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Waste Management Economic Analysis of a GIS-Based System Implementation in Bisha, Saudi Arabia

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Abstract

Efficiency in waste management is critical for urban sustainability, particularly in rapidly expanding cities such as Bisha in the Kingdom of Saudi Arabia. This study examines the effectiveness of the implementation of a GIS-based waste management system through the application of project management techniques and economic analysis. The system aims to enhance operational efficiency, economic savings, and environmental sustainability by optimizing waste collection routes and waste bin placement. The processes of the GIS-based system implementation are analyzed using project management techniques such as the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT). These techniques have defined critical activities and optimized the project timeline. Additionally, an economic analysis evaluates the system's cost-effectiveness by computing the payback period, which estimates the duration required for the system to recover its initial investment through operational savings. The study results support the hypothesis that a GIS-based waste management system's efficiency may be increased by implementing project management techniques, resulting in a 9-month reduction in the overall duration of implementation from 63 months to 54 months. The economic study further confirms the cost-effectiveness and sustainability of the system over its expected 20-year lifespan, as seen by a positive payback period of less than five years. Contributing to broader environmental sustainability and public health goals, the paper concludes that such a model could be utilized as a guide for improving waste management practices in Bisha and other similar urban cities.

Keywords

Smart waste management, GIS-based system, Project Management, Economic Analysis, Critical Path Method (CPM)

1.Introduction

The city of Bisha, located in the southern Kingdom of Saudi Arabia, is experiencing a rapid population increase, which has led to an escalation in solid waste generation. As the city continues to develop, aligning with global urbanization trends, there is an urgent need to establish sustainable waste management that can efficiently deal with the increasing volume of waste. To address these challenges, this paper seeks to examine the implementation of a GIS-based smart system, supported by project management techniques such as CPM and PERT, along with an economic analysis study. The aim of the system is to optimize the spatial distribution of waste bins, thereby reducing the costs associated with waste collection and improving overall system effectiveness and efficiency. The rapid increase in solid waste generation can be attributed to factors such as the continuous economic growth experienced by cities, urbanization, and the continuous industrialization that the world is still experiencing (Danbuzu et al., 2014).

A study conducted by Danbuzu et al. (2014) indicates that GIS is essential in combining spatial data, that is, maps, aerial photographs, and satellite images, with non-spatial data, both quantitative and qualitative, to help in collection operations, customer service, analyzing optimal locations for transfer stations, and planning routes for vehicles that transport waste, all of which help in the effective disposal of solid waste. Fuseini et al. (2021) indicate that the stakeholders involved must assess the spatial distribution of the waste bins that have already been provided using an accurate technique of the GIS methodology, which was hitherto not employed in earlier assessments of communal waste bin utilization.

According to Vu et al. (2020), waste collection is said to constitute about 50% of the total costs incurred in waste management endeavors. This issue has necessitated the innovation of a sustainable waste management program to help eliminate the threat that solid waste poses to people and the environment. In this context of evaluating the cost-effectiveness of GIS-based systems in waste management, Singh and Gupta's (2022) study emphasizes that collection and transportation alone can constitute up to 70% of total municipal solid waste (MSW) system costs, further highlighting the need for accurate cost assessment and monitoring of waste collection costs to determine the most economical waste collection system.

This study investigates the integration of project management techniques with economic feasibility analysis to enhance the system's efficiency and reduce operational costs. Analytical methodologies and tools are essential for environmental project management, especially with GIS technology. Project planning and execution are best done using CPM and PERT. These structured methods select the best project completion order to minimize delays and maximize resource allocation (Maulana and Kurniawan, 2019). In the "Sustainable Green City Development Project," Abuhasel (2023) emphasizes the importance of the CPM in managing complex projects, demonstrating how effectively it works to optimize work schedules for better time and cost management outcomes.

This paper examines GIS-based waste management system implementation to show that combining solid project management with thorough economic analysis can lead to a more efficient and cost-effective system. Technical innovations and good project management are needed to boost waste management system efficiency, sustainability, and profitability (Mashudi et al., 2023). The paper aims to provide practical insights into the city's waste management strategy and offer a model for other urban areas with similar challenges.

This article (Jufriyanto & Fathoni, 2019) explores the use of the Critical Path Method (CPM) and Project Evaluation and Review Technique (PERT) in managing the Rungkut Tower Apartments project. The study illustrates how CPM helps identify the crucial sequence of tasks that dictate the project's overall timeline, allowing project managers to prioritize these key activities to ensure timely completion. PERT, on the other hand, incorporates probabilistic time estimates to manage uncertainties and variability in task durations, providing a more adaptable framework for scheduling. The research highlights the synergistic benefits of combining CPM and PERT, showing how these methodologies can improve project planning, enhance resource allocation, and better manage risks, ultimately leading to more efficient project execution and accurate scheduling.

