Application of Linear Programming in the Optimal Installation of Waterproofing Membrane in the Construction Projects

Mark Anthony V. Santiago, Rianina D. Borres, and Maria Victorina D. Rada
School of Industrial and Engineering Management,
Mapua University
658 Muralla St., Intramuros, Manila, Philippines 1002
mavsantiago@mymail.mapua.edu.ph; rdborres@yahoo.com; mvdrada@mapua.edu.ph

Abstract

This research study determined the maximum profit of the installation and application of waterproofing membrane using a linear programming model with the Microsoft Excel Solver aid. Setting the decision variables, objective function, and constraints on the real-life construction projects, some essential decision-making pointers were collected after getting the optimal result. This case is set in a month-long availability of the areas for installation and application of waterproofing system. Each activity's production rates are taken from previous and on-going projects in a different location in the State of Qatar. The construction projects are located in the municipalities and cities of Lusail, Doha, Rayyan, Al Khor, Umm Salal, Al Wakrah, Al Daayen, Al Shamal, and Al Sheehaniya. The waterproofing system consists of PVC (Polyvinyl Chloride) T-Lock, Bituminous membrane, cold-spray membrane, and cementitious membrane.

Keywords
Linear Programming Model, Maximization, Simplex Method, Waterproofing

1. Introduction

Linear programming is used to maximize the efficiency of resources and was developed during World War II. The development can be traced back to when a member of the US Air Force, George Dantzig, developed the Simplex method of optimization in 1947 when the need to provide an efficient algorithm in the solution of programming problems linear structures were present. Thus, through the years, Linear Programming developments expanded their applications by experts in different fields such as mathematics and economics (Lewis 2008). In recent years, advances in business, computer technology, and engineering research have created the need to develop different mathematical models. These models represent various conditions and systems that use variables, functions, and parameters. The mathematical models in creating and manipulating simple techniques and found to be a cheaper, safer, and faster idea (Martinich 1997), linear programming is defined as "*the problem of maximizing or minimizing a linear function subject to linear constraints*." In addition, linear programming can handle various problems like scheduling construction projects and transporting fuel from the refinery to consumers (Miller 2007). Most managers use linear programming because of its benefits of it enable the practice problem formulation and result from the analysis that includes variable bounds and inequality constraints. It gives vision to the ability of optimization. It is commonly known as the foundation of other major optimization algorithms and is widely used in business and engineering practices (Marlin 2003).

Qatar has an approximately 2.78 million population for a small peninsular state located west of the Arabian Gulf. Qatar's economy is continuously growing and expanding. As a result of this, its commitment to hosting the prestigious 2022 FIFA World Cup, infrastructure, and industrial projects have been in full blast for the past years. In 2020, the state allocated an estimated 11.50 billion Qatari Riyals for new projects. These government projects include the 2022 FIFA World Cup Stadiums strategically located in different parts of the peninsula, such as Al Rayyan, Al Wakrah, and Al Khor. Also, the Qatar Integrated Rail features a new US$40 billion railway and metro subway system with a high-speed passenger railway and freight line. Furthermore, Qatar's Public Works Authority (ASHGHAL) has an expressway project program costing US$20 billion in projects in the development of significant motorways to address traffic congestion across the country. These include are the Al Bustan Highway, Orbital Expressway, Al Rayyan-

Dukhan Road, and Al Khor Coastal Road featuring several tunnels, underpasses, bridges, and landmarks. In addition to this, Public Works Authority allotted a drainage program costing US$14.6 billion of networks of drainage, roads, utilities, and accompanying infrastructures. To name more of those projects included, the Hamad International Airport Expansion, Lusail City Development, Msheireb Downtown Doha Regeneration, the New Doha Port, Bul Haninine Oilfield Redevelopment, Barzan Gas Development, North Field Liquefied Natural Gas Expansion, and the Al Kharasaah Solar Photovoltaic Power Project (Jones et al. 2020).

