

A Web-Based GIS Tool for Progress Monitoring of Linear Construction Projects

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Abstract -

Efficient project monitoring is a key to a project's success. Linear construction projects span across large distances and require similar activities to be carried out repeatedly over multiple small segments for project completion. Thus, monitoring their progress becomes challenging. This is a matter of concern since proper progress monitoring can aid in efficient utilization and distribution of project resources. Existing methods of monitoring are either time-consuming, expensive, or require significant human efforts. GIS has been used for monitoring linear projects, but the use has been limited. Therefore, this study aims to explore the potential of using GIS for collecting and visualizing data for enhanced progress monitoring of linear projects. For this purpose, this study proposes a process incorporating GIS and various open-source platforms in the form of a figure. The open-source platforms used are Open Data Kit (ODK) tools, PostgreSQL (and its PostGIS extension), and different JavaScript libraries. The development and illustration of a Web-based GIS tool for progress monitoring of linear projects are the main objectives of the study. Visualization and quantification of project progress using this tool would result in time and cost savings due to reduction in manual efforts expended, manual errors in processing data, and time taken for the process. The developed tool would make progress monitoring easier, faster, and more efficient since site data can be recorded even in the absence of the internet and processed later.

Keywords –

Progress Monitoring, Linear Infrastructure Projects, Geographic Information System, Web-Based Interface, Geospatial, Data Visualization, Open Data Kit (ODK), Leaflet Library, Construction Management, Construction Automation

1 Introduction

Proper management of construction projects can facilitate the timely completion of projects adhering to the required quality, cost, and sustainability [1].

Methods currently available for monitoring the progress of construction projects include manual recording, RFID tags or QR codes, satellite imagery, photogrammetry, Light Detection and Ranging (LiDAR), Global Navigation Satellite System (GNSS), Building Information Modelling (BIM), and Geographic Information System (GIS) [2,3].

However, the management of linear construction projects, for example, road projects, pipeline networks, or cable laying projects, requires a carefully designed progress monitoring process in place and associated control steps to be taken. Monitoring such projects is challenging due to variable workplaces, remote locations, multiple work-sites required to be monitored at once, and repetitive resources being used [4]. Therefore, only some of the methods mentioned above can be efficiently used for linear projects since the other methods either become too expensive, time-consuming or need significant efforts.

The current technologies widely used for monitoring linear construction projects include satellite remote sensing [5], Unmanned Aerial Systems (UAS), BIM, GIS, and a combination of satellite imagery and ArcGIS [6]. However, the progress monitoring cycle of linear projects could be improved by automating the complete process, which is currently being implemented only for structural components in buildings [3].

The use of GIS in linear project monitoring has been limited compared to its use in monitoring other types of construction projects. 4D GIS was used only to consider the effect of surroundings on the project in many cases and for the concept of time and schedules in the monitoring process along with 3D data [7].

Therefore, the potential of using GIS for collecting data related to the work done in linear projects and visualization of their progress should be explored. A study showed the potential of using Web-based GIS as a powerful visualization tool for utility management [8].

Hence, the current study explores the option of utilizing a web-based approach for monitoring linear projects. The primary objectives of this study are

1. To propose a process involving a Web-based GIS-enabled monitoring tool to visualize and quantify progress for monitoring linear construction projects.

2. To develop the tool and to illustrate its utility for monitoring a linear construction project.

In terms of structure, this paper is broadly divided into seven sections. Section 2 briefly describes the methods currently used for monitoring linear construction projects. The proposed process for incorporating a Web-based GIS tool for monitoring linear projects is presented in Section 3. Section 4 elaborates the design and development of this tool. The various open-source resources used for developing the tool are described in this section. Section 5 and 6 discuss the results of a case study, and the advantages and limitations of the developed tool, respectively. Finally, the study is concluded in Section 7, with the future scope of work.

2 State-of-art in Linear Construction Projects Monitoring

Previously, researchers have explored various methods for progress monitoring of linear construction projects involving combinations of several technologies. This section provides a brief review of these methods and studies.

Automated data acquisition technologies were studied, which included the description of a centralized database holding all the data required for project monitoring. This database was capable of hosting data from all possible methods of data collection – RFID, Bar codes, pen-based records, LiDAR, or Photogrammetry, and stored data regarding manpower, material usage, machinery, and images [2]. Efficient management of project data, tracking and control, and construction claims could be facilitated through this database.

Omar et al. studied IT technologies, geospatial technologies, 3D imaging, and augmented reality with respect to various criteria like initial costs, training required for use, and automation level [9]. They concluded that the most suitable technology had to be chosen based on the level of automation, accuracy required, project size, and the specific progress tracking objectives of the project.

Specific studies describing the use of varied technologies for progress monitoring of linear projects have been briefed in the following sub-sections.

2.1 UAS, UAV, and Satellite Imagery

Satellite imagery and ArcGIS were used to monitor the progress of a metro rail project in India using United States Geological Survey (USGS) images corresponding to the initial and final points over the period. These images were subjected to change detection after processing and georeferencing in ArcGIS software [6]. It was concluded that using such visualization techniques

would provide construction data quickly, and project monitoring would become faster.

Using a combination of satellite remote sensing for collecting site images and Location Based Management System for planning for progress monitoring was also demonstrated [5]. A web-based platform was developed to provide the monitoring team with progress charts, location-based progress maps, and line-of-balance diagrams. It worked as an effective supporting visualization method at the macro-monitoring level by displaying the tasks behind and ahead of schedule.

2.2 Combined use of BIM and GIS

Highway Information Modelling (HIM) technology – a combination of BIM and GIS, was adopted for managing a highway project in Malaysia [10]. Data capture was done using ground survey data, LiDAR, satellite imagery, UAV imagery, and Underground Detection Mapping (UDM). The collected data was stored in numerous GIS layers to create a database for information for the design. HIM combines the features of both BIM: physical representation and functional characteristics of the facility and GIS: the associated geolocation, along with time information. Integration was carried out by first converting CAD and BIM data to ArcGIS by converting individual BIM elements to GIS features. Then, WebGIS was used to view the integrated model.

The effectiveness of the technologies and tangible benefits of using BIM+GIS in many methodologies or processes were examined. It was concluded that technology provides optimum benefits only when deployed through a proper and efficient process, modified to suit the project requirements [11].

The integrated use of BIM and GIS, specifically considering the spatiotemporal characteristics, was reviewed. The result of this study was the potential use of BIM+GIS to provide more accurate and dynamic data for decision making and analysis throughout the lifecycle of AEC projects. It had several benefits like improved communication, coordination, significant time and cost savings, and improvement in quality levels and Health, Safety and Environment (HSE) performance [12].

2.3 GIS

Integrating spatial data related to the project with other project information and using an improved system compared to Management Information System (MIS) was considered necessary. A web-based GIS tool was developed for utility management, using open source technologies [8]. This model could help in data management, spatial planning, mapping all the utilities for visualization, and other GIS-related operations.

4D GIS concept for storage and representation of complete project data (drawings, specifications,

resources, and schedules) in a single environment was proposed to visualize progress of construction projects in which Primavera was integrated with GIS, and a 4D model developed [13,14]. As a result, logical errors in schedules, time-space conflicts, and working place restrictions could be identified, and thus cost control could also be achieved. However, the focus was only on the visualization of major structural activities in buildings. Also, automating the maintenance of schedules and drawings is necessary for constructability review and project planning, and this can be achieved by integrating CAD and other available data [1].

Having an open-source GIS environment can ensure that all data can be utilized by all parties involved in the project in the construction industry [1]. Also, incorporating GIS into progress monitoring brings in the effects of the surroundings on the project scheduling related to repetitive projects [7].

2.4 Miscellaneous Techniques

The combination of Product Lifecycle Management (PLM) and BIM for linear infrastructure construction projects was also proposed for its effective lifecycle management. A digital twin was employed in the process to automate the data transfer between the digital and physical models [15]. This combination would improve the information flow and monitoring quality by establishing digital continuity throughout the value chain.

Monitoring techniques were classified into four broad categories: i) non-spatial progress monitoring, ii) spatial monitoring, iii) indirect methods, and iv) specific studies for transportation and earthwork studies [3]. The study concluded that the existing methods either required too much time, did not have the required accuracy, or were expensive.

The potential use of GIS has not been utilized suitably for progress monitoring of linear construction projects.

Thus, the need to explore and develop a web-based GIS tool specifically for monitoring linear construction projects is the aim of the current study. This tool should be easier and simpler to use, and less expensive. The process for adopting this tool for progress monitoring is explored in the next section.

3 Proposed Process for Progress Monitoring

This section presents a process for monitoring the progress of linear projects incorporating GIS on a web platform, thus creating a Web-based GIS tool, which is proposed in this study. This process requires several tasks to be carried out by three major stakeholders, namely i) the project management team, ii) the project monitoring team, and iii) the project execution team on site. Figure 1 outlines these responsibilities and the order in which the tasks are to be carried out.

The key responsibilities of the monitoring team, as presented in Figure 1, include discussions with the top management to set the project progress goals and to define the monitoring requirements based on these goals. The team then creates a proper medium to enable the people at the site to fill the data, creates a medium for data storage, creates a method to visualize this data and, analyzes and interprets the data. They can also provide suggestions to the top management to improve the rate of execution on site. The execution team at the site should have access to these mediums to update project data as per the predetermined monitoring requirements of the project. Proper coordination and communication between all these teams would facilitate the tool development, its usage and decision-making based on the results from this tool.

The flow of data in this system consists of three main stages, namely data collection, data storage and analysis, and data visualization, as shown in Figure 2.

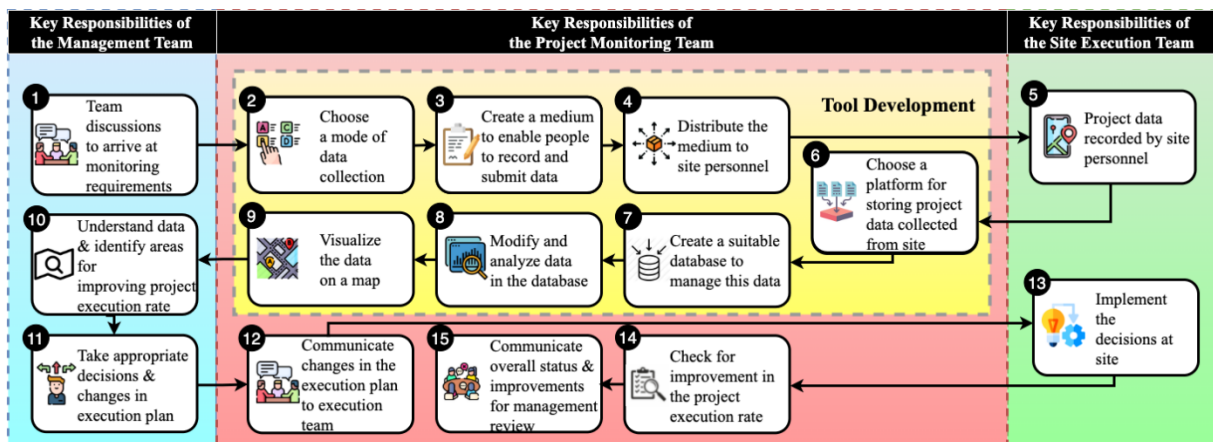


Figure 1. Proposed Process Flow for Progress Monitoring of Projects

First, the monitoring requirements of the management are translated into data entries collectable in a form. This form is then circulated among the people assigned with the responsibility of executing the work at site. As they carry out the project work at site, they can update the related location data in the forms and submit it to the server. The team at the office responsible for monitoring can then access this data and create a database. The Web-based GIS tool for monitoring is then created using the data from this database. This tool creates the visual form of the recorded data along with its numeric form. The use of different open-source resources, as illustrated in Figure 2, is explained in the following sections.

4 Design and Development of the Web-based GIS monitoring tool

After identifying the technical requirements of the process proposed in Figure 1, various open-source resources employed for data collection, data storage and analysis, and data visualization functions of the proposed tool are described in this section.

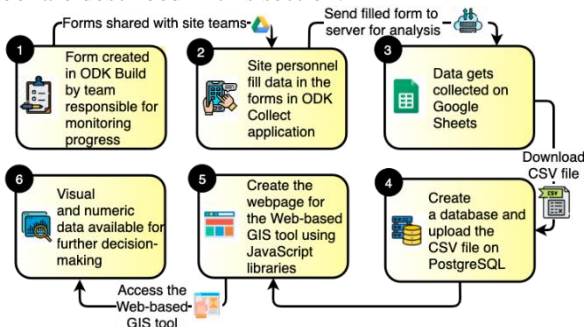


Figure 2. Flow of Data in the Proposed Monitoring System

4.1 Data Acquisition through Open Data Kit (ODK) Tools

Open Data Kit, an open-source platform that can be used to collect data in remote areas, was chosen for collecting data from the site. The data can be stored on the mobile device till the need for submitting the data to the server arises and can be submitted in the presence of internet connectivity. ODK is a collection of tools that can be used for collecting and storing data.

ODK Build was used for creating the forms for data collection. Forms can be made for text, numeric, location (geospatial points, paths, and shapes using GPS location of the device or manual selection from the map), time, and date inputs. In addition, different media, including images, videos, audios, and signatures, can be sought from the user filling the forms. These forms on ODK Collect application enable the people at site to record data like the route name and length, GPS data for points, operational stage, date of data entry, and other comments.

Once the user submits this form to the server, all the data entered by the users gets collected in the designated Google Sheet chosen while creating the form on ODK Build. For further analysis of the data, this Google Sheet was downloaded in a comma-separated value (CSV) format and saved on the computer or the local hard drive, where the Web-based monitoring tool is to be built.

4.2 Database Creation and Management on PostgreSQL and PostGIS

All the data stored in the Google Sheet must be entered in a proper database management system capable of defining, manipulating, handling, and managing all the data stored.

PostgreSQL is an open-source database management system that can manage data collected from various kinds of applications. PostGIS is its spatial extension to enable the storage and spatial querying of geographic data.

A database was created in PostgreSQL, and a table was then created in this database. Using the several data types available in PostgreSQL, different types of data collected from the site can be stored in this table. The data downloaded as a CSV file was then imported into this table. The PostGIS extension enabled the creation of geometry like points and linestrings from the location data and querying on this data represented spatially on the map.

4.3 Data Visualization using JavaScript Libraries (NodeJS and Leaflet Library)

Various JavaScript libraries were used to render the Web-based GIS tool utilizing the data stored on the PostgreSQL database. NodeJS environment, an open-source JavaScript environment, was used to set up maps on a webpage using the data delivered dynamically based on the queries generated using PostgreSQL. The base map in the webpage, which displays the required data related to the routes, was rendered using Leaflet library, a mapping application in JavaScript.

The Web-based GIS platform connects to the PostgreSQL database, