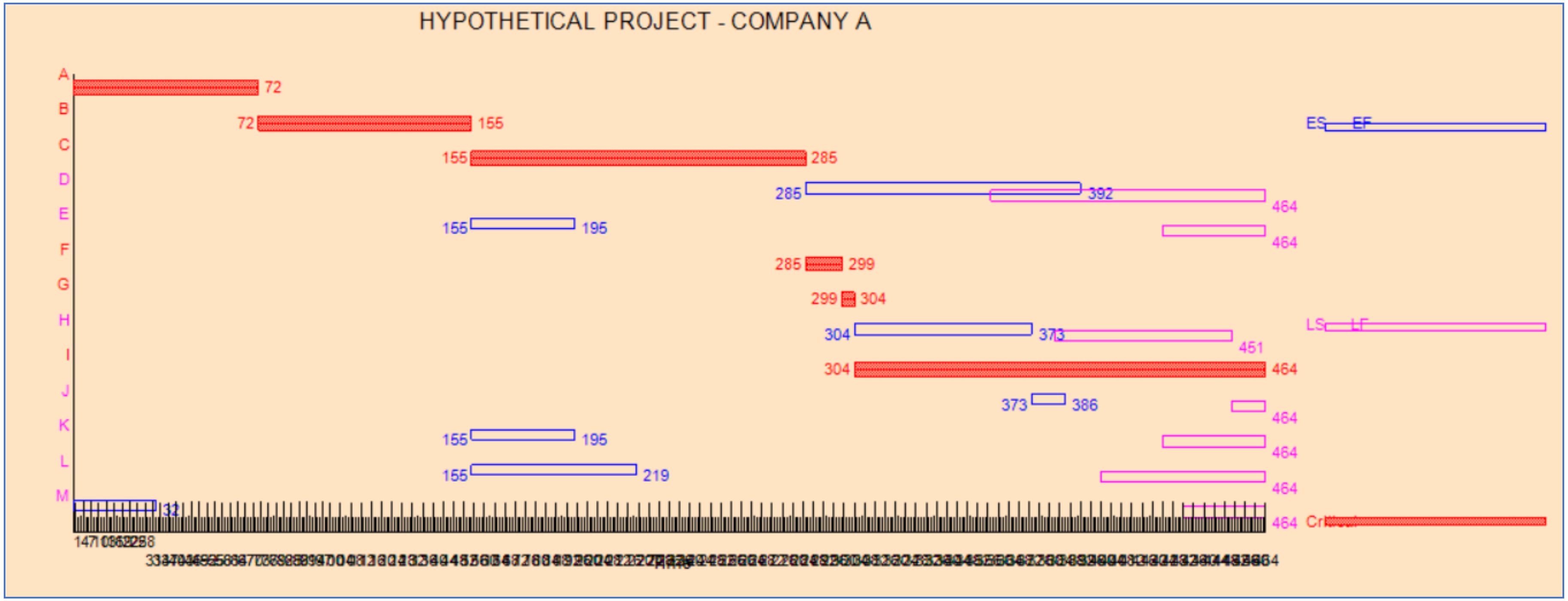


Figure 3. Gantt Chart – Company A Hypothetical Project

Table 7. Company B Hypothetical Project Cost Breakdown, Planned vs. Actual

	Planned			Actual		
Description	**% of cost**	**Unit Price**	**Total**	**% of cost**	**Unit Price**	**Total**
Business development	2%		15,832,905.90	2%		15,832,905.90
Land Acquisition	10%		79,164,529.50	10%		79,164,529.50
Direct Works	70%		558,505,755.60	59%		468,471,936.20
Substructures		64,749,617.40			64,749,617.40	
Concrete works		100,571,093.70			100,571,093.70	
Masonry		82,886,309.70			82,886,309.70	
Thermal and moisture protection		30,712,136.70			30,712,136.70	
Metalwork		11,066,356.50			11,066,356.50	
Woodwork		183,754.20			183,754.20	
Doors and windows		53,149,907.40			53,149,907.40	
Finishes		124,051,290.60			124,051,290.60	
Accessories		10,411,800.00			10,411,800.00	
Mechanical engineering installations		30,752,356.80			30,752,356.80	
Electrical engineering installations		49,971,132.60			49,971,132.60	
Mobilization and demobilization	1%		6,728,985.01	1%		6,728,985.01
OCM	7%		53,831,880.06	7%		53,831,880.06
Profit	7%		53,831,880.06	18%		143,865,699.45
Project Management	3%		23,749,358.85	3%		23,749,358.85
Total Project Cost	100%		791,645,294.97	100%		791,645,294.97

Table 8. Network Precedence Table

HYPOTHETICAL PROJECT COMPANY A					
		Activity Time	**Activity Cost**	**Predecessor 1**	**Predecessor 2**
A	Business development	15	15,832,905.90		
B	Land Acquisition	70	79,164,529.50	A	
C	Substructures	83	64,749,617.40	B	
D	Concrete works	130	100,571,093.70	C	
E	Masonry	107	82,886,309.70	D	
F	Thermal and moisture protection	40	30,712,136.70	C	
G	Metalwork	14	11,066,356.50	D	
H	Woodwork	5	183,754.20	G	
I	Doors and windows	69	53,149,907.40	E	
J	Finishes	160	124,051,290.60	E	
K	Accessories	13	10,411,800.00	I	J
L	Mechanical engineering installations	40	30,752,356.80	C	
M	Electrical engineering installations	64	49,971,132.60	C	
N	Mobilization and demobilization	6	6,728,985.01		
O	OCM	50	53,831,880.06		
P	Profit	50	53,831,880.06		
Q	Project Management	20	23,749,358.85		

COMPANY B

Table 7 illustrates an 11% reduction in planned to actual direct costs, as well as an 11% gain in profit. Value engineering and savings from subcontract activities are used to achieve the stated reductions in direct costs.

Table 8 shows the network precedence table for a hypothetical project containing 17 activities with the corresponding activity time.

Table 9 shows activities of the project with the corresponding duration, cost, early start and finish, late start and finish, and slack. It shows that activities A – B – C- D - E – J – K is the critical path which has a total duration of project identified to be 578 days.

Figure 4 shows the network diagram showing the predecessor and successor activities. The activities are described in nodes or circles with corresponding duration of activity completion. The red line shows the critical path of the project which at the same time describes the total project duration. From the figure, it shows that activities A – B – C- D – E – J – K are the critical path.

Figure 5 shows the Gantt Chart describing all the activities in horizontal bar. Activities A – B – C- D – E – J – K is the critical path of the project.

Table 9. Network Precedence Table with ES/EF/LS/LF

	Activity Time	Activity Cost	Early Start	Early Finish	Late Start	Late Finish	Slack
Project	578						
A	15	15,832,905.90	0	15	0	15	0
B	70	79,164,529.50	15	85	15	85	0
C	83	64,749,617.40	85	168	85	168	0
D	130	100,571,093.70	168	298	168	298	0
E	107	82,886,309.70	298	405	298	405	0
F	40	30,712,136.70	168	208	538	578	370
G	14	11,066,356.50	298	312	559	573	261
H	5	183,754.20	312	317	573	578	261
I	69	53,149,907.40	405	474	496	565	91
J	160	124,051,290.60	405	565	405	565	0
K	13	10,411,800.00	565	578	565	578	0
L	40	30,752,356.80	168	208	538	578	370
M	64	49,971,132.60	168	232	514	578	346
N	6	6,728,985.01	0	6	572	578	572
O	50	53,831,880.06	0	50	528	578	528
P	50	53,831,880.06	0	50	528	578	528
Q	20	23,749,358.85	0	20	558	578	558

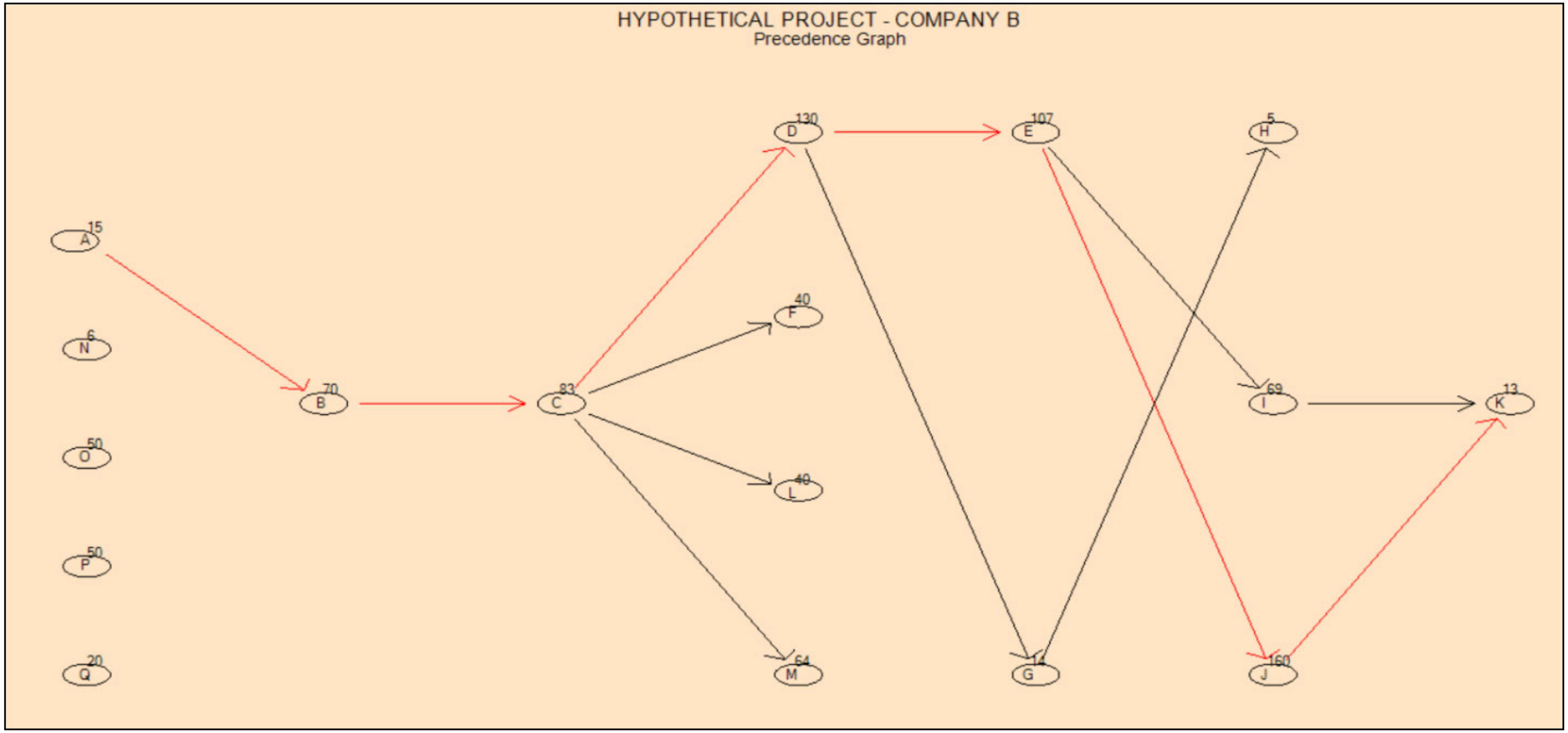


Figure 4. Network Diagram – Company B Hypothetical Project

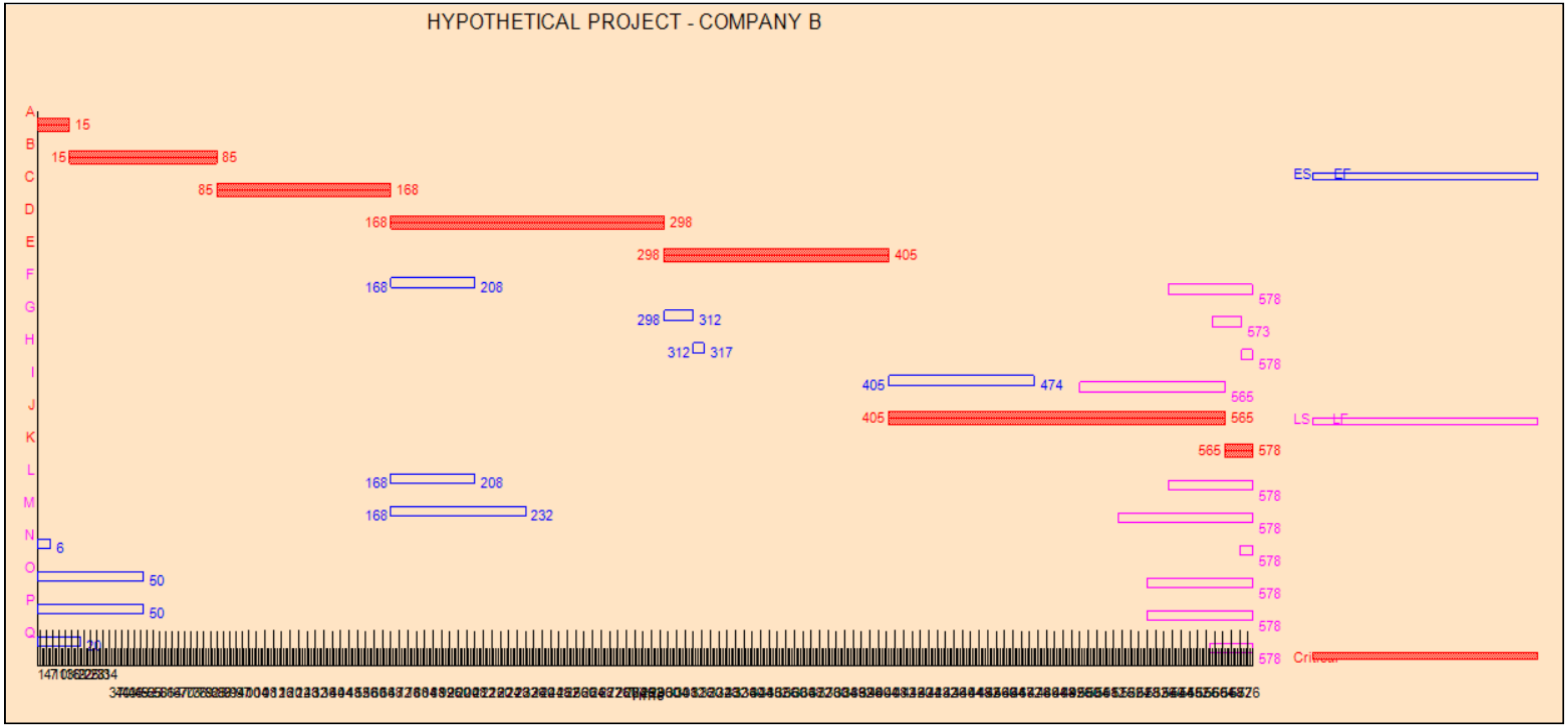


Figure 5. Gantt Chart – Company B Hypothetical Project

Table 10. Company C Hypothetical Project Cost Breakdown

Description	% of cost	Unit Price	Total
Construction Survey and Staking	0.05%		416,326.37
Bridge Survey and Staking	0.19%		1,516,056.41
Miscellaneous survey	0.10%		801,231.89
Occupational Safety and Health Program	0.23%		1,838,120.21
Environmental Management and Monitoring	0.31%		2,458,682.16
Detailed Engineering Design	16.00%		125,683,433.05
Profit	12.00%		94,262,574.78
Civil Works	71.10%		558,505,755.60
Substructures		64,749,617.40	
Concrete works		100,571,093.70	
Masonry		82,886,309.70	
Thermal and moisture protection		30,712,136.70	
Metalwork		11,066,356.50	
Woodwork		183,754.20	
Doors and windows		53,149,907.40	
Finishes		124,051,290.60	
Accessories		10,411,800.00	
Mechanical engineering installations		30,752,356.80	
Electrical engineering installations		49,971,132.60	
Total Project Cost	100%		785,482,180.47

Table 11. Network Precedence Table

HYPOTHETICAL PROJECT COMPANY C						
		Activity Time	**Activity Cost**	**Predecessor 1**	**Predecessor 2**	**Predecessor 3**
A	Construction Survey and Staking	1	416,326.37			
B	Bridge Survey and Staking	2	1,516,056.41			
C	Miscellaneous survey	1	801,231.89			
D	Occupational Safety and Health Program	2	1,838,120.21			
E	Environmental Management and Monitoring	3	2,458,682.16			
F	Detailed Engineering Design	116	125,683,433.05			
G	Profit	87	94,262,574.78			
H	Substructures	83	64,749,617.40	A	B	C
I	Concrete works	130	100,571,093.70	H		
J	Masonry	107	82,886,309.70	I		
K	Thermal and moisture protection	40	30,712,136.70	I		
L	Metalwork	14	11,066,356.50	J		
M	Woodwork	5	183,754.20	J		
N	Doors and windows	69	53,149,907.40	J		
O	Finishes	160	124,051,290.60	M		
P	Accessories	13	10,411,800.00	O		
Q	Mechanical engineering installations	40	30,752,356.80	I		
R	Electrical engineering installations	64	49,971,132.60	I		

Table 12. Network Precedence Table with ES/EF/LS/LF

	Activity Time	Activity Cost	Early Start	Early Finish	Late Start	Late Finish	Slack
Project	500						
A	1	416,326.37	0	1	1	2	1
B	2	1,516,056.41	0	2	0	2	0
C	1	801,231.89	0	1	1	2	1
D	2	1,838,120.21	0	2	498	500	498
E	3	2,458,682.16	0	3	497	500	497
F	116	125,683,433.05	0	116	384	500	384
G	87	94,262,574.78	0	87	413	500	413
H	83	64,749,617.40	2	85	2	85	0
I	130	100,571,093.70	85	215	85	215	0
J	107	82,886,309.70	215	322	215	322	0
K	40	30,712,136.70	215	255	460	500	245
L	14	11,066,356.50	322	336	486	500	164
M	5	183,754.20	322	327	322	327	0
N	69	53,149,907.40	322	391	431	500	109
O	160	124,051,290.60	327	487	327	487	0
P	13	10,411,800.00	487	500	487	500	0
Q	40	30,752,356.80	215	255	460	500	245
R	64	49,971,132.60	215	297	436	500	221

COMPANY C

Table 10 below shows the corresponding item of works for the hypothetical project based on the construction practices of company C.

Table 11 shows the network precedence table for a hypothetical project containing 17 activities with the corresponding activity time.

Table 12 shows activities of the project with the corresponding duration, cost, early start and finish, late start and finish, and slack. It shows that activities B – H - I – J – M – O – P is the critical path which has a total duration of project identified to be 500 days.

Figure 6 shows the network diagram showing the predecessor and successor activities. The activities are described in nodes or circles with corresponding duration of activity completion. From the figure, it shows that activities B – H - I – J – M – O – P is the critical path.

Figure 7 shows the Gantt Chart of the project schedule describing all the activities in horizontal bar. Activities B – H - I – J – M – O – P are in red color and do not have slack time which described the critical activities of the project.

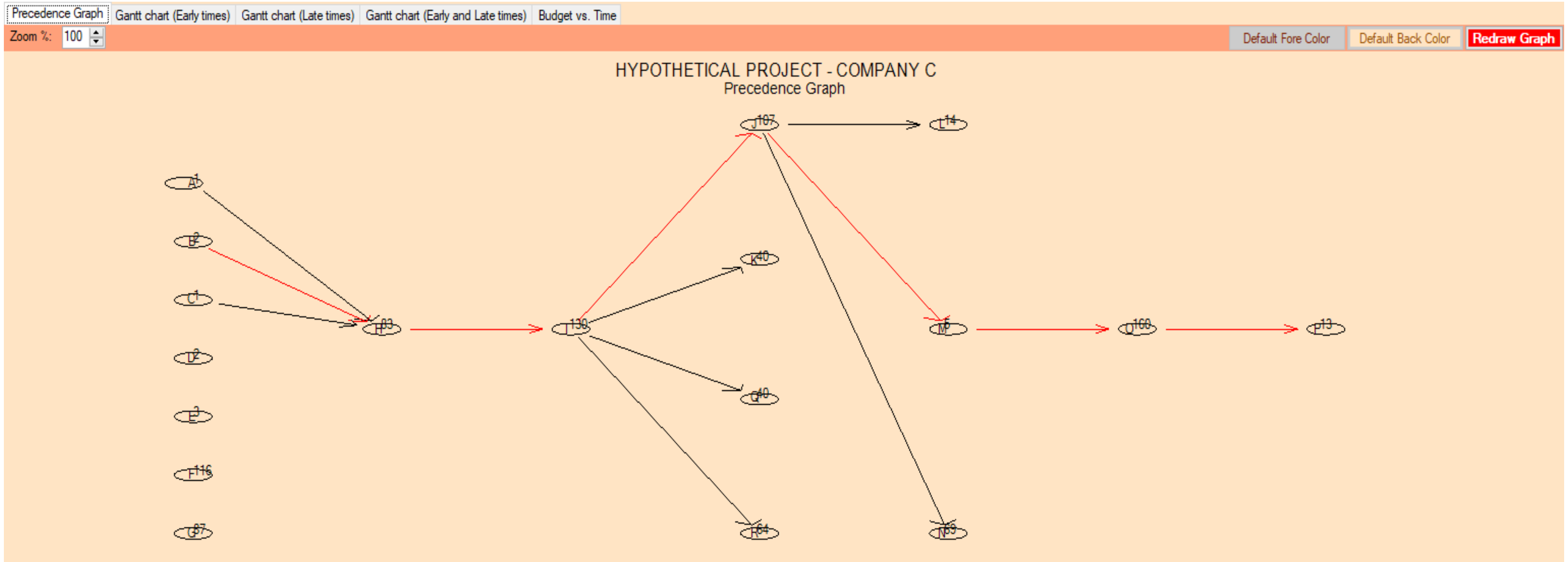


Figure 6. Network Diagram – Company C Hypothetical Project

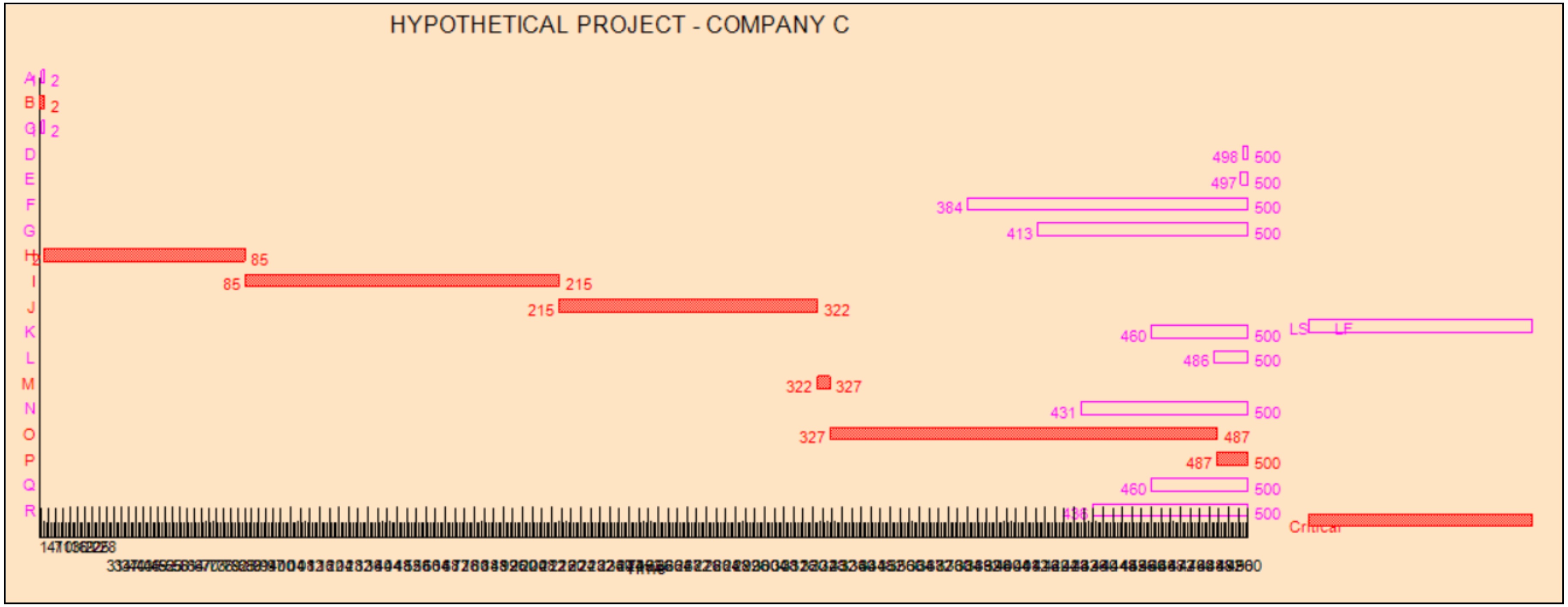


Figure 7. Gantt Chart – Company B Hypothetical Project

4. Conclusions

The results of the study showed the significant contribution of construction operations practices and the application operations research tool in a hypothetical construction project. Specifically, it showed that the majority of contractors had similar organizational delivery systems with functional departments such as business development, finance, human resources, and construction operations, and that they fell into the PCAB group.

In construction operations, it showed the significance of health and safety, quality control, construction management, financial, and marketing aspects of the project. It further revealed the significant contributions of licensed engineers composing the construction operations team.

It can also be concluded that health and safety have significant factors in reducing project costs. The three companies agree that fatal accidents entail substantial monetary expenses which affect greatly in the maximization of project profit.

According to respondents, efficiency in resource use, avoidance of non-conformance works, elimination of wastes or non-value-added activities, value engineering, bulk order discounts, listing of different suppliers, double shifting of work scheme, prioritizing activities suitable for weather conditions, delegating work packages to subcontractors, resequencing the project schedule, application of value engineering are all important factors in optimizing project costs. Delays attributed to the contractor, such as site office extensions, temporary facilities, insurances, equipment and vehicles, price escalation, defective works and products, mismanagement of resources, poor supervision, weather conditions, delays from client handover, and delays due to the COVID 19 pandemic's health protocols, are among the issues encountered in the construction operations.

It may also be deduced that operations research methodologies are essential in project management, particularly in terms of reducing construction costs and maximizing project profit. The results demonstrated how the operations research tool made it appear simple to determine project schedule priorities. Furthermore, the usage of software such as QM for Windows demonstrated the importance of using a computer-assisted OR tool to manage large and complex project operations.

Lastly, this research emphasizes the importance of using three case studies and corresponding hypothetical studies in evaluating construction operations practices with varying budget allocations because it reflects the fundamental construction operations and basic operation research tools that would aid in project implementation on various project types. It also demonstrated how to use an operations research tool can aid in reaching the goal of achieving the lowest project cost possible, regardless of project size. Students and engineering practitioners gained more information from the construction operations practices and detailed steps of operation research tool application.

5. Recommendations

The following recommendations are forwarded:

Construction operations strategies were found to have a significant impact on project cost reduction and profit maximization. As a result, it's an excellent idea to look at the contractors' best practices in terms of organizational structures, construction operations, health and safety, project management and quality control, and strategy in minimizing cost. The importance of health and safety, as well as the licenses of the engineers on the construction team, was emphasized in the study. As a result, engineers should seek further training in health and safety certification.

The study also revealed the causes of construction delays, which have a significant impact on project cost optimization. It is suggested to follow the strategies suggested in this study, which are fundamental in project implementation and cost reduction.