In "Critical-Path Planning and Scheduling," (Kelley & Walker ,1959) introduced the Critical Path Method (CPM) during the Eastern Joint Computer Conference (IRE-AIEE-ACM). This seminal work established CPM as a transformative project management technique by emphasizing the identification of the longest sequence of dependent tasks, known as the critical path. This path determines the shortest possible project duration and highlights tasks that must be managed carefully to avoid delays. By identifying and focusing on these critical activities, CPM enables project managers to optimize scheduling and resource allocation. Kelley and Walker's contributions through CPM have profoundly shaped modern project management, providing a robust framework for effective planning, scheduling, and executing complex projects across various industries.

A study by Dong et al. (2019) demonstrated the effectiveness of CPM in large-scale infrastructure projects, including waste management systems. The study highlighted how CPM helped streamline operations, reduce project duration, and improve resource utilization.

In the realm of waste management, a case study by Cynthia (2020) demonstrated the application of PERT in the planning and execution of waste treatment plant projects. The study showed how PERT improved project scheduling, reduced uncertainties, and facilitated better risk management. As Bisha seeks to implement a GIS-based smart waste management system, the application of CPM and PERT can provide the necessary structure and flexibility to navigate the project's complexities. This literature review underscores the importance of adopting these analytical tools to achieve sustainable and efficient waste management solutions.

1.1 Objectives of Study

The main objective of the study is to comprehensively analyze the application of project management techniques alongside an economic analysis of GIS-based system implementation to optimize Bisha's waste management system through improved operational efficiency, economic savings, and environmental sustainability.
The research objectives include the following:

1. To explore how project management techniques can be applied to optimize the implementation and operation of a GIS-based waste management system.
2. Conduct a thorough economic analysis to assess the cost-effectiveness of the GIS-based waste management system by calculating its payback period.

1.2 Problem Statement

A world with safe environments and effective waste management systems is what the United Nations Environment Programme (UNEP) envisions. Waste management is one of UNEP's primary focus areas between 2022 and 2025 to improve climatic stability and build a future free from pollution. UNEP is identified as the people's partner for the planet (UNEP, 2022). UNEP's vision and mission are in line with the Sustainable Development Goals (SDGs), particularly the eleventh goal, which focuses on the sustainability of communities and cities, and the twelfth goal, which identifies ways to maintain sustainable production and consumption patterns. Waste management takes center stage in efforts towards attaining the global SDGs (Rodić & Wilson, 2017).

However, waste management continues to be a major global challenge, despite international efforts and commitments. Experts state that approximately 2 billion tons of solidified waste are produced annually worldwide, and that number is expected to rise to 3 billion tons over the next 17 years (World Bank, 2022). The fast-paced patterns of population growth, urbanization, and development in the Middle East, including Saudi Arabia, show increasing challenges for waste management practices (Hussein, Uren, Rekik, & Hammami, 2022). In Saudi Arabia, particularly in the city of Bisha, inadequate waste management has severe consequences, including environmental degradation, public health risks, and financial burdens (Ali, 2019). The issue is exacerbated by the waste bins' inadequate spatial distribution and ineffective collection routes.

Recognizing the urgency of addressing issues of managing waste, smart waste management systems have been recommended as a viable solution (Farooq et al., 2022). However, a thorough evaluation is necessary to ensure the success of deploying these systems in rapidly expanding urban areas like Bisha. The purpose of this study is to evaluate the effectiveness of implementing a smart waste management system based on GIS by using project management tools and economic analysis to enhance waste management processes, reduce environmental and health impacts, and contribute to the sustainability targets set by UNEP and the SDGs.

The project management techniques used for managing GIS-based smart waste management systems in Bisha City, including CPM and PERT, are effective in handling complexities and uncertainties, enhancing resource optimization, identifying critical tasks, and ensuring efficient use of time and resources.

1.3 Area of Study

The research examines Bisha City as a case study, an urban city nestled in the Asir province within the northwestern reaches of the Asir region, as shown in Figure 1. It shares its northern borders with the Makkah Al-Mukarramah region, while to the south is the center of Khaybar in Khamis Mushait Governorate. To the east, Bisha City's limits extend to the districts of Tathleeth and Jash, and to the west, it adjoins the Al-Baha region, along with the governorates of Balqarn and Al-Namas. Geographically, the city spans 185 kilometers from north to south, varying its width from east to west. Bisha City covers a total area of 659 square kilometers, and as of 2022, it was home to a population of 248,452 people. It also contains 25 neighborhoods, including Al-Khuzama, Al-Naseem, Al-Fahd, Al-Nakhil, and Al-Rabwa, etc.

Its significance predominantly revolves around its milestone, the King Fahd bin Abdulaziz Dam, strategically erected in Wadi Bisha, positioned 35 kilometers southwest of the city. Ranking as the second-largest dam in the Middle East, it impressively spans 507 meters in length and soars to a height of 113 meters. Remarkably, it hosts the largest artificial freshwater lake in the Kingdom, spanning 30 square kilometers, and features a remarkable storage capacity of 352 million cubic meters of fresh water. Bisha is a significant agricultural region due to its fertile soil and its various valleys, as it is famous for date palm cultivation.

Figure 1. The location of the city of Bisha in the Kingdom of Saudi Arabia in 2023

1.4 Hypotheses of the study

To achieve the primary objective of the research, the following hypotheses were developed:
Hypothesis 1: There is a strong relationship between the application of project management techniques and the enhanced efficiency of a GIS-based waste management system in Bisha.
Hypothesis 2: The economic analysis of the GIS-based waste management system will provide a payback period that falls within an acceptable range for sustainable investment, hence confirming its cost-effectiveness.

2. Methodology

The researcher employed the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) as analytical tools to examine the project management aspects of the GIS-Based Smart Waste Management system implementation. The objective was to employ specialized project management approaches to thoroughly determine the sequence and duration of the tasks required to implement the system.

An economic analysis was also conducted to evaluate the GIS-based smart waste management system's cost-effectiveness. The approach involves the determination of the initial cost expenses, the estimation of operating cost savings, and the computation of the net annual savings. The methodology concludes with the calculation of the payback period to assess the duration required for the system's savings to recover its initial costs.

We used project management techniques well suited for managing GIS-based smart waste management systems in Bisha City due to their ability to handle the complexities and uncertainties inherent in such large-scale projects. CPM offers clear, deterministic scheduling and detailed planning, ensuring meticulous management of project aspects. PERT complements this by incorporating probabilistic time estimates, providing flexibility to account for uncertainties (Salhab et al., 2022). Together, these techniques enhance resource optimization by identifying critical tasks and potential delays, ensuring efficient use of time and resources. This comprehensive approach balances structure and flexibility, making it ideal for achieving efficient and effective project execution in Bisha City.

To achieve the research objectives, the study is structured into two primary parts.

- The project management of the GIS-based system implementation involves the practical application of PERT and CPM, which ensures that all tasks are completed within the time allowed and resource constraints.
- The economic analysis emphasizes the assessment of the payback period to determine the estimated period to recover the investment in the GIS-based system implementation through cost savings.

2.1 Data Collection

This research uses data from various sources, including research studies, surveys, government databases, public records, private companies, and academic institutions. Accessibility depends on the source, legal or privacy restrictions, and the availability of data. Public datasets, or open-source databases, are often easily accessible, while proprietary datasets require specific permissions or licenses. Sensitive data, like personal information or classified government data, may have strict regulations.

3. Results & Discussion

3.1 Project Management Techniques

The situation faced here is that there is a difference between the project implementation time and the predetermined project plan time. The project planning time is usually shorter than the project implementation time.

Network analysis and Slack were utilized to conduct a study on how to accelerate the project. Quantitative data analysis was performed using the PERT (Program Evaluation and Review Technique) method, which served as a guiding principle for approving project acceleration.

1. **Stage 1: CPM analysis**

In this stage, network analysis is used to create a CPM (Critical Path Method) network in order to determine the shortest time for project completion. Network analysis includes the following:

- Reviewing and defining the project scope, description, and breakdown, and determining the sequencing of activities by identifying the relationships between different activities.
- Drawing the network using a graphical representation that illustrates the activities and their relationships.
- Estimating the time required to complete the activities is important, as the expected duration of each activity is an important factor in determining the project's completion time.
- Identifying the critical path, which is the longest chain of interdependent activities, determines the overall project duration.
- Performing forward and backward calculations based on the sequence of activities.

2. **Stage 2: PERT analysis**

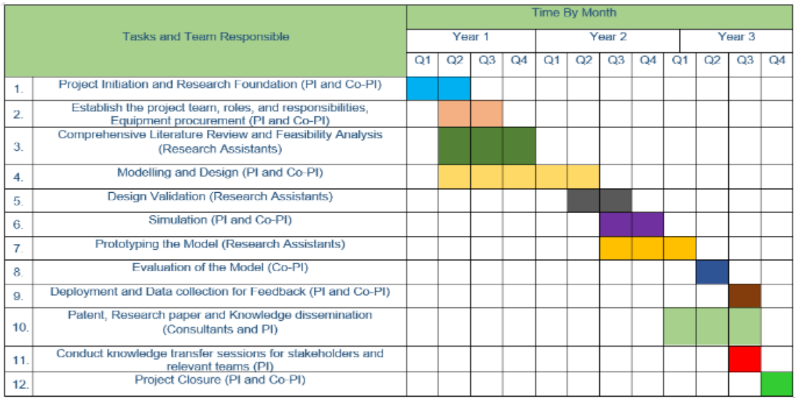
In this stage, PERT (Program Evaluation and Review Technique) analysis is conducted to determine the duration of each task based on the available data and assess the probability of the company meeting the target schedule. To apply the PERT method, the following steps are involved:
-Estimating the duration of each activity.
-Determining the standard deviation of project activities.
-Assessing the range of activities within the project.
-Evaluating the probability of achieving the target schedule.

3.1.1 Gantt Chart

The chart consists of a horizontal timeline representing the duration of the project, divided into months. The activities of the project are listed on the left side of the chart, along with their respective codes and descriptions.

Each activity is represented by a horizontal bar on the timeline, indicating its start and end dates. The length of the bar corresponds to the estimated duration of the activity. The activities are arranged in sequential order based on their immediate predecessors, which are listed under the "Immediate Predecessors" column in the table.

