Optimization of the Cost and Duration in the Tower Crane Installation Using Goal Programming (GP) Model

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Abstract

This study utilized the pre-emptive Goal Programming (GP) model in the optimization problem in the Tower Crane Installation process. Secondary data was collected from an anonymous tower crane installer covering the entire operations in the Philippines. The preemptive GP model contains 4 variables and 12 constraints which and this study showed the preemptive GP results where only 3 out of 12 goals were achieved. The other 9 goals were not satisfied. Priority 1 and Priority 2 were not attained with positive deviations, suggesting that the total tower crane installation hours exceeded beyond 30 hours as well as incurring rental cost reserve of not more than P105,000. Priority 3, meanwhile, was attained with no positive deviation, suggesting that the mast can be installed in around 10 hours. Priority 4,5,6,7,8, and 9 were not attained with slight positive deviations observed, represented in hours, indicating that the goals established by the organization are not attainable. Priority 10 was attained with no deviations observed and Priority 12 was attained with negative deviation, suggesting that the organization can extend the total headcount and deploy additional headcount whenever necessary to ease the cost and duration of the tower crane installation. The results of the preemptive GP model were anchored in the formulation Risk Management Plan, reinforced by Cost-Benefit Analysis (CBA), helping the small to middle-market tower crane operators in the Philippines to mitigate the risk of installation delays and potential wastage in the cost and budget, as induced by this delay.

Keywords
Cost-Benefit Analysis (CBA), Goal Programming (GP), Risk Management Plan, Tower Crane Installation,

1. Introduction
The construction industry in the Philippines is deemed to be a key sector and one of the key economic drivers. As reported by Statista Research, the industry contributed to a gross value of approximately 336 billion pesos in the Q4 of 2020. In addition, the total construction expenditures by both private and public firms, have shown significant contractions in 2020 mainly due to the impact of COVID-19 pandemic. While slowdown in the industry has seen, it has been projected to propel in the next few years, as the current political and regulatory environment of the country makes it very conducive for the construction industry to thrive. One market that greatly benefited from the construction industry's growth in the Philippines, is the tower crane market. As Market Study reported, the global tower crane market size is poised to expand in the next 3 years, with a Compound Annual Growth Rate (CAGR) of 3.1%, or forecasted to exceed $2304.9 million by 2025, from $2042.9 million in 2019. The tower crane market is segmented by type such as the Self-erecting tower cranes, Flat Top tower cranes, Hammerhead tower cranes, Luffing Jib tower cranes. While in terms of application, tower cranes are used in the Dam building, Bridge building, Shipyards, Power Plants, and High-rise buildings.

Tower Crane market is broad in its scope and there are various business activities that are performed under this domain. One business activity is the tower crane installation, which is a niche segment under the tower crane market. Tower crane installation activity is deemed to be a critical aspect of the whole construction pipeline and is considered to be the preliminary step for contractors and owners who engaged in any types of construction activities. Installation requires highly specialized individuals and mechanical engineers. As crucial to the whole construction and/or project management pipeline, Tower crane installers must ensure that they meet the Service-level-agreement (SLA), specifically, the agreed timeline for the completion of tower crane installations. In this regard, various causes of delays have examined, and financial and labor-related delays are the main causes of delay. In construction in general, delay has its repercussion in the both the contractor and owners and normally it entails monetary implications.

This paper aims to optimize the tower crane installation duration and cost using the Goal Programming (GP) model, helping the tower crane operators in creating informed, sustainable, data-driven and mathematical bound decision-making framework, pivotal in the formulation Risk Management Plan to mitigate the risk of installation delays and potential wastage in the cost and budget, as induced by this delay.

1.1 Objectives

The main objective of this paper is to optimize the cost and duration of the tower crane installation, as these are the perennial problem encountered by the organizations operating in the small to middle markets in the Philippines through the application of GP model. Given that problems and/or goals in this context are not equally important, preemptive GP model was utilized and that the results of this study will be integrated in the formulation Risk Management Plan in order to mitigate the risk of installation delays and potential wastage in the cost and budget incurred by the tower crane operators.

2. Literature Review

The most common causes of delays in any construction projects are a normal scenario from engineering standpoint as it is generally known that the most common reasons for these are due to the complexities, costs and risks entailed in these projects (Prasad , 2019). Problem encountered in construction projects, as explained by Fashina et al. (2021), that the potential delay factors in construction projects are mainly caused by the contractor and consultants. Another study asserted the factors for construction delays, indicating that the causes of non-negotiable and inexcusable delays are clustered into twelve groups which are the material-related delays and labor-related delays (Abdelkrim & Tissourassi 2014). Furthermore, it was asserted factors such as lack of control, improper planning, poor coordination, subcontractor-related delays, as well as inadequate supervision might contribute to the delay in completion (Arantes et al. 2015). The schedule is typically prepared given that the construction activities were carried out at constant duration, although, the duration of activities changes due to factors such as skill of workers, weather, supply of materials, and efficiency of the resources particularly the plant and equipment (Tran, et al. 2016).

Furthermore, Zhou et al. (2015) postulated that in examination and development of the optimization models for tower cranes will help in reducing the transportation costs. Aziz and Abdel- Hakam (2016) postulated that the influencing factors that causes the delays specifically on the high-rise construction projects are the design changes, sub-par labor productivity, inadequate planning, and overall shortages on the company's resources. This was supported by Donnelly and Ika (2017) as they examined the most important causes of delays in construction projects in their study where they were able to identify some of the root causes such as the improper planning, lack of effective communication, and supply delays. Tariq and Gardezi (2022), examined the delays and conflicts in the construction projects in which the results of the study surfaced that the financial aspect is one crucial factor for the delay. Similar results from the study conducted by Fashina et al. (2021), revealing that the underestimation and overestimation of the project cost is one of the significant factors of delay. This further compelled the researchers to look at the financial aspect of the business in the context of tower crane.

Furthermore, it was suggested by Abdelkrim and Tissourassi (2014) that in their study an improved system for the application of GP model specifically in the allocation of the time and cost in construction management. Etemadi (2016), introduced the application of GP model in the capital budgeting variability and complexity considered in the context of construction. Meanwhile, Hada (2017), utilized the same approach with the difference of the utilization of the weight assignment in the GP model in the context of project management. Various GP application can be seen especially in the construction setting as utilization of GP model in the TCQT or time-cost-quality trade-off were seen on the study by Hamta et al. (2021). Furthermore, Prasad (2019) developed a project selection model specifically, a GP model to examine the safety management practices on the performance of a selected Indian construction organization. In addition, the decision model used goal programming model as evaluated through the application in a real project selection data.

Rabbani (2021) also applied the GP model for the project scheduling problem and resource leveling in the context of civil project. Given the extensive application of GP, this paper reinforced the decision to proceed with the application of GP model in the context of tower crane operation as to examined the various ways to optimize the resources in order to mitigate the delay and the entailed cost for these delays. This allowed the researchers to synthesize all of those approaches to create a new and tailored fit set of variables specifically useful and feasible in the context of tower crane installation.

3. Methods

In this study, a problem is modelled into a goal programming model is regarded an extension of a linear programming model as the goal programming model solves multiple and, in most cases, conflicting dimension of goals. A particular priority order or hierarchy is established by ranking or weighing various goals in accordance with their level of importance, as agreed by the researcher and the owner of the tower crane installer.

Pre-emptive Goal Programming (GP) method specifically used in this study where both the researchers and key stakeholders from the tower crane installation firm, ranked the goals based on order of importance, so as to realistically and accurately solve for the multiple problems. The priority structure encompasses all the goals that will never be simultaneously achieved, at least in this context of this study, in such a manner that more important goals are achieved first, in reciprocation of the less valued goals, ergo, it can be seen below the GP formulation:

$$\text{Minimize} \quad z = \sum_{k=1}^{K} \sum_{i=1}^{m} w_{ki} P_k \left(d_i^- + d_i^+ \right) \qquad (1)$$

s.t.

$$\sum_{i=1}^{m} a_{ij} x_j + d_i^- - d_i^+ = b_i \qquad (2)$$

x_j, $d_i \geq 0$, for all j is non-negative constraints for both deviational and decision variables.

where:

- b_i is the value for the $_i$th goal constraint.
- d_i^+ represents the positive deviational variable
- d_i^- represents the negative deviational variable
- P_k represents the $_i$th preemptive priority

4. Data Collection

Secondary data source will be utilized in this study, which was provided by the tower crane operator, given that the data should be treated based on the ethical bounds. The data comprised of both qualitative and quantitative data. For the qualitative data, it will be primarily used to describe the data pertaining to the projects and the overall operations of the company.

Table 1. Project Status Comparison on Actual Projects

Variables	**Project Status**		**Proposed Pre-emptive GP Goals**
	Delayed	**On time**	
Total Installation Hours	37.2	28.6	**Goal 1:** Total tower crane erection/ installation hours should not exceed at 30 hours
Average of Delay Cost	₱107,354.65	-	**Goal 2:** Do not spend more than the rental cost reserve of P105,000
Average of Crane Base/ Ballast Install Hours	5.4	4.4	**Goal 3:** Ballast Installation should be done not more than 6 hours
Average of Mast Installation Hours	9.1	8.7	**Goal 4:** 9 sections of mast should be installed within 8 hours
Average of Slewing Install Hours	1.6	1.0	**Goal 5:** Slewing and tower head installation should be executed within 1.5 hours

Average of Counter jib Install Hours	1.4	1.0	**Goal 6:** Counter jib installation should not exceed for 1 hour
Average of Main Jib Install Hours	5.2	3.5	**Goal 7:** Main jib installation should not exceed at 5 hours
Average of Energization Hours	5.7	1.5	**Goal 8:** Energization should be done within 3 hours
Average of Cable Reeving Hours	6.7	4.5	**Goal 9:** Cable Reeving should be completed not more than 6 hours
Average of Riggers #	1	4	**Goal 10:** Riggers should not exceed at 2
Average of Erectors #	1	3	**Goal 11:** Erectors should not exceed at 2
Average of Workforce	4	9	**Goal 12:** Total workforce should not exceed at 6

Table 1 shows the Project Status Comparison on Actual Projects which served as bases for each of the stated goals that were examined thoroughly. On the data that was provided, it was shown that out of the 50 projects rolled out from 2016-2021, 43 or 86% were delayed and the remaining 7 or 14% were installed on time. Overall, this only supports how this paper, as backed by the anonymous subject in this study, utilize the Pre-emptive GP model in the formulation of the goals of this paper.

Table 2. Derivation of the Coefficients in the Preemptive GP model

Factors	Riggers (x1)	Erectors (x2)	Total Hours Rendered
Crane Base/ Ballast Install Hours	2.10	3.14	5.24
Mast Installation Hours	3.62	5.42	9.04
Slewing Install Hours	0.60	0.89	1.49
Tower head Hours	0.54	0.81	1.35
Counter jib Install Hours	0.54	0.82	1.36
Main Jib Install Hours	1.99	2.98	4.97
Cabin Install Hours	0.27	0.41	0.68
Energization Hours	2.04	3.05	5.09
Cable Reeving Hours	2.56	3.84	6.40
Workforce Size	2.01	3.01	5.02
Total Installation Hours	14.25	21.37	35.62
Delay Cost	₱42,942.00	₱64,413.00	₱107,355.00

Table 2 shows how the coefficients were derived for each of the goals. As per the company, 60% of the ground work always come from the Erectors, as they are mainly responsible for preparing for construction material and tools; monitoring of the correct procedures, instructions technical specifications and manuals of instruction; interpretation of technical specifications and manuals; maintenance of equipment and tools; fitting up structural member, and/ or; performing tack welding whenever necessary. On the other hand, the remaining 40% of the utilization, goes to the riggers, as they are mainly responsible for the following: Inspection of the rigging gears, installations of the rigging gears, and/ or assisting in the crane operations. With this information, it was used in the derivation of the coefficients for each of the goals where x1 refers to the hours spent for riggers and x2 for the erectors.