With those vast infrastructure and construction projects in Qatar's State, managing the waterproofing industry's operation and business is more critical than ever. With the region's current political and economic turmoil, optimizing the systems' implementation concerning the process and financial condition is vital to address project specifications and standards.

Waterproofing is used to eliminate or minimize any post-completion problems caused by several water damages like molds, rusts, and liquefactions. Waterproofing systems come from various forms and are applied in combination with other factors, including membrane details and design, product specification, application methodology, substrate penetration, quality inspection and assurance, and operation and maintenance (Sriravindrarajah & Tran 2018). The application of waterproofing must follow the project requirements, environmental factors, and materials availability (Song et al. 2017).

2. Literature Review

In the study (Akpan & Iwok 2016), linear programming was used to determine the maximum profit that can be attained in the allocation of raw materials in bread making. The competing variables are the bread's sizes: small, big, and giant loaf. The raw materials include flour, sugar, yeast, salt, wheat gluten, and soybean oil. The profit per unit on each size of the small, big, and giant loaves are N30, N40, and N20, respectively. The research study used TORA software to find the optimal result. The Temporary-Oriented Routing Algorithm (TORA) is an operations research software that is an optimization system. The software may be executed in automated or tutorial mode that deals with simultaneous linear equations, linear programming, transportation model, integer programming, network models, CPM/PERT, Poisson queuing models, and Zero-Sum games (StudyMoose 2021). The optimal results include producing a small-sized loaf of 962 units, a big-sized loaf of 38 units, a giant-sized loaf of 0 units, and a maximum profit of N20385.00.

In another study by Saxena et al (2020), the researchers aim to determine the profit of a pharma companies Mascot Herbals Pvt. Ltd. and Ashwini Herbal Pharmacy in manufacturing O. Porosys powder and minimize the cost of transportation of its cough syrup in different plants of the company. The research paper used linear programming with Type A's variables containing 50grams and Type B containing 100grams per packet. The optimal result includes Type A of 400 packets and Type B of 20 packets with a maximum profit of 11,760 Indian Rupees. While minimizing the transportation cost, linear programming gave them 19,200 Indian Rupees.

3. Methodology

This research paper utilized the linear programming model to optimize the monthly profit of installation and application of the waterproofing membrane of a Building Specialist Company to its various on-going construction projects in the peninsular state. The objective includes the determination of the manhour required on each materials' installation and application to maximize the company's profit. Another aim was to determine which location impeded the optimal profit of the company in the project portfolio.

3.1 Materials

Keyed PVC Membrane

Keyed PVC Membrane is an innovative waterproofing material designed for subterranean areas like basements, carparks, cellars, tunnels, drainages, retaining walls, and pits. Its structure includes a "T" shaped design that secures a mechanical bonding with the concrete to ensure the proper adhesion into it. Its benefits include an ability to resist mechanical damage, chemical penetration, and weathering to the underground structures (JV Polymers 2017).

Bituminous Membrane

These materials provide a waterproof barrier between subgrade and roof waterproofing in residential, commercial, and industrial structures. This material gives the structure water tightness to the substrate (Sahal & Ozkan 1999) and is applied by torch-on membrane or self-adhesive to the subject structure (Shaheen 2021). It is a popular material to use in low-sloped roofs due to its performance.

Spray-Applied Waterproofing
The cold spray materials are composed of an elastomeric membrane based on Methyl Methacrylate (MMA) resin that has quick curing properties and a robust and impermeable waterproofing membrane. The application can be either by spray or manual application. It is designed to protect the structures from water, oils, fuels, and other aggressive chemicals from penetration. It is an approved material from different countries, especially in the Middle East and Europe. It is consisting of two resin components (Part A and Part B) with an additional catalyst. Its application methodology includes two coats with different colors to distinguish the application period. The application temperature ranges from -20 to +50 degrees Celsius with a typical two coats interval of approximately 60 minutes.

Cementitious Waterproofing
Cementitious waterproofing may be considered the most straightforward method in waterproofing applications. This method is usually seen in wet areas such as the bathroom and toilet constructions. On the other hand, its semi-flexible properties are not recommended in an exposed location for sunlight and weathering (Shaheen, 2021). This material is a cement-based coating that prevents water penetration, vapor, moisture, and oil to the concrete substrate (O'Conner, 2019).

3.2 Project Locations
The company's project locations are scattered in various cities and municipalities in Qatar. One of these is the Lusail City, a futuristic, modern, and promising city located just north of Doha. Rayyan municipality is geographically situated east of Doha, north of Al Wakrah, and south of Umm Salal. While Al Daayen municipality is located in the east of Umm Qarn, and Al Shamal is situated north of the peninsula. Lastly, Al Shahaneeya was formerly a part of the municipality of Rayyan and became a municipality. Construction projects in those parts of Qatar vary from infrastructures, residential, commercial, and industrial construction projects, such as tunnels, basements, buildings, government structures, underpasses, bridges, and roofing (MME, Qatar 2021).

3.3 Linear Programming
To be able to address the objectives of this research paper, the following general form of linear programming objective function will be used:

$$Optimize\ (\text{max.})\ Z = C_1X_1 + C_2X_2 + C_3X_3 + \ldots + C_nX_n + 0s_1 + 0s_2 \ldots + 0s_m$$

Subject to the following linear constraints:

$$\begin{array}{c} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1 \\ a_{12}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2 \\ \vdots \qquad \vdots \qquad \vdots \qquad \vdots \\ \vdots \qquad \vdots \qquad \vdots \qquad \vdots \\ a_mx_1 + a_{m2} + \cdots + a_{mn}x_n + s_m = b_m \end{array}$$

Where:

$$x_1, x_2 \cdots\cdots, x_n, s_1, s_2, \cdots\cdots s_m = s_m \geq 0$$

In which, we can simplify the general form with the following:

$$(x+a)^n = \sum_{j=1}^{n} a_{ij}\, x_j s_i = b_i\ ,\ i = 1, 2, \ldots\ldots m \qquad \text{; and}$$

$$x_j, s_i \geq 0 \quad \text{(for all i and j)}$$

Assumptions:

- It is assumed that the project requirements on each project will not be affected.
- It is assumed that the effective production rate is constant on each project.
- It is assumed that the materials, including miscellaneous parts, are readily available at each project location.
- It is assumed that environmental factors such as rain, humidity, temperature, and gustiness are in normal conditions.

Data Presentation and Analysis

The data that was collected for this research paper is from a Building Specialist Company in Doha, Qatar. The data consist of the applicable production rate for the installation of waterproofing materials of PVC (Polyvinyl Chloride) T-Lock, Bituminous Membrane, Cold Spray Applied Waterproofing Membrane (Methyl Methacrylate), and Cementitious Membrane expressed in square meter per hour (sq.m./hour). The project locations cover where the company has its on-going projects in Qatar, namely, Lusail City, Doha, Rayyan, Al Khor, Umm Salal, Al Wakrah Al Daayen, Al Shamal, and Al Sheehaniya. The data analysis was done by using Linear Programming in Microsoft Excel. The following gathered data on each project location are shown below:

Lusail City
Available Area for Installation This Month = 25,000 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.88 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Spray Application = 2.08 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.69sq.m. Per Manhour

Doha
Available Area for Installation This Month = 35,000 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.88 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Spray Application = 2.08 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.69sq.m. Per Manhour

Rayyan
Available Area for Installation This Month = 12,000 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.88 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Spray Application = 2.08 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.69sq.m. Per Manhour

Al Khor
Available Area for Installation This Month = 12,500 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.56 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.88 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.56sq.m. Per Manhour

Umm Salal
Available Area for Installation This Month = 11,000 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.56 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.88 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.56sq.m. Per Manhour

Al Wakrah
Available Area for Installation This Month = 15,000 sq.m.

Effective Production Rate for PVC T-Lock Installation = 1.75 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.98 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.63sq.m. Per Manhour

Al Daayen
Available Area for Installation This Month = 18,500 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.81 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.63 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.88 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.69sq.m. Per Manhour

Al Shamal
Available Area for Installation This Month = 10,500 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.81 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.56 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.77 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.50sq.m. Per Manhour

Al Sheehaniya
Available Area for Installation This Month = 9,500 sq.m.
Effective Production Rate for PVC T-Lock Installation = 1.81 sq.m. Per Manhour
Effective Production Rate for Bitumen Installation = 1.56 sq.m. Per Manhour
Effective Production Rate for Spray Application = 1.77 sq.m. Per Manhour
Effective Production Rate for Cementitious Application = 1.50sq.m. Per Manhour

The data above were summarized in a tabular below in table 1:

Table 1. The Effective Production Rate of Waterproofing Installation

	Effective Production Rate (sq.m. per manhour)				
Project Location	PVC T-Lock	Bitumen	Spray Membrane	Cementitious Materials	Available Area for the Month (sq.m.)
Lusail	1.88	1.63	2.08	1.69	25,000
Doha	1.88	1.63	2.08	1.69	35,000
Rayyan	1.88	1.63	2.08	1.69	12,000
Al Khor	1.63	1.56	1.88	1.56	12,500
Umm Slal	1.63	1.56	1.88	1.56	11,000
Al Wakrah	1.75	1.63	1.98	1.63	15,000
Al Daayen	1.81	1.63	1.88	1.69	18,500
Al Shamal	1.81	1.56	1.77	1.50	10,500
Al Sheehaniya	1.81	1.56	1.77	1.50	9,500
Profit per manhour	16.00	15.00	21.00	12.00	

Model Formulation:
Let the manhour of PVC T-Lock Installation = X_1

Let the manhour of Bitumen Installation = X_2
Let the manhour of Spray Membrane Application = X_3
Let the manhour of Cementitious Membrane Application = X_4
And, let Z be the profit to be maximized.

Where linear programming model for the above production data is shown below:

$$Max\ Z = 16X_1 + 15X_2 + 21X_3 + 12X_4$$

Subject to:

$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 \le 25{,}000$$
$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 \le 35{,}000$$
$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 \le 12{,}000$$
$$1.63X_1 + 1.56X_2 + 1.88X_3 + 1.56X_4 \le 12{,}500$$
$$1.63X_1 + 1.56X_2 + 1.88X_3 + 1.56X_4 \le 11{,}000$$
$$1.75X_1 + 1.63X_2 + 1.98X_3 + 1.63X_4 \le 15{,}000$$
$$1.81X_1 + 1.56X_2 + 1.88X_3 + 1.69X_4 \le 18{,}500$$
$$1.81X_1 + 1.56X_2 + 1.77X_3 + 1.50X_4 \le 10{,}500$$
$$1.81X_1 + 1.56X_2 + 1.77X_3 + 1.50X_4 \le 9{,}500$$

Where, $X_1\ ,\ X_2\ ,\ X_3\ ,\ X_4\ \ge\ 0$

Using slack variables and simplifying, the problem is then converted to:

$$Max\ Z = 16X_1 + 15X_2 + 21X_3 + 12X_4 + 0s_1 + 0s_2 + 0s_3 + 0s_4 + 0s_5 + 0s_6 + 0s_7 + 0s_8 + 0s_9$$

Subject to:

$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 + 0s_1 \le 25{,}000$$
$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 + 0s_2 \le 35{,}000$$
$$1.88X_1 + 1.63X_2 + 2.08X_3 + 1.69X_4 + 0s_3 \le 12{,}000$$
$$1.63X_1 + 1.56X_2 + 1.88X_3 + 1.56X_4 + 0s_4 \le 12{,}500$$
$$1.63X_1 + 1.56X_2 + 1.88X_3 + 1.56X_4 + 0s_5 \le 11{,}000$$
$$1.75X_1 + 1.63X_2 + 1.98X_3 + 1.63X_4 + 0s_6 \le 15{,}000$$
$$1.81X_1 + 1.56X_2 + 1.88X_3 + 1.69X_4 + 0s_7 \le 18{,}500$$
$$1.81X_1 + 1.56X_2 + 1.77X_3 + 1.50X_4 + 0s_8 \le 10{,}500$$
$$1.81X_1 + 1.56X_2 + 1.77X_3 + 1.50X_4 + 0s_9 \le 9{,}500$$

Where, $X_1\ ,\ X_2\ ,\ X_3\ ,\ X_4\ ,\ 0s_1\ , 0s_2\ , 0s_3\ , 0s_4\ , 0s_5\ , 0s_6\ , 0s_7\ , 0s_8\ , 0s_9\ \ge\ 0$

4.Results

Following the above linear programming model, Linear Programming using Microsoft Excel was used to solve it, and the optimal result was given below (Table 2):

Man-hour of PVC T-Lock Installation = X_1 = 0
Man-hour of Bitumen Installation = X_2 = 0
Man-hour of Spray Membrane Application = X_3 = 5,365
Man-hour of Cementitious Membrane Application = X_4 = 0
And, the Optimal Profit Z = QAR 112,658.82

Table 2. Profit Optimization

	Effective Production Rate (sq.m. per manhour)					
Project Location	PVC T-Lock	Bitumen	Spray Membrane	Cementitious Materials	Area Applied	Available Area for the Month (sq.m.)
Lusail	1.88	1.63	2.08	1.69	11176.47	25,000
Doha	1.88	1.63	2.08	1.69	11176.47	35,000
Rayyan	1.88	1.63	2.08	1.69	11176.47	12,000
Al Khor	1.63	1.56	1.88	1.56	10058.82	12,500
Umm Slal	1.63	1.56	1.88	1.56	10058.82	11,000
Al Wakrah	1.75	1.63	1.98	1.63	10617.65	15,000
Al Daayen	1.81	1.63	1.88	1.69	10058.82	18,500
Al Shamal	1.81	1.56	1.77	1.50	9500.00	10,500
Al Sheehaniya	1.81	1.56	1.77	1.50	9500.00	9,500
Profit per manhour	QAR 16.00	QAR 15.00	QAR 21.00	QAR 12.00		
Manhour Required	0	0	5365	0	Total Profit:	QAR 112,658.82

Below is the result obtained from Linear Programming using Microsoft Excel (Table 3):

Table 3. Answer Report from Microsoft Excel Solver

Objective Cell (Max)				
	Cell	**Name**	**Original Value**	**Final Value**
	$J$18	Total Profit: Available Area for the Month (sq.m.)	QAR 0.00	QAR 112,658.82

Variable Cells					
	Cell	**Name**	**Original Value**	**Final Value**	**Integer**
	$D$18	Manhour Required PVC T-Lock	0	0	Contin
	$E$18	Manhour Required Bitumen	0	0	Contin
	$F$18	Manhour Required Spray Membrane	0	5365	Contin
	$G$18	Manhour Required Cementitous Materials	0	0	Contin

Constraints						
	Cell	**Name**	**Cell Value**	**Formula**	**Status**	**Slack**
	$H$7	Lusail Area Applied	11176.47	$H$7<=$J$7	Not Binding	13823.52941

	$H$8	Doha Area Applied	11176.47	$H$8<=$J$8	Not Binding	23823.52941
	$H$9	Rayyan Area Applied	11176.47	$H$9<=$J$9	Not Binding	823.5294118
	$H$10	Al Khor Area Applied	10058.82	$H$10<=$J$10	Not Binding	2441.176471
	$H$11	Umm Salal Area Applied	10058.82	$H$11<=$J$11	Not Binding	941.1764706
	$H$12	Al Wakrah Area Applied	10617.65	$H$12<=$J$12	Not Binding	4382.352941
	$H$13	Al Daayen Area Applied	10058.82	$H$13<=$J$13	Not Binding	8441.176471
	$H$14	Al Shamal Area Applied	9500.00	$H$14<=$J$14	Not Binding	1000
	$H$15	Al Sheehaniya Area Applied	9500.00	$H$15<=$J$15	Binding	0

In addition, the availability of area in the Al Sheehaniya project is limiting the profit increase as the projects in Lusail still has an available area of 13,823.53 square meters, in Doha has an available area of 23,823.53 square meters, in Rayyan has an available area of 823.53 square meters, in Al Khor has an available area of 2,441.18 square meters, Umm Salal has an available area of 941.18 square meters, Al Wakrah has an available area of 4,382.35 square meters, Al Daayen has an available area of 8,441.18 square meters, and lastly, in Al Shamal with an available area of 1,000 square meters. Lastly, the maximum profit we can get from those projects with linear programming is QAR 112,658.82.

5. Discussions

The linear programming model we used in these scenarios indicates that the optimum result or maximum profit can be improved even more if the available areas for installation and application in the zero slack or binding constraint are increased. In that way, our objective function will get a higher value where our objective is by knowing where our weaknesses in our operations, especially in construction projects, managers and executives of the company, can quickly decide to achieve a better result. It is also essential to know that there is a great need to improve the production rate of PVC T-Lock installation, Bitumen installation, and cementitious application as it is far away from the production rate of spray membrane application to make a considerable advantageous and competitive revenue to the company. It is highly recommended to have better and more frequent training to those weaker constraints on this case project.

6. Conclusion

Based on our analysis using linear programming carried out in the given scenario, the researcher concluded that opening more areas in the project location of Al Sheehaniya would increase a more significant profit. Results revealed that the other materials' production rate is lesser than the spray waterproofing membrane. Thus, the researcher concludes the need for more training and continuous improvement to both the operations and managers involved in the systems. Also, the availability of installation and application areas affects its good advantage, thus, recommending having better resource planning and workforce allotment to maximize its profit. The researcher recommended applying other accompanying risks to the task for further studies, such as environmental, safety, and other construction-related risks. It is also recommended to look for other linear programming programs such as LINGO and TARO software to have a vast array of solutions to the problem.

References

Akpan, N., & Iwok, I., Application of Linear Programming for Optimal Use of Raw Materials in Bakery. *International Journal of Mathematics and Statistics Invention (IJMSI). 4*, pp. 51-57. University of Port Harcourt, 2016.

Ferguson, T. S., Linear Programming. Retrieved from https://www.usna.edu/Users/weaprcon/avramov/_files/documents/compressed-sensing-tutorial/LP.pdf, 2020.

Jain, A. K., Saxena, H., Bhardwaj, R., Rao, G. J., & Nanda, C. S., Application of Linear Programming for Profit Maximization of a Pharma Company. *7*(12), 2020.

Jones, A., Nammour, Z., Clancy, N., Prescott, P., & Motti, P., *The Projects and Construction Review: Qatar.* Retrieved from The Law Reviews: https://thelawreviews.co.uk/title/the-projects-and-construction-review/qatar, 2020.