The critical path, which is the longest sequence of dependent activities that determines the project's overall duration, is identified in the chart. In this case, the critical path is represented by activities A, B, C, D, G, H, K, and L in Figure (2). Any delay in these critical activities would have a direct impact on the project timeline.



	Tasks and Team Responsible	Time By Month											
		Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.	Project Initiation and Research Foundation (PI and Co-PI)	🟦	🟦										
2.	Establish the project team, roles, and responsibilities, Equipment procurement (PI and Co-PI)		🟧	🟧									
3.	Comprehensive Literature Review and Feasibility Analysis (Research Assistants)		🟩	🟩	🟩								
4.	Modelling and Design (PI and Co-PI)		🟨	🟨	🟨	🟨	🟨						
5.	Design Validation (Research Assistants)						⬛	⬛					
6.	Simulation (PI and Co-PI)							🟪	🟪				
7.	Prototyping the Model (Research Assistants)							🟨	🟨	🟨			
8.	Evaluation of the Model (Co-PI)										🟦		
9.	Deployment and Data collection for Feedback (PI and Co-PI)											🟫	
10.	Patent, Research paper and Knowledge dissemination (Consultants and PI)									🟩	🟩	🟩	
11.	Conduct knowledge transfer sessions for stakeholders and relevant teams (PI)											🟥	
12.	Project Closure (PI and Co-PI)												🟩

Figure 2. Gantt Chart for The Project

3.1.2 Description of Activities

In this step, an assessment is carried out to determine and define the project scope by dividing the activities outlined in the Gantt chart into groups of activities that constitute project components. This sequencing is based on the data provided in the Gantt chart, which includes activity details, their interrelationships, and the duration of each activity as specified in Table 1:

Table 1. The activities and stages for the project

Activity Code	Activity Description	Immediate Predecessors	Estimated Duration
A	Project Initiation and Research Foundation	-	6m
B	Establish the project team, roles, and responsibilities, Equipment procurement	A	6m
C	Comprehensive Literature Review and Feasibility Analysis	A,B	9m
D	Modelling and Design	A,B,C	15m
E	Design Validation	D	6m
F	Simulation	D	6m
G	Prototyping the Model	D	9m
H	Evaluation of the Model	G	3m
I	Deployment and Data collection for Feedback	H	3m
J	Patent, Research paper and Knowledge dissemination	F	9m
K	Conduct knowledge transfer sessions for stakeholders and relevant teams	H	3m
L	Project Closure	K	3m

3.1.3 Network planning

When developing both small and large projects, it is important to take into account the shortest possible time period in which the project can be completed. In this case, a critical path is calculated. The objective of the method is to identify the longest sequence of activities from the project's start to its completion. When determining the minimum project duration, it is assumed that critical path tasks have no float or reserve schedule time for delays. This assumption is crucial because project development is highly influenced by accurate scheduling. Incorrect sequencing of the most time-consuming tasks can significantly impact the actual project completion date. There are tasks that are not on the critical path but still contribute to the project's success. These tasks may have slack, allowing for the definition of two dates: the earliest and latest start or finish dates for each stage. By utilizing the network diagram, it becomes possible to calculate the early and late start dates for all tasks.

Calculate ES, EF, and project duration. To calculate the earliest start date for a stage, we need to identify the longest path leading to that stage on the network diagram. The early start of the next task is then determined by the early finish of the previous task. The early start and early finish dates are determined for each task on the chart sequentially, starting from the initial event in Figure 3. The durations of the tasks are taken into consideration to calculate the early finish dates, using the maximum duration values.

$\mathrm{EF} = \mathrm{ES} + \mathrm{D}$

$EF = Early\ Finish$

$ES = Early\ Start$

$D = \text{Duration}$

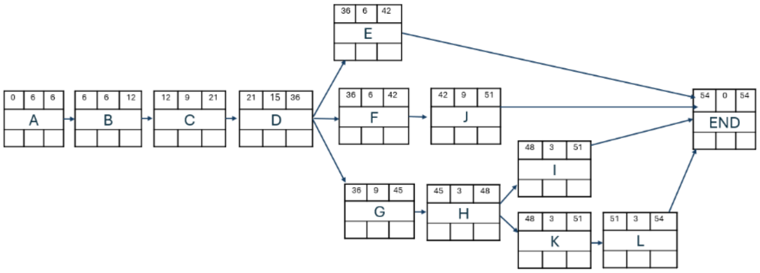


Figure 3. ES and EF and Project Duration

Calculate the LS and LF. The late start date for a task, which does not cause delays in the development process, is determined by subtracting the duration of the critical path from the longest path between the previous task and the final task. Similarly, the late start date for a specific stage is calculated by subtracting the lengths of the critical path and the longest path from the previous stage to the final stage. Figure 4. In cases where there are multiple previous stages, it is necessary to identify the minimum value in order to prevent delays in subsequent tasks.

$\mathrm{LS} = \mathrm{LF} - \mathrm{D}$

$LS = Late\ Start$

$LF = LateS\ Finish$

$D = \text{Duration}$

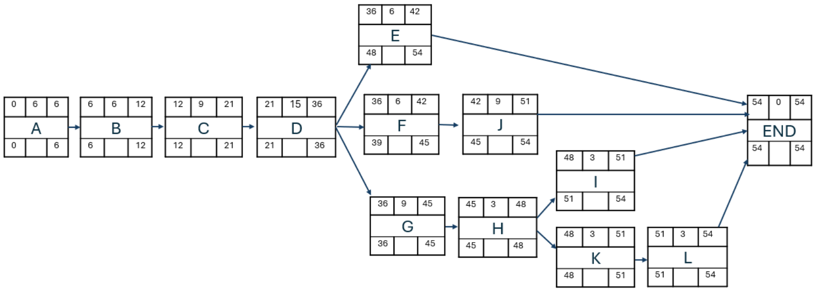


Figure 4. Calculate LS and LF

Calculate Slack represents the degree of schedule flexibility within a project. It refers to the amount of time that a task can be delayed without causing any impact on subsequent tasks or the overall project completion date. Slack is calculated by subtracting the early start date of a stage from its corresponding late start date, as shown in Figure 5.

Slack = LS – ES …. Slack = LF – EF

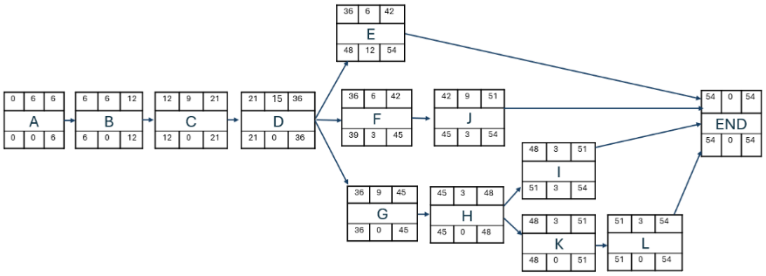


Figure 5. Calculate Slack

The result is that the tasks on the critical path are primarily responsible for the project duration, and any delays in these tasks will result in a delay in the overall project (Figure 6). In addition, the results can be inferred.

Project duration: 54 months.
Critical Path: It includes the following tasks: A, B, C, D, G, H, K, and L. these tasks determine the project duration and cannot be delayed without affecting subsequent tasks or the project completion date.

Near Critical Path: It includes the following tasks: A, B, C, D, H, K, and L. although this path is not critical, any delays in these tasks may affect the project completion date.

Third Critical Path: It includes the following tasks: A, B, C, D, J, K, and L. Although this path is not critical, any delays in these tasks may affect the project completion date.

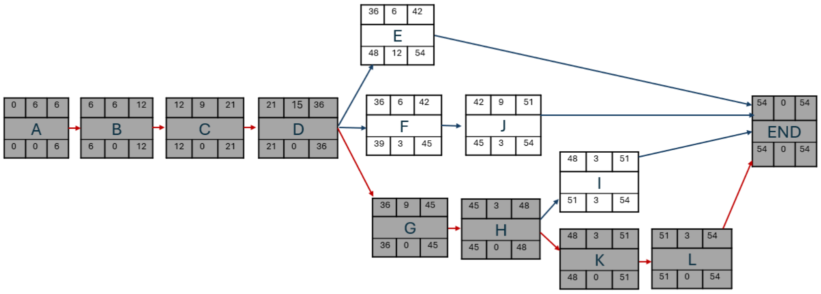


Figure 6. Critical Path for a Network Diagram

All results are detailed in Table (2):

Table 2. Calculating the Completion Time by CPM

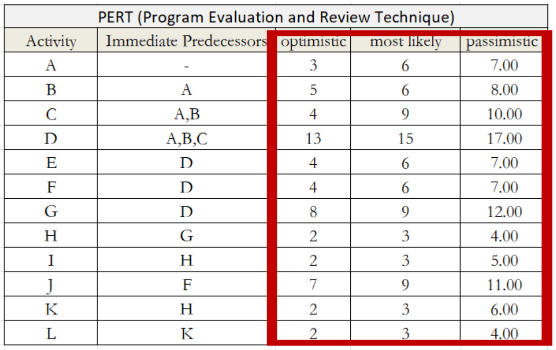
Activate	ES	EF	LF	LS	TF	Criticality
A	0	6	6	0	0	**Critical Path**
B	6	12	12	6	0	
C	12	21	21	12	0	
D	21	36	36	21	0	
G	36	45	45	36	0	
H	45	48	48	45	0	
K	48	51	51	48	0	
L	51	54	54	51	0	
F	36	42	45	39	3	**Near critical Path**
I	48	51	54	51	3	
J	42	51	54	45	3	
E	36	42	54	48	12	**Third critical Path**

3.1.4 Project Evaluation and Review Technique (PERT)

PERT (Project Evaluation Review Technique) method Like the CPM method, PERT also uses an arrow chart to illustrate the project's trajectory. In terms of understanding and calculation, critical activity is the same; the critical path or floating in PERT is known as slack. The difference between CPM and PERT, which is clearly visible, is in the estimation of activity duration. In PERT, time estimates are used to account for uncertainty and variability in activity durations. Instead of a single deterministic time estimate, PERT employs three different time estimates, as shown in Table (3).

- Optimistic time: This represents the shortest possible time in which an activity can be completed under ideal conditions.
- Most likely time: This is the estimated time that an activity would typically take under normal circumstances.
- Pessimistic time: This represents the longest possible time needed to complete an activity considering potential delays or obstacles.

Table 3. Optimistic Time, Most Likely Time, Pessimistic Time. (PERT Technique)



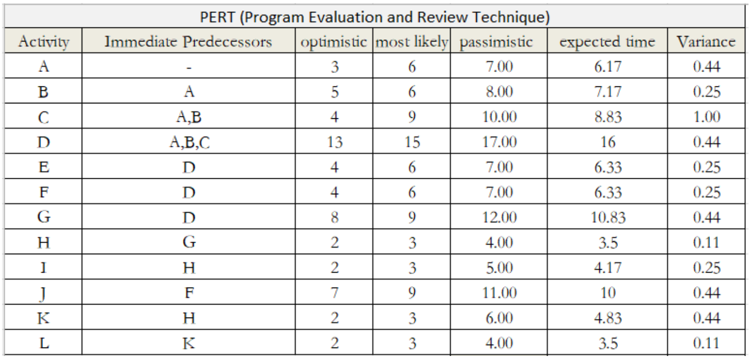
PERT (Program Evaluation and Review Technique)				
Activity	Immediate Predecessors	optimistic	most likely	passimistic
A	-	3	6	7.00
B	A	5	6	8.00
C	A,B	4	9	10.00
D	A,B,C	13	15	17.00
E	D	4	6	7.00
F	D	4	6	7.00
G	D	8	9	12.00
H	G	2	3	4.00
I	H	2	3	5.00
J	F	7	9	11.00
K	H	2	3	6.00
L	K	2	3	4.00

Calculate the expected time and variance. The estimates used in the PERT method are optimistic time (ta), real-time (tm), and pessimistic time (tb). The three estimates are used to determine the expected time (1) and variance σ^2 (2) to calculate the project time risk shown in Table (4).

$$\text{Expected time ;} \qquad te = \frac{ta + 4tm + tb}{6} \tag{1}$$

$$\text{Variance;} \qquad \sigma^2 = \left[\frac{ta + tb}{6}\right]^2 \tag{2}$$

Table 4. Calculate Expected time and Variance.



PERT (Program Evaluation and Review Technique)						
Activity	Immediate Predecessors	optimistic	most likely	passimistic	expected time	Variance
A	-	3	6	7.00	6.17	0.44
B	A	5	6	8.00	7.17	0.25
C	A,B	4	9	10.00	8.83	1.00
D	A,B,C	13	15	17.00	16	0.44
E	D	4	6	7.00	6.33	0.25
F	D	4	6	7.00	6.33	0.25
G	D	8	9	12.00	10.83	0.44
H	G	2	3	4.00	3.5	0.11
I	H	2	3	5.00	4.17	0.25
J	F	7	9	11.00	10	0.44
K	H	2	3	6.00	4.83	0.44
L	K	2	3	4.00	3.5	0.11

The expected time in PERT provides an estimate of the average duration for each activity in the project. It considers optimistic, most likely, and pessimistic time estimates. After using the mathematical equation for expected time, it appears to us that the results are between optimistic time and pessimistic time in Figure (7), so the results are considered correct.Since the horizontal and vertical axes all represent random values, this is to count the values of Optimistic time, Pessimistic time, and Expected time in order to know the relationship between them and whether the values are correct or not.

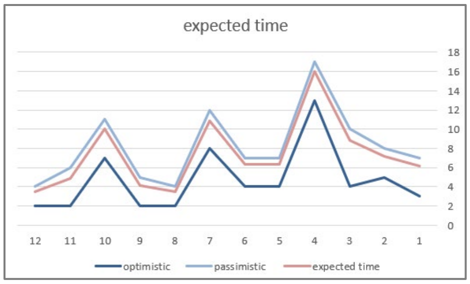


Figure 7. Expected Time Results

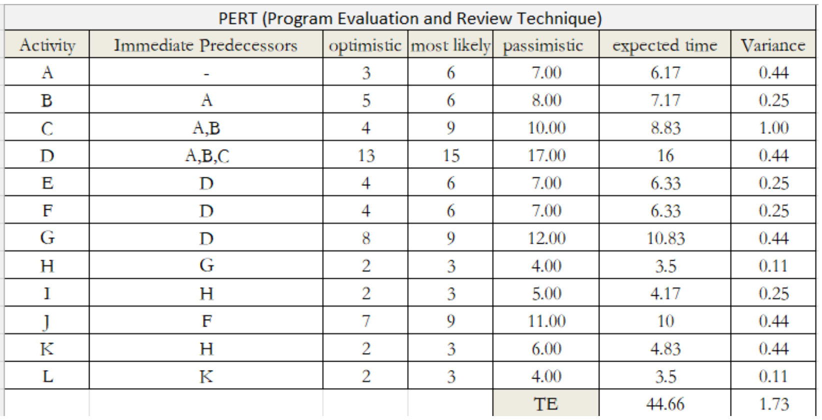
Variance in PERT measures the variability or uncertainty associated with activity durations. It quantifies the spread of possible durations around the expected time. A higher variance indicates a greater level of uncertainty and potential for variation in completing the activities. Variance is calculated using optimistic, most likely, and pessimistic time estimates.

Calculate the total expected time and probability. The sum of expected time and variance is calculated by summing all the elements present in both expected time (3) and variance (4) to use the result of expected time to calculate probabilities (Table 5).

$$TE(\text{Expected time}) = e_1 + e_3 + e_5 \ldots. \tag{3}$$

$$TE(\text{Variance}) = \sqrt{v_1 + v_3 + v_5 \ldots.} \tag{4}$$

Table 5. Calculate Total Expected Time and Variance



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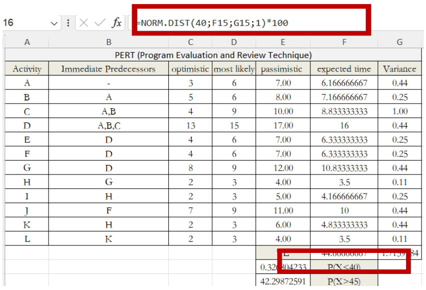
C	A,B	4	9	10.00	8.83	1.00
D	A,B,C	13	15	17.00	16	0.44
E	D	4	6	7.00	6.33	0.25
F	D	4	6	7.00	6.33	0.25
G	D	8	9	12.00	10.83	0.44
H	G	2	3	4.00	3.5	0.11
I	H	2	3	5.00	4.17	0.25
J	F	7	9	11.00	10	0.44
K	H	2	3	6.00	4.83	0.44
L	K	2	3	4.00	3.5	0.11
				TE	44.66	1.73

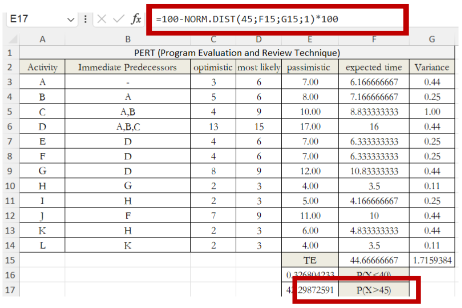
Table 6. Probability calculation, P(X<40)



16 =NORM.DIST(40;F15;G15;1)*100

PERT (Program Evaluation and Review Technique)						
Activity	Immediate Predecessors	optimistic	most likely	passimistic	expected time	Variance
A	-	3	6	7.00	6.166666667	0.44
B	A	5	6	8.00	7.166666667	0.25
C	A,B	4	9	10.00	8.833333333	1.00
D	A,B,C	13	15	17.00	16	0.44
E	D	4	6	7.00	6.333333333	0.25
F	D	4	6	7.00	6.333333333	0.25
G	D	8	9	12.00	10.83333333	0.44
H	G	2	3	4.00	3.5	0.11
I	H	2	3	5.00	4.166666667	0.25
J	F	7	9	11.00	10	0.44
K	H	2	3	6.00	4.833333333	0.44
L	K	2	3	4.00	3.5	0.11
				TE	44.66666667	1.7159384
				0.326804233	P(X<40)	
				42.29872591	P(X>45)	

Table 7. Probability calculation, P(X>45)



E17 =100-NORM.DIST(45;F15;G15;1)*100

	A	B	C	D	E	F	G
1	PERT (Program Evaluation and Review Technique)						
2	Activity	Immediate Predecessors	optimistic	most likely	passimistic	expected time	Variance
3	A	-	3	6	7.00	6.166666667	0.44
4	B	A	5	6	8.00	7.166666667	0.25
5	C	A,B	4	9	10.00	8.833333333	1.00
6	D	A,B,C	13	15	17.00	16	0.44
7	E	D	4	6	7.00	6.333333333	0.25
8	F	D	4	6	7.00	6.333333333	0.25
9	G	D	8	9	12.00	10.83333333	0.44
10	H	G	2	3	4.00	3.5	0.11
11	I	H	2	3	5.00	4.166666667	0.25
12	J	F	7	9	11.00	10	0.44
13	K	H	2	3	6.00	4.833333333	0.44
14	L	K	2	3	4.00	3.5	0.11
15					TE	44.66666667	1.7159384
16					0.326804233	P(X<40)	
17					42.29872591	P(X>45)	

The probabilities are determined based on the total expected time, which equals 44.7. The value of 40 will be determined, as it will indicate the probability that the total time of the project will be less than 40, and the probability of its occurrence will become 32%, as in Table (6), and the value of 45 will be determined, as it will indicate the probability that the total time of the project will be 45, and the probability of it occurring will become 42%, as in Table (7).