Table 3. Derivations of Coefficients for the Workforce-related Goals

Decision Variables	Values	Total
x1	Rigger count	1.5
x2	Erectors count	1.4
x3	Foreman count	1.0
x4	Project Engineer count	1.1

Table 3 shows the derivations of coefficients for the workforce-related goals. This specifically refers to the Goal 10: Riggers should not exceed at 2, Goal 11: Erectors should not exceed at 2, and Goal 12: Total workforce should not exceed at 6. Take note that in the derivation of the coefficients, the decimal values were always rounded up as from the mathematical standpoint, persons are always counted in discrete values, not continuous.

5. Results and Discussion

As part of the preliminary analysis, the anonymous company's data were described in order to provide context on the current standing of their operation.

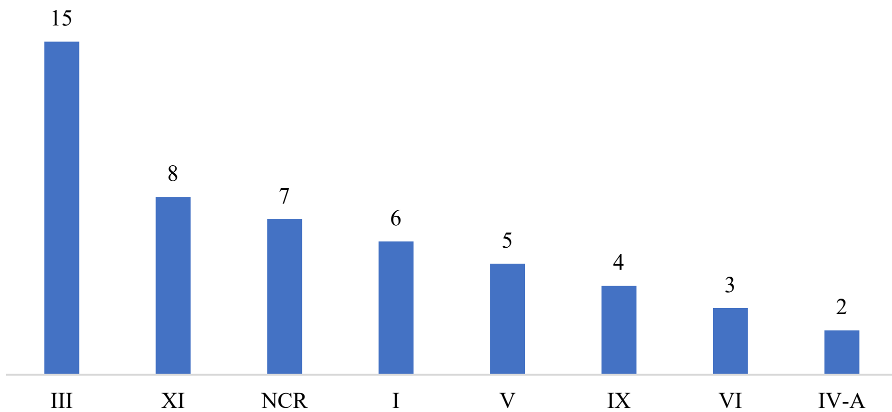

Figure 1. Regional Breakdown of Number of Projects Taken

First, it can be seen in figure 1 the number of projects taken by the company throughout the country. In order to provide more clarity on how and where the business normally operates, the researcher presented the regional breakdown of projects taken since the company's inception up to the present date. It can be seen that the highest number of projects taken are mainly on the Region III, which in other words, represents the Central Luzon. Specifically, in the province of Pampanga. Take note that projects are won through the bidding process and that based on the data, there are 12 private and 3 public tower crane installation in the abovementioned province. This was followed by Region XI, specifically Davao City where there are 5 private and 3 public projects completed on the said location. On the other hand, Laguna, as part of Region IV-A, also known as CALABARZON region, has seen to have the lowest number of tower crane installation activities completed with only 2 private projects completed.

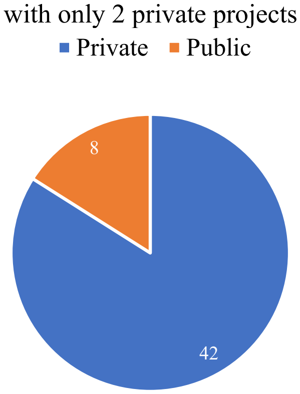

Figure 2. Breakdown of Projects Types

Figure 2 shows the breakdown of project types taken since the company's inception. 42 or 84% of projects are Private and the remaining 16% or 8 projects are public constructions. Drilling further into the tower crane installation for Private constructions, 17% or 7 of these 42 private operations are done in Clark Global City, followed by Naga City and Davao City at both 12% or 5 private projects. On the other hand, there are 8 public projects and drilling further into the details of these projects, it was seen that 37.5% or 3 out of 8 public projects were done in Davao City. With this data, this only shows that the company's operation spanned across the country, from farthest north to southernmost region of the country, with most operations are private-related projects mainly in Central Luzon and Region XI of the country.

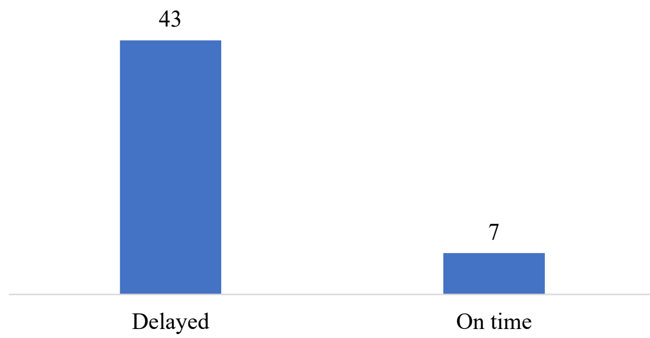

Figure 3. Breakdown of Projects Status

Figure 3 shows the breakdown of the project status of the tower crane installation on both private and public constructions, carried out since the company's inception in 2016 up to 2021. 86% or 43 projects are delayed and only 14% or 7 projects were done either ahead or on time. Analyzing further these numbers, 37 of these 43 delayed projects are attributed to private projects, translating to 86% of the total delayed projects, while the remaining 14% or 6 from the delayed projects are public related constructions. On the flipside, 71% or 5 out of 7 on time projects are private and the remaining 29% or 2 are public related constructions.

Table 4. Preemptive GP Results

Goals	D+	D-	Result
Total tower crane installation hours should not exceed at 30 hours	10.78	-	Not Achieved
Do not spend more than the rental cost reserve of P105,000	17.92	-	Not Achieved
Ballast Installation should be done not more than 6 hours	**-**	**-**	**Achieved**
9 sections of mast should be installed within 8 hours	2.35	-	Not Achieved
Slewing and tower head installation should be executed within 1.5 hours	0.21	-	Not Achieved
Counter jib installation should not exceed for 1 hour	0.56	-	Not Achieved
Main jib installation should not exceed at 5 hours	0.69	-	Not Achieved
Energization should be done within 3 hours	2.83	-	Not Achieved
Cable Reeving should be completed not more than 6 hours	1.33	-	Not Achieved
Riggers should not exceed at 2	**-**	**-**	**Achieved**
Erectors should not exceed at 2	0.48	-	Not Achieved
Total workforce should not exceed at 6	**-**	**1.52**	**Achieved**

Using excel solver, the preemptive GP model found a solution and that all constraints and optimal conditions were satisfied. The preemptive GP model contains 4 variables and 12 constraints which was solved using the MS Excel Solver. Table 4 shows the preemptive GP results and it can be postulated that only 3 out of 12 goals were achieved. The other 9 goals were not satisfied. Priority 1 and Priority 2 were not attained with positive deviations observed, which to the organization, are considered unwanted. This only suggests that does not achieve the goal of the total/overall tower crane erection/ installation hours should not exceed at 30 hours as well as incurring rental cost reserve of not more than P105,000. Priority 3, meanwhile, was attained with no positive deviation has seen. Priority 4,5,6,7,8, and 9 were not attained with all positive deviations observed, Priority 10, on the other hand was attained with no deviations observed. Also, Priority 12 was attained with negative deviations of 1.52 or rounded up by 2, providing more cushion for the organization to deploy headcount whenever necessary to ease the cost and duration of the tower crane installation.

Several studies revealed similar results when GP model was used in the construction industry, specifically the tower market, indicating that the GP result showed what are the causes of delay as well as inefficiencies in the process or operation of completing the project on time as well as minimizing the wastages in the cost incurred during the operations (Rabbani, 2021; Hamta et al., 2021; Prasad, 2019; Siu & Tang, 2018; Etemadi et al., 2018; Hada, 2017).

6. Conclusion

The results indicated that out of 12 goals, 3 were only attained and the rest of 9 goals were not, suggesting that the company should revisit their existing strategy and recalibrate their metrics as the GP might signal infeasibility of the company's goals/ targets which leads to delays in the completion of the projects. As this study utilized the pre-emptive GP model, it will evoke further interest from various researchers globally due to the promising and highly interesting deterministic method to come up with the mathematical bounds of decision support tool. The application to optimize the duration and cost of tower crane installation activities in the context of small to middle markets in the Philippines, allowed the decision makers to efficiently manage the workforce, budget and also the attainment of the overall installation duration. This study exemplified a more robust, mathematical, and data driven approach in dealing with the specific dilemma in the tower crane operation space, reassuring that the preemptive GP has always been one of the best choices and that it showed a more comprehensive and more granular approach.

As for recommendations which were based on the results of the preemptive GP model, the Risk Management Plan was formulated as shown in the summary from Table 5 below, this was reinforced by Cost-Benefit Analysis (CBA) to ensure the feasibility, applicability, accuracy and practicality of the framework suggested, creating a robust model to help the small to middle-market tower crane operators in the Philippines to mitigate the risk of installation delays and potential wastage in the cost and budget, as induced by this delay.

Table 5. Summary of the Risk Management Plan

Risks	**Mitigation Plan**	**Expected Outcome**
Total tower crane erection/ installation hours should not exceed at 30 hours	Add 1 more Erector **(Risk Avoidance)**	Additional Erector ensures on time completion as the GP showed it normally takes 21.37 hours for an erector to perform ballast installation. Hence, taking additional head count (HC) will ease the utilization of erectors deployed in this task and therefore will ensure the timely delivery especially that this goal over exceed by 10 hours.
9 sections of mast installed beyond 8 hours	Deploy 1 more Erector **(Risk Avoidance)**	Since additional Erector might be required in Ballast Installation, an erector should be deployed in ballast installation as the 4th goal shows positive/ unwanted deviation of 2.35 hours. Hence, requiring new HC will avoid the risk of delay for this task.
Slewing and tower head installation executed more than 1.5 hours	If further exceeded for 1 more hour, then deploy 1 Erector **(Risk Avoidance)**	This goal is not achieved per the GP model, this means that the existing HC deployed is slightly insufficient and is projected to create minimal impact. Therefore, the contractor will only take action if the execution time increased by almost 200%, which the showed as a rare instance.
Counter jib installation exceeded beyond 1 hour	Add 1 more Erector **(Risk Avoidance)**	Additional Erector ensures on time completion hence, taking additional head count (HC) will ease the utilization of erectors deployed in this task and therefore will ensure the timely delivery. Apparently, the surplus in utilization of the additional erector can be redeployed for other mitigation plan.
Main jib installation exceeded beyond 5 hours	Add 1 more Erector **(Risk Avoidance)**	This goal is not achieved based on GP, and therefore must ensure to be attained. From the data, it takes 4 hours for erection to complete the installation, hence, might require another HC to ensure timely delivery.
Cable Reeving was done beyond 6 hours	Share/ Split hours from Main jib installation **(Risk Reduction)**	This goal is also not achieved and from the data, it takes 3 hours for erector and 3 hrs. for riggers to complete the installation, hence, to ensure timely delivery, the contractor should pull the surplus hours from the additional HC from the main jib installation.
Energization is not done within 3 hours	If further exceeded for 1 more hour, then deploy 1 Erector **(Risk Reduction)**	From the data, it takes 3 hours for erectors to complete this process, still this goal is not attained due to prioritization of the goal. To ensure timeliness on this task, deployment of additional erector will be required once the execution time increments to 33% from the normal process.

Requires more Riggers	1 additional Rigger **(Risk Avoidance)**	Based on the existing data provided by the company on the on-time and delayed projects, the most logical number of riggers should be 2. On time projects have 4 riggers while delayed projects only have 1 rigger. So, the decision is to go in between of the two project statuses.
Requires more Erectors	2 additional Erectors **(Risk Avoidance)**	Based on the existing data provided by the company on the on-time and delayed projects, the most logical number of erectors should also be 2. On time projects have 4 erectors while delayed projects only have 1 erector. So, the decision is to go in between of the two project statuses.
Do not spend more than the rental cost reserve of P105,000	Early assessment of the workforce, immediately add riggers and erectors whenever necessary before installation progress reached 30% completion **(Risk Avoidance)**	Ensuring that correct HC is followed- 2 erectors and 2 riggers, at least, will help in minimizing the approximate 7 hours of delay in the installation of tower crane. In addition, hourly monitoring of the progress, will help whether reinforcement is needed to ensure delay in installation is mitigated.
There should only be 1 Project Engineers in the site/ project undertaken.	Assessment of the workforce, more than 100% of the riggers and erectors headcount were required/ deployed, that is the only time another Project Engineer will be required **(Monitor Risk)**	As Project Engineers are mainly in charge of all aspects of a project which includes the following: planning, budgeting, and workload allocation, it was decided by the company to limit it to only one. Hence, the company's stance is to monitor any potential risk on this.

Cost-Benefit Analysis (CBA) was carried out to reinforce the formulated risk management plan and also to create a solid basis for the mitigation measure for each of the risks identified in the above framework. This will also create a systematic process for the tower crane operators in analyzing which decisions to opt to versus what decisions to be abandoned. Given the applicability to the current context of the company, this paper specifically utilized the Benefit-Cost Ratio (BCR) method, where the ratio of the benefits versus the costs were assessed. Hence, it computes for the total benefits for the entire duration of the project and then dividing over the total costs of the project.

As part of understanding the BCR result, a value of less than 1.0 (<1.0) indicates that the costs exceed the benefits, therefore, it was asserted that the project should not proceed. A BCR value equal to 1 (BCR=1.0), signifies that the costs equal the benefits, indicating that the project can proceed, but with the caveat of little viability. Finally, a BCR value of greater than 1.0 (BCR>1.0), means that benefits exceed the costs, and the project proceed without any expected complications.

Table 6. Benefit-Cost Ratio (BCR) Results

Mitigation Plan	Legend	Cost	Benefit	BCR
2 Erectors	Risk Avoidance	₱60,000.00		
2 Riggers	Risk Avoidance	₱56,000.00		
		₱116,000.00	₱161,708.02	**1.39**

Table 6 shows the BCR results which was based on the risk management plan. This means that as part of risk avoidance, 2 erectors and 2 riggers should be deployed on site at an additional cost through their salary amounting to ₱110,000, where 1 erector earns a total compensation of ₱30,000 and ₱28,000 for a rigger, for the whole contract/ duration of the installation. Take note that the installation process takes 30 hours, but the whole team most of the time, requires to travel and prepare materials pre and post installation, hence, the salary is pegged for 72 hours. This will be then accounted under the Cost in BCR. Next, the benefit is anchored on the results of the GP model. As examined, the existing workforce deployed are at 2 erectors and 2 riggers which deemed to be insufficient and therefore, incurring cost of delay to the company, amounting to ₱161,708. As additional of 2 erectors and 2 riggers are posited, the

₱161,708 cost of delay will be eradicated. Hence, the computed BCR is 1.39 means that the benefits exceed the costs, and the project can proceed without any expected complications should they opted to deploy additional headcount of 2 erectors and 2 riggers, in order to mitigate or better, eliminate the delay in the completion of the tower crane installation.

As for the direction for future research, the locus of the study creates an opportunity for future research to examine the similar mathematical model on a specific context or location given that this study focused on all the activities throughout the country from the selected company, hence, results might change, geographically and demographically. This study emphasizes the need of the tower crane market to implement quantitative approaches, specifically the preemptive GP model that was utilized in this paper, in order to optimize the cost and duration in the tower crane installation.

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