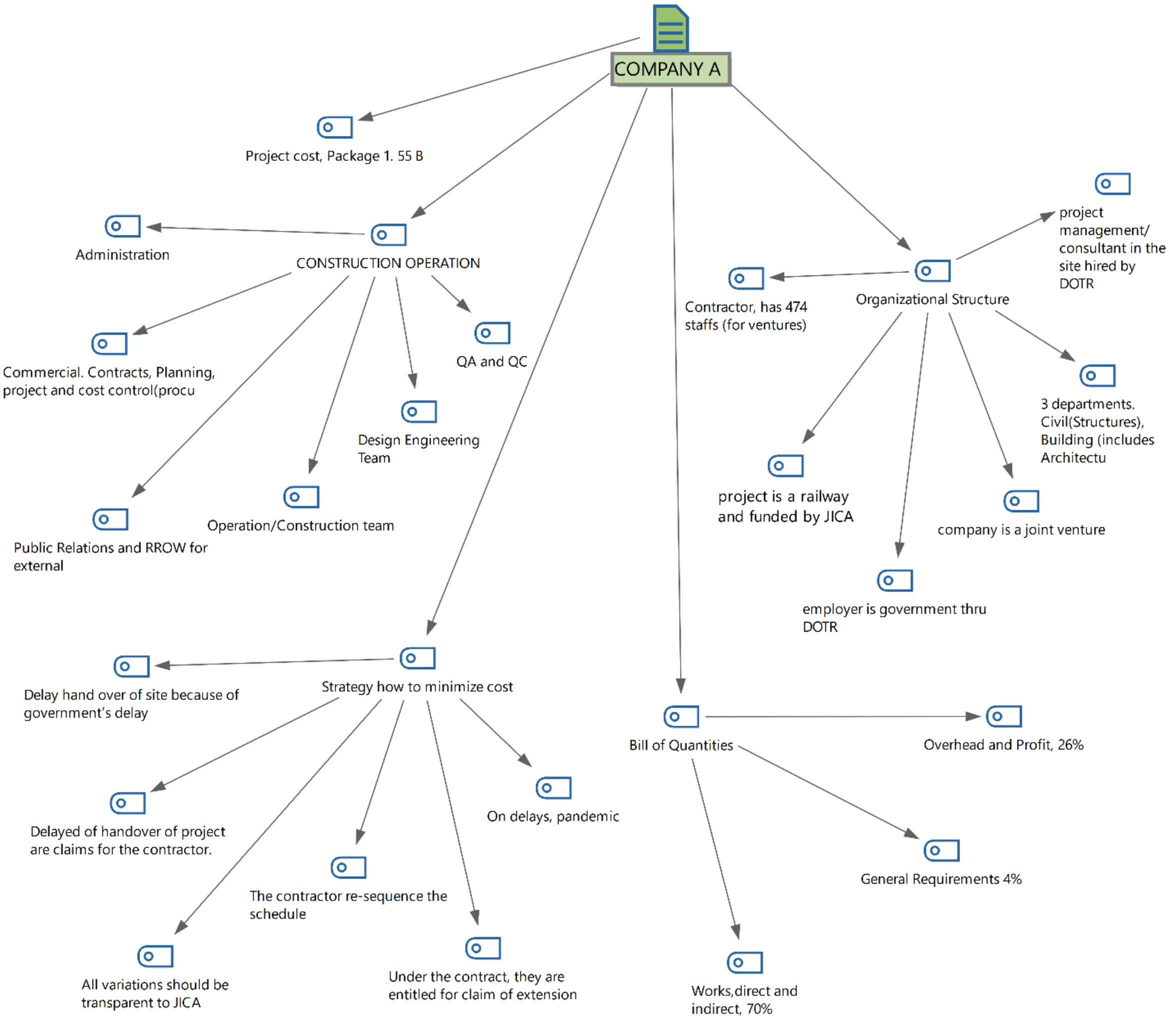
Most importantly, this research demonstrated the importance of using an operations research tool to maximize profit. The application of PERT CPM in many types of construction projects is strongly recommended. It is strongly recommended to gather detailed information on PERT CPM using any computer-assisted application.

It is also suggested that construction operations practice and detailed steps of operation research tool application be included in academic institutions' learning resources.

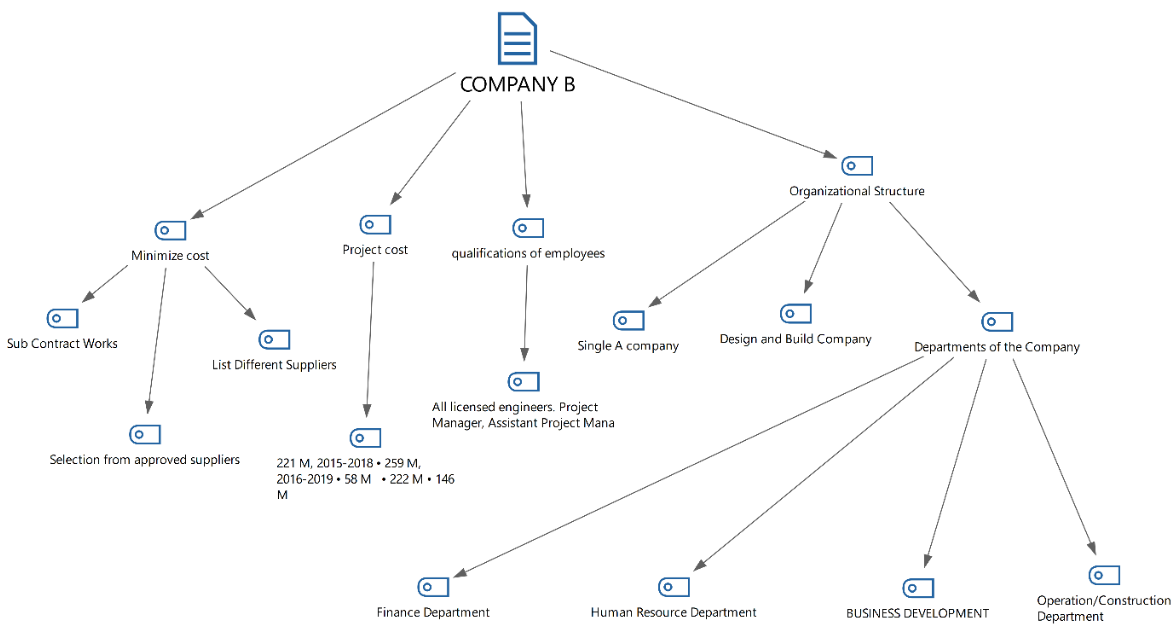
Further research into the applicability of other operations research methodologies suitable to construction operations is also encouraged.

Finally, future research in other areas of construction operations related to operations research is greatly recommended.

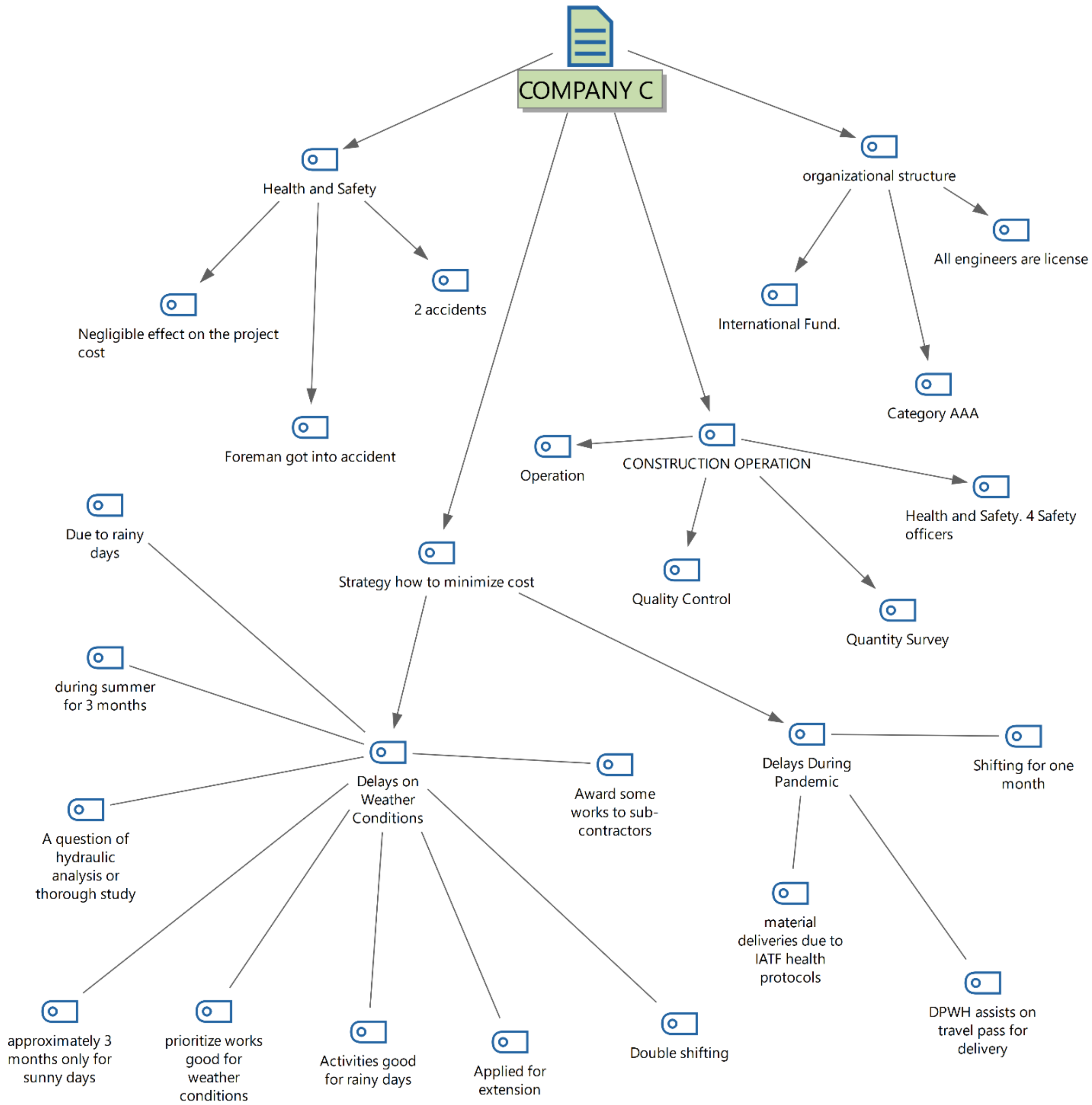
APPENDIX



Civil Engineer's Response to the Construction Operations of the Company A



Civil Engineer's Response to the Construction Operations of Company B



Civil Engineer's Response to the Construction Operations of Company C

REFERENCES

[1] Statista Research Department. Construction sector in the Philippines - statistics & facts, https://www.statista.com/topics/6011/construction-sector-in-the-philippines/ (accessed Nov. 12, 2021).

[2] Manila Times. PH construction sector seen to contract 9.8% in 2020, https://www.manilatimes.net/2020/08/18/business/real-estate-and-property/ph-construction-sector-seen-to-contract-9-8-in-2020/756884 (accessed Nov. 12, 2021)

[3] Manila standard business. Construction sector seen to rebound from 26% slump in 2020. https://www.manilastandard.net/business/economy-trade/347659/construction-sector-seen-to-rebound-from-26-slump-in-2020.html (accessed Nov. 13, 2021).

[4] Aftab H. M., Ismail A. R., Abdullah M. R., Azis A. S. A. Factors affecting construction cost performance in project management project: Case of MARA large projects. International Journal of Civil Engineering and Built Environment, vol. 1, no. 2, pp. 30-35. 2014. https://www.researchgate.net/publication/256662475_Factors_Affecting_Construction_Cost_in_Mara_Large_Construction_Project_Perspective_of_Project_Management_Consultant

[5] Sears S.K., Sears G.A.., Clough R.H., Rounds J.L., Segner R.O., "Construction Practices" in Construction project management: a practical guide to field construction management" —Sixth edition. John Wiley & Sons, Inc., Hoboken, New Jersey. 2015, pp. 3 and 4.

[6] Hasan, R., Suliman S., Malki Yx`., An Investigation into

the Delays in Road Projects in Bahrain. International Journal of Research in Engineering and Science, vol 2 Issue 2, pp. 38-47, 2014. http://www.ijres.org/papers/Volume%202/v2-i2/G2203847.pdf

[7] Banna, M. 6 Principles of Lean Construction. KaiNexus. 2020. https://blog.kainexus.com/improvement-disciplines/lean/lean-construction/6-principles-of-lean-construction (accessed Nov. 14, 2021).

[8] Hillier F.S. and Lieberman G.J. "The origins of operation research" in Introduction to Operations Research, Seventh Edition. McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY, 10020. 2001, pp. 4 and 5.

[9] Heiman, D.W. & General, B., Operations Research as Applied to Construction. Management Science MT-1(2):20-25, 1960, http://dx.doi.org/10.1287/mantech.1.2.20

[10] Creswell, J., "Glossary" in Educational Research, 4th edition. Pearson, USA. 2012. pp. 626.

[11] DTI, PCAB Categorization – Classification Table (Board Resolution No. 201, series of 2017). Contractors Industry Authority of the Philippines, Department of Trade and Industry. https://ciap.dti.gov.ph/sites/default/files/Categorization-Classification%20Table_12052017.doc (accessed Nov. 20, 2021).

[12] Memon, A. H., Abdul Rahman, I., Abdullah, M. R., & Abdu Azis, A. A., Factors Affecting Construction Cost in Mara Large Construction Project: Perspective of Project Management Consultant. International Journal of Sustainable Construction Engineering and Technology, 1(2), 41-54. 2011. https://publisher.uthm.edu.my/ojs/index.php/IJSCET/article/view/62

[13] Nurimbetov and Zikriyoev, Modern challenges in health and safety at construction industry, Bulletin of Science and PractiCe, vol. 5, no. 3, 2019. DOI:10.33619/2414-2948/40/32

[14] Koskela, L., An Exploration Towards a Production Theory and its Application to Construction, PhD Dissertation, VTT Building Technology, Espoo, Finland. 296 p., VTT Publications: 408, ISBN 951-38-5565-1; 951-38-5566-X 2000. http://www.leanconstruction.org/pdf/P408.pdf

[15] Proverbs D. and Holt G., Reducing construction costs: European best practice supply chain implications, European Journal of Purchasing & Supply Management, 2000. DOI:10.1016/S0969-7012(00)00011-3

[16] Gamil, Y., & Alhagar, A., The Impact of Pandemic Crisis on the Survival of Construction Industry: A Case of COVID-19. Mediterranean Journal of Social Sciences, 11(4), 122. 2020. https://doi.org/10.36941/mjss-2020-0047

[17] Hodge B.J; Anthony, P.W., & Gales M.L., "Organization Theory and Management Practices" in Organization theory: A strategic approach. 6th ed. 2003. pp 7-8 DOI:10.13140/RG.2.2.24671.41128

[18] Kerzner, H., Project Management, A Systems Approach to Planning, Scheduling, and Controlling. Tenth Edition. John Wiley & Sons, Inc., Hoboken, New Jersey. 2013. pp 917-919.

[19] NEBOSH, Our Global Organisation. https://www.nebosh.org.uk/about-nebosh/our-organisation/ (accessed Nov. 20, 2021).

[20] Nghitanwa, E.M. and Zungu, L., Occupational Health and Safety Status in the Windhoek Construction Industry: A Namibian Perspective. Open Journal of Safety Science and Technology, 7, 113-127. 2017. https://doi.org/10.4236/ojsst.2017.73011

[21] Stark, R. M., & Rothkopf, M. H., Competitive Bidding: A Comprehensive Bibliography. Operations Research, 27(2), 364–390. 1979. http://www.jstor.org/stable/170135

[22] Rachwan, R., Abotaleb, I., & Elgazouli, M., The Influence of Value Engineering and Sustainability Considerations on the Project Value. Procedia Environmental Sciences, 2016. https://doi.org/10.1016/j.proenv.2016.04.038

[23] Rosie, Org Chart. Construction Company Organizational Chart – Introduction and Example. https://www.orgcharting.com/construction-company-org-chart/ (accessed Nov. 20, 2021).

[24] Chaterjee, S. And Roy B., "Comparative study of health and safety awareness process with reference to the large, middle and small scale industry," International Journal of Marketing, Financial Services & Management Research. 2014. Https://www.researchgate.net/publication/273004273_comparative_study_of_health_and_safety_awareness_process_with_reference_to_the_large_middle_and_small_scale_industry

[25] Paor, R. "Wind, rain, temperature and construction contracts: how to provide for climate change in your engineering and construction project," JDSUPRA. https://www.jdsupra.com/legalnews/wind-rain-temperature-and-construction-9918027/ (accessed Nov. 27, 2021).

[26] Vaardini, S., Karthiyayini, S., and Ezhilmathi P., "Study on cost overruns in construction projects –a review," International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.11,No.3, 2016. https://www.researchgate.net/publication/303459769_STUDY_ON_COST_OVERRUNS_IN_CONSTRUCTION_PROJECTS_-A_REVIEW

[27] Chen, W.F. and Richard Liew, J.Y. The Civil Engineering Handbook, Second Edition. CRC Press. New York, USA. 2003. pp. 64 – 65.

[28] Nebrida, J., "Construction Industry in Bahrain: Update of Performance," International Journal of Engineering Research in Mechanical and Civil Engineering, ISSN 2456-1290, Vol.6,No.10, 2021. http://ijermce.com/abstract.php?id=15674&issue=Issue8