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Enhancing Efficiency in Industrial Metal Roof Replacement: Utilizing Goal Programming for Cost Optimization

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ABSTRACT

This study explores the use of Goal Programming (GP) to optimise project management decisions in the construction industry, focusing on a case study of a roof replacement project. The construction industry is crucial to a country's development, contributing significantly to economic growth and employment rates. However, construction projects are often complex and resource-intensive. Project management is essential in ensuring the successful completion of construction projects. The study uses GP to address the time-cost trade-off in project management, aiming to minimise project costs while meeting project deadlines and quality requirements. The GP model considers various constraints, such as the availability of workers and equipment, project duration, and budget limitations. The study presents two optimisation options: a time-focused option and a cost-focused ed option. The time-focused option prioritises timely project completion, while the cost-focused option aims to minimise project costs. In the case study, the time-focused option is the most suitable choice. This approach allows the project to be completed in time as the alternative option delay delays the project far too unacceptable. Overall, the study demonstrates the effectiveness of GP in optimising project management decisions in the construction industry. By carefully evaluating project constraints and objectives, GP can help construction companies achieve the best possible outcomes in terms of cost, time, and quality.

Keywords: *Goal Programming, Construction Industry, Project Management, Time-Cost Trade-off, Optimization*

Introduction

A country's social and economic development is driven by its construction industry [1]. The construction industry accounts for around 13% of global expenditures and generates $10 trillion in revenue annually, which is likely to expand in the future years [2]. The building business creates infrastructure for residential, commercial, and industrial uses, enhancing people's quality of life. The construction sector contributes significantly to urban growth in emerging countries by designing and constructing high-rise buildings, highways, tunnels, health facilities, sports centres, transportation systems, and power plants [3]. Construction, a labour-intensive business, contributes to a country's employment rate and reduces poverty [4], [5]. Construction business is resource-intensive and frequently involves complex, uncertain, and risky projects that take a long time to complete [6].

Project management (PM) is a key factor in business and industry, with every organisational activity resembling a project—a precisely managed series of operations to attain a common goal [7]. Analysing data to achieve the best balance between the project's objectives is an important component of project management. Each project comprises a series of interconnected activities, each having its own success criteria, with time, and cost[8], [9], [10]. Delays in project completion can result in penalties and additional costs, while underestimating costs might indicate disaster for the project manager [11]. In contrast, quality is the most important factor in determining success. The goal of the time-cost trade-off problem is to carefully select a set of tasks and appropriate execution modes in order to reduce project costs and time while increasing project quality. This study proposes a goal programming that addresses the time-cost trade-off in project management.

According to the PMBOK Guide, project management encompasses ten knowledge areas: project integration, scope, schedule, cost, quality, human resources, communication, risk, procurement, and stakeholder management [12]. Successful projects are typically completed before their due dates and within budget; however, these limits are occasionally exceeded, leading to significant variances between projected and actual outcomes. Unexpected changes in construction technology, techniques, materials, or human resources can create budgetary and scheduling pressures, increasing the risk of failure [13].

PT. XYZ is a small to medium construction company contracted for the roof replacement project. Replacing a corroded metal roof in commercial buildings is a crucial task focused on maintaining the structural integrity, appearance, and usability of the facility. Metal roofs can corrode when exposed to environmental factors like moisture, oxygen, and pollutants. The formation of rust weakens the roof, causing leaks, structural damage, and safety risks. Timely replacement of rusty metal roofs is crucial to reduce risks and uphold a safe and suitable environment for occupants and operations in commercial buildings.

A corroded metal roof usually starts with thoroughly evaluating the current roof's condition. This assessment includes examining the level of corrosion, pinpointing areas of deterioration or vulnerability, and evaluating the general structural soundness of the roof system. A comprehensive plan is created after analysing the results, which includes the project's scope and timeline for the replacement project. Building regulations, environmental factors, and budget limitations are considered during the planning phase to ensure compliance and cost efficiency.

Various equipment could be introduced to speed up the roof replacement, such as scaffolding, which allows easier maneuverability of workers than using a ladder. Another more advanced option is using a mobile crane to install a metal roof on a commercial building, which is a more complex procedure than the former. Mobile cranes are essential for lifting and placing heavy roofing materials, allowing for efficient installation with safety and accuracy. Metal roofing panels, flashing, insulation, and other components are carefully arranged and prepared for effective installation. Effective coordination among the crane operator, roofing contractors, and other personnel is crucial to optimise workflow and reduce downtime [14].

This study analyses the case study of the company to finish their project with limited resources and the minimum cost possible by using the goal programming (GP) approach. The GP model offers optimal solutions for multi-objective scenarios [15], [16], [17], [18], [19]. Using the GP model to achieve the objective with minimum cost can help construction companies optimise profit. This model can also help many cases outside the studied case for similar cases and objectives. The GP model in this study gives how long is the optimal time for renting and which extra equipment is needed to finish the project with the minimum cost of operation.

In previous studies by [14], managers often grapple with optimising project implementation while considering time, cost, and quality objectives. To address this, the balancing method, a prevalent approach, is employed to harmonise these three facets effectively. In a recent study conducted at Arak Machine Sazi Company in Iran, a goal programming model was developed and rigorously tested to manage project objectives efficiently. This model showcased its efficacy in optimising project cost, time, and quality simultaneously. The computational results from the case study underscored the practical applicability and effectiveness of the proposed model, offering project managers a robust tool to navigate the complexities of project management with greater precision and success.

[20] used the GP model for target cost control in China for target cost control in construction projects, aiming to maximise economic benefits by minimising input costs. Target cost programming established through goal programming facilitates accurate cost control. While the simplex method is foundational, its time-consuming nature with numerous variables and constraints necessitates using mathematical software like Lingo for faster solutions. Effective target cost control involves determining project target costs and fostering staff enthusiasm through control programs, which enhance profitability by ensuring efficient resource allocation and cost management throughout project execution.

According to [16] research, the system of objectives for the construction schedule of highway projects is comprised of a vast array of factors. A multidimensional target construction schedule planning system can provide a more comprehensive assessment of the uncertain factors that may arise throughout the project. By utilising risk management tools in a timely and efficient manner, it is possible to ensure that the project will be completed within the designated timeframe. Nevertheless, in order to address the dynamic and uncertain aspects of the highway project construction schedule objectives system, it is imperative to implement countermeasures. This will enable timely problem identification and resolution, thereby guaranteeing the successful completion of the project objectives.

[17] paper tested Mubiru's goal programming model for allocating time and cost in project management with a case study in SEROR's company for construction projects in Algeria. Results showed satisfactory achievement for three preemptive projects, but the solution value for planning time was illogical and impractical, as without planning, the project failed.

The objective of [21] research is to simplify the analysis of financial ratios for construction businesses by identifying key characteristics that significantly impact financial performance. A combination of qualitative and quantitative methodologies was used to perform factor analysis on financial ratios obtained from a sample of 100 Indian construction enterprises over ten years. Were five SFPFs identified: investor return, company efficiency, operations management, activity efficiency and risk coverage, and asset management. An analysis was conducted to assess the relative significance of each element to get valuable insights into the organisation's performance. This analysis assists in strategic planning and policy formulation by concentrating on crucial areas for enhancement, which may result in establishing a specialised financial performance assessment framework designed specifically for the construction sector.

[22] employed a metaheuristic algorithm to tackle the trade-off problem involving discrete time, cost, and quality considerations in project activities. Unlike other methods, this approach allows for multiple alternatives for each activity, offering various options for time, cost, and quality. The algorithm determines the best options for project activities to minimise total project cost, maximise quality, and meet a specified deadline, assuming that activity duration and quality are discrete. They used the Particle Swarm Optimization (PSO) algorithm[22], which generates a population of feasible solutions and then selects and improves some locally.

[23] introduced a model for time-cost-quality optimisation, enabling managers to optimise multiple objectives. This model is derived from the project breakdown structure method, where task resources in construction projects are divided into activities, which are further subdivided into construction labour, materials, equipment, and administration. The resources allocated to each construction activity determine its time, cost, and quality, resulting in a complex trade-off model based on activity correlations. They applied a Genetic Algorithm (GA) to solve the nonlinear time-cost-quality problems in this model.

Kim and his team [24] proposed a mixed-integer linear programming model that addresses the Project Quality Loss Control (PQLC) for excessive crashing activities. This model assists project planners in developing practical project schedules.

Previous studies also provide us with insight insight into goal programming and linear programming's advantages and shortcomings, among other methods that were. The goal programming objective is optimising project objectives efficiently, including cost, time, and quality, while providing a systematic approach to balancing multiple objectives, offering project managers a robust tool for decision-making in complex projects. Linear programming, on the other hand, minimises input costs and maximises economic benefits, particularly in target cost control. However, linear programming can be time-consuming, especially considering the limited resources available.

Research Methods

When it comes to roof replacement, there is a need for additional consideration on how to keep the cost of workers efficient and carefully survey to obtain the best goal to minimise all costs whenever possible. The below Figure 1 explains methods to minimise roof replacement costs with goal programming.

1. Field survey: Performing a field survey to replace a metal roof requires a number of essential steps to be taken to guarantee precise measurements and an evaluation of the location. The first step in the process is preparation, which includes gathering the necessary equipment, which includes a measuring tape, a laser measurer, a notepad, a camera, and safety gear. It is important to review any documentation that is already available concerning the current roof structure and materials.
2. Identification: Carry out a visual inspection of the existing roof in order to evaluate its condition, taking into consideration any damage, rust, leaks, or structural issues that may be present. It is important to note any areas that might need additional attention or repairs before replacement. The slope and shape of the roof, as well as any obstacles or architectural features that may have an impact on the process of replacing the roof, should either be evaluated.
3. Material Quantification: Take into consideration the requirements of the metal roof as well as the overlaps between the metal roofing panels in order to guarantee adequate coverage. Incorporate a provision for waste that may occur due to cutting and fitting. Manufacturers typically provide guidelines for overlap and wastage percentages and can be used as guidelines for estimation purposes.

4. Data Collection: In order to replace a metal roof, it is necessary to collect all of the data and notes in the field. This includes gathering specific information about the site's conditions and the roof currently being counted.
5. Goal Programming: Objective programming is a powerful technique that is utilised in optimisation problems that require the balancing of multiple objectives that are in conflict with one another. We might have multiple goals for minimising the costs of replacing a metal roof. These goals include minimising the costs of materials and workers, as well as minimising the amount of time it takes to complete the project [25].
6. Decision: Summarize the results of goal programming in the context of a roof replacement project.

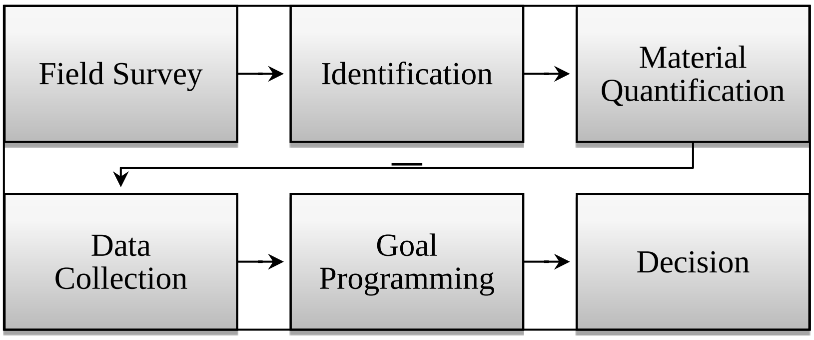

Figure 1. Methodology process of metal roof replacement

Case Study

In a scenario where 731 square meters (m^2) of roofs needed replacement within a tight 5-day timeframe, the total workload encompassed 1462 square meters (m^2) due to the two-step process of removing and installing the new roof. This study aims to complete removal and installation for the total area, with removal and installation times assumed equal. Equipment capabilities crucial for the project were assessed through field observations.

The primary goal of this study, a hard constraint, is to complete the replacement of 1462 m^2 of roofs (731 m^2 for removal and 731 m^2 for installation). A secondary goal, considered a soft constraint, is to complete the project within the 5-day. Additionally, the study seeks to minimise the overall project cost. To meet these objectives, the utilisation of scaffolding and a mobile crane has been considered. Field observations provided insights into the capabilities and pricing of these variables, as summarised in Table 1 below.

Table 1. Variables capability and price

Variables	**Capabilities (m^2/h)**	**Rp/Hours**
Worker	4	IDR 15,000
Worker with Scaffolding	10	IDR 35,000
Worker with Mobile Crane	40	IDR 200,000

The project faces several constraints that must be carefully managed to ensure successful completion within the specified parameters. Firstly, there are only 5 workers available for the project, each contributing 40 hours of work per week, totalling 200 working hours for the project duration. This translates to 8 hours of work per day for each worker.

Additionally, the operation of scaffolding and mobile cranes requires 2 workers each, which means using this equipment is limited to 100 hours each for the entire project duration.