JV Polymers., *PVC T-Lock Sheet Membrane, 2017.*
Lewis, C., Linear Programming: Theory and Applications, 2008.
Marlin, T., Linear Programming: Key Terms, Concepts, & Methods for the User. Ontario, Canada. Retrieved from https://learnche.org/wiki_4G3/images/5/54/4G3-Linear-Programming-Notes-Thomas-Marlin.pdf, 2003.
Martinich, J. S., Production and Operations Management: An Applied Modern Approach. New York: Wiley, 1997.
Miller, S. J., An Introduction to Linear Programming. Retrieved from https://web.williams.edu/Mathematics/sjmiller/public_html/BrownClasses/54/handouts/LinearProgramming.pdf, 2007.
MME, Qatar. , *Municipalities.* Retrieved from Ministry of Municipality and Environment, Qatar: http://www.mme.gov.qa/cui/view.dox?id=612&siteID=2, 2021.
O'Conner, D., *Why Everyone Uses Cementitious Waterproofing.* Retrieved from News n'York: https://www.newsnyork.com/why-everyone-uses-cementitious-waterproofing, 2019.
Sahal, N., & Ozkan, E., Performance of Strained Bituminous Waterproofing Membranes Under Hydrostatic Pressure. National Research Council Canada, 1999.
Shaheen., *Waterproofing.* Retrieved from Shaheen: http://shaheenengineeringconsultants.com/water-proofing.html, 2021.
Song, J., Oh, K., Kim, B., & Oh, S., Performance Evaluation of Waterproofing Membrane Systems Subject to the Concrete Joint Load Behavior of Below-Grade Concrete Structures. (J. d. Brito, Ed.) *Applied Sciences*. , 2017.
Sriravindrarajah, R., & Tran, E., Waterproofing Practices in Australia for Building Construction. *MATEC Web of Conferences.* Sydney: EDP Sciences, 2018.
StudyMoose., *Tora Software.* Retrieved from StudyMoose: https://studymoose.com/tora-software-essay#:~:text=Temporary%2DOrdered%20Routing%20Algorithm%20(TORA,is%20very%20easy%20to%20use, 2021.

Biographies

Mark Anthony V. Santiago, MBA has been with the construction industry for more than eleven years with extensive international exposure of about eight years in the State of Qatar and the Kingdom of Saudi Arabia. He received his Bachelor of Science in Civil Engineering from Bulacan State University at Malolos City, Bulacan, Philippines. In 2020, he was awarded Master of Business Administration (MBA) from AMA University, Philippines. Professionally, he is a registered Civil Engineer by the Professional Regulation Commission in the Philippines, a registered Incorporated Engineer (IEng) by the Engineering Council, UK, and a registered engineer awarded by the Ministry of Municipality and Environment (MME) in the State of Qatar. Mark is also a Lean Six Sigma Professional at the Yellow Belt level by the Technical University of Munich, Germany. He is currently working on significant infrastructure projects in Qatar, continuously developing his managerial and technical skills. He is now pursuing another master's degree in industrial engineering major in engineering management at Mapua University Philippines.

Rianina D. Borres, MEP-IE received her Bachelor of Science Degree in Industrial Engineering from Mapua Institute of Technology, now known as Mapua University. She further on took her Master of Engineering - Major in Industrial Engineering Degree, also at Mapua, where she is now a full-time faculty and professor of the following subjects: Total Quality Management, Production Technology, Computer Integrated Manufacturing, Advanced IE Mathematics, Introduction to Statistics, Methods of Research, Design of Experiments, Operations Research, Operations Research, and Decision Making Laboratory, IE Applications Laboratory, Systems Improvement, Industrial and Manufacturing Processes, Methods Engineering and Work Measurement, Project Management and Compensation. She facilitates Computer Integrated Manufacturing training, particularly in Basic Robot Operations and Robotic Programming using Manufacturing Controllers Language. She also devises several research proposals for Production and Quality Cluster courses. Prof. Borres is also a freelance corporate consultant with expertise in evaluating companies' existing operations through process analysis and systems review to have effective business systems. Her expertise also includes continuously designing or developing new marketing, planning/forecasting, scheduling, and inventory management strategies/techniques as needed by the company or company's target market.

Maria Victorina D. Rada, MEP-IE has a Bachelor of Science in Industrial Engineering and a Master of Engineering in Industrial Engineering. She has 20-year experience in various fields of Industrial Engineering and Research with areas concerning Continuous Improvement, Engineering Statistics, Work Design, Measurement and Improvement, Impact Assessments, Management, and Financial Planning. Eleven years of working experience in SAP solutions covering from planning and design to implementation and support.