expected time ensures that the resulting estimate falls between optimistic and pessimistic times, providing a balanced approach to project scheduling. Variability helps in understanding the level of uncertainty, allowing planning for potential delays and risks. These calculations are essential for identifying critical paths and slack times, ensuring that resources are allocated efficiently and potential delays are managed effectively. The duration of time required to complete the project is 54 months, as obtained from the critical path method calculation. The total duration of 54 months to complete the project is obtained from the sequence of 8 activities in the critical path. These activities need more attention from the project team because if any one or more activities in the critical path are delayed, it will result in a delay in the completion of the project according to a predetermined schedule. Further analysis of the project. schedule using PERT results in a probability of completing the project within 45 months of 45% because the estimated time at PERT estimation is the median of the beta distribution. The PERT method can also use the approach of sigma to look for other probabilities. There is a 68% probability to complete the project within 40 months and a 32% probability to complete the project.

3.2 Economic Study

In this economic study, we assess the cost-effectiveness of a new GIS-based smart waste management system over its projected 20-year service lifetime. The analysis includes a detailed look at the initial costs for purchasing equipment, setting up the system, and training staff. We also estimate the ongoing savings from using less fuel, spending less on labor, and lowering maintenance costs. The analysis is designed to determine the payback period, clarifying the time frame in which the system's accumulated savings will cover the initial investment costs.

3.2.1 Assumption

The system is expected to have a service lifetime of 20 years.

3.2.2 Total Initial Costs

The initial costs for the new system (5) include an equipment investment of SAR 209,750, covering the equipment purchase, maintenance, software, upgrades, and installation. Costs of SAR 30,000 include expenses for labor needed for installation and training staff to operate the new system.

$$Total\ Initial\ Costs\ = Total\ Equipment\ Investment\ +\ Installation\ Costs \tag{5}$$
$$Total\ Initial\ Costs = \ 209{,}750\ SR\ +\ 30{,}000\ SR$$
$$Total\ Initial\ Costs\ =\ 239{,}750\ SR$$

3.2.3 Annual Net Savings

The system's implementation leads to annual savings through reduced operational expenses: fuel consumption drops due to efficient collection routes, saving SAR 30,000; improved collection efficiency cuts labor costs by SAR 20,000; and lower vehicle wear reduces maintenance costs by SAR 10,000. Operational costs remain at SAR 10,000 annually.

The gross annual savings are calculated as in (6):

$$Total\ Annual\ Gross\ Savings\ =\ Fuel\ Savings\ +\ Labor\ Savings\ +\ Maintenance\ Savings \tag{6}$$
$$Total\ Annual\ Gross\ Savings\ =\ 30{,}000\ SR\ +\ 20{,}000\ SR\ +\ 10{,}000\ SR$$
$$Total\ Annual\ Gross\ Savings\ =\ 60{,}000\ SR$$

Subtracting the annual operational costs from the gross savings yields the Annual Net Savings (7):

$$Annual\ Net\ Savings\ =\ Total\ Annual\ Gross\ Savings\ -\ Annual\ Operational\ Costs \tag{7}$$
$$Annual\ Net\ Savings\ =\ 60{,}000\ SR\ -\ 10{,}000\ SR$$
$$Annual\ Net\ Savings\ =\ 50{,}000\ SR$$

3.2.4 Payback Period Calculation

The payback period is the time it takes for the net savings to equal the total initial costs. It is calculated using the formula (8):

$$Payback\ Period\ =\frac{Total\ Initial\ Costs}{Annual\ Net\ Savings} \tag{8}$$
$$Payback\ Period\ =\frac{239{,}750\ SR}{50{,}000\ SR/year}$$
$$Payback\ Period\ =\ 4.795\ years$$

As the system will take approximately 5 years, which is less than its lifetime, to repay itself, the investment is worth the cost.

4. Conclusion

In conclusion, to achieve more efficient and sustainable waste management, it is essential to develop strategies that result in enhanced management of waste operations across the city of Bisha. The research aimed to comprehensively analyze the application of project management techniques alongside an economic analysis of GIS-based system implementation to optimize Bisha's waste management system through improved operational efficiency, economic savings, and environmental sustainability.

The rapid population growth and urban development in Bisha necessitate a sustainable approach to waste management. This paper assesses the effectiveness of a GIS-based smart system using project management techniques and economic analysis. By leveraging GIS technology and project management methodologies like CPM and PERT, cities can better address the challenges posed by increasing solid waste generation. By precisely identifying the critical path and allocating resources to those responsive components, the application of CPM and PERT methodologies in project management has improved efficiency and punctuality and resulted in a 9-month timeline reduction, from 63 months to 54 months. The system's economic analysis indicates a payback period of less than five years, indicating its worth within its expected 20-year lifespan.

The approaches used with the smart waste management system based on GIS analysis provide a valuable tool for city planners and waste management authorities. The system's benefits include improved waste collection routes, reduced operational costs, and enhanced overall cleanliness. Leveraging technical innovations and project management practices will be crucial in realizing efficient, sustainable, and profitable waste management systems not only in Bisha but also in other urban areas facing similar challenges.

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