Moreover, there is a budget target or constraint, with the project's overall cost targeted not to exceed IDR 5,500,000. This target underscores the need for cost-effective strategies and resource management throughout the project. All of the formulas for constraints can be seen below.

Constraints:

1. 1462 m^2 workload

$$C_1X_1 + C_2X_2 + C_3X_3 \geq W \tag{1}$$

2. Finish project in less than 5 days (200 hours)

$$X_1 + 2X_2 + 2X_3 + d_{t1}^- + 2d_{t2}^- + 2d_{t3}^- - d_{t1}^+ - 2d_{t2}^+ - 2d_{t3}^+ = T \tag{2}$$

3. Minimize the cost

$$15.000X_2 + 35.000X_2 + 200.000X_3 + d_p^- - d_p^+ = P \quad (3)$$

While the objective for this problem can then be defined as below:

$$F_t d_{t1}^- + F_t d_{t2}^- + F_t d_{t3}^- + F_t d_p^- + F_t d_{t1}^+ + F_t d_{t2}^+ + F_t d_{t3}^+ + F_t d_p^+ = Min\ Z \quad (4)$$

Where:
X_1 = workers workload (hours)
X_2 = workers with scaffolding workload (hours)
X_3= workers with mobile crane workload (hours)
C = Capabilities (m^2/h)
W = workload total (m^2)
T = project duration (hours)
d_t^- = underage of project duration (hours)
d_t^+= overage of project duration (hours)
F_t = weight for project duration
P = cost of the project (Rap)
d_P^- = underage of project duration (Rap)
d_P^+= overage of project duration (Rap)
F_p = weight for project cost

Results and Discussion

To address the project constraints and objectives, Excel Solver was utilized with the Simplex LP method, with unconstrained variables non-negative, while the solving limits is set to 100 s and max iteration is set to 100. The variables selected for adjustment were the hours allocated to roof removal and installation, both constrained to integer values. The objective function (Z) aimed to minimize the project cost, as indicated by the formula (4) provided earlier.

The Solver was set up to determine the best solution within the constraints by assigning a weight of 1 to all variables except for Worker with Scaffolding and Worker with Mobile Crane. Recall in previous chapter, these equipments need 2 workers to operate which mean the weight is always double of that of Worker variable. Additionally, any underage is advantageous, signifying a weight of 0, and can thus be eliminated. Refer to Formula (4), which has been adjusted with the weights, as shown below:

$$d_{t1}^+ + 2d_{t2}^+ + 2d_{t3}^+ + d_p^+ = Min\ Z \quad (5)$$

The Solver results, presented in Table 2, indicate that it is possible to complete the project within the specified timeframe. However, the total project cost amounts to IDR 6,115,000, which exceeds the budget by IDR 615,000. This increase in cost is a result of prioritising project duration over cost efficiency.

Table 2. Actual hours and cost of the project with time focus

Variables	Roof removal (hours)	Roof Installation (hours)	Actual (hours)	
Worker	0	3	3	
Worker with Scaffolding	66	16	82	199
Worker with Mobile Crane	2	14	16	
Price/Cost			IDR 6,115,000	

Table 3. Overage of the project with time focus

Variables	Weights	Overage	Total	Target
Labour	1	0		
Labour with Scaffolding	2	0	199	200
Labour with Mobile Crane	2	0		
Price/Cost	1	IDR 615,000.00	IDR 5,500,000	IDR 5,500,000.00

As previously established, the primary goal of the project is to remove and install 731 square meters (m^2) of roofs. This target is a hard constraint, meaning it must be strictly accomplished. Each variable in the model already includes the cost of workers needed to operate the equipment, simplifying the overall model.

To ensure that the project meets this hard constraint, the sum of roof removal and installation for each variable must be greater than or equal to 731 m^2 as can be seen in Table 4. This constraint is crucial for achieving the project's objectives while also making the model is possible with integer constraint.

Table 4. Total work on each variable with time focus

Variables	Roof removal (m2)	Roof Installation (m2)
Labour	0	12
Labour with Scaffolding	660	160
Labour with Mobile Crane	80	560
Total Work	740	732
Target	731	731

An alternative approach to the project optimization involves adjusting the weight of the project cost (F_p) in Formula (5) to 4 to prioritize cost savings can be seen below in Formula (6). By doing so, it is possible to reduce the project cost to the targeted IDR 5,500,000, as demonstrated in Table 5. However, this cost reduction comes at the expense of project duration, with the total time required increasing to 258 hours, equivalent to 6 and a half days.

$$d_{t1}^{+} + 2d_{t2}^{+} + 2d_{t3}^{+} + 4d_{p}^{+} = Min\ Z \tag{6}$$

This cost-focused model requires an additional 29 hours of worker time with scaffolding, extending the project duration beyond the original 5-day timeframe as seen in Table 7. The trade-off between cost and time is evident in this approach, highlighting the need to balance these factors to achieve an optimal solution.

Table 5. Actual hours and cost of the project with cost focus

Variables	Roof removal (hours)	Roof Installation (hours)	Actual (hours)	
Labour	1	3	4	
Labour with Scaffolding	49	72	121	258
Labour with Mobile Crane	6	0	6	
Price/Cost			IDR 5,495,000	

Table 6. Overage of the project with cost focus

Variables	Weights	Overage	Total	Target
Labour	1	0		
Labour with Scaffolding	2	0	200	200
Labour with Mobile Crane	2	29		
Price/Cost	4	IDR 0.00	IDR 5,495,000	IDR 5,500,000.00

Table 7. Total work on each variable with cost focus

Variables	Roof removal (m2)	Roof Installation (m2)
Labour	4	12
Labour with Scaffolding	490	720
Labour with Mobile Crane	240	0
Total Work	734	732
Target	731	731

The results presented offer three distinct options for consideration: minimising costs and completing the project within the targeted time frame. The choice between these options depends on various factors that must be carefully evaluated. For instance, in a project tender, prioritizing cost minimisation can provide a competitive advantage by offering a more economical solution than competitors. This approach may resonate with clients seeking cost-effective solutions and could significantly enhance the chances of winning the tender.

Conversely, emphasising timely project completion is essential for upholding the company's reputation and image. Meeting deadlines demonstrates reliability, professionalism, and a commitment to delivering on promises, which are crucial for maintaining client satisfaction and fostering long-term relationships.

Other factors that may influence the decision include the nature of the project, client priorities, and the strategic objectives of the company. For instance, in projects where quality is paramount, focusing on cost minimisation at the expense of quality or time may not be advisable. Similarly, in industries where time-to-market is critical, such as construction or technology, completing the project on schedule may take precedence over cost considerations.

In this case study, the delay is far too long to be acceptable, so opting for the time focus approach is the most suitable choice. This approach allows the project to be completed on time. While it may not fully achieve all objectives, it still provides the best overall solution and allocation for each variable to ease project management. The options summarize can be seen below in Table 8.

Table 8. Summarize of the option for the project

Objectives	**Option 1 (Time focus)**	**Option 2 (Cost focus)**	**Target**
Project duration (hours)	199	258	200
Project cost (Rp)	IDR 6,115,000	IDR 5,495,000	IDR 5,500,000

Conclusion

In this case study, Goal Programming explored several project optimisation options, such as cost minimisation, meeting project deadlines, and balancing cost and time objectives. Each option presented its own set of trade-offs:

1) Time-Focused Option: Prioritizing timely completion of the project resulted in completing the project within 199 hours but exceeding the budget by IDR 615,000.
2) Cost-Focused Option: Emphasizing cost minimisation led to reducing the project cost to IDR 5,500,000 but extending the project duration to 258 hours, equivalent to 6 and a half days.

The time focus approach is the most suitable choice for PT. XYZ, considering the delay for cost focus is far too long to be acceptable. This approach allows the project to be completed on time. Furthermore, the use of Goal Programming also provided the allocation for each variable to save a considerable amount of time in project management.

In conclusion, Goal Programming serves as a valuable decision-making tool that helps to make informed decisions leading to the most favorable overall outcomes. However, to effectively utilise Goal Programming, it is essential to understand or evaluate multiple factors. These include understanding the project's situations, such as its scope, timeline, and resource requirements. Additionally, considering client priorities and aligning them with the strategic objectives of the company is crucial. Other factors, such as budget constraints, risk management, and stakeholder expectations, also play a significant role in determining the optimal solution. By carefully evaluating these factors, Goal Programming can be utilised to achieve the best possible results.

Moreover, the authors believe that the resulting model is easily adaptable to various scenarios in different construction projects, involving different variables, or even extending beyond the realm of construction. Additionally, the model could be expanded in the future by incorporating more variables related to the construction project or by incorporating machine learning programs and simulations such as Discrete-event simulation to be able to acquire more accurate data or models that are relevant to the project, thereby providing further flexibility and accuracy for optimising project outcomes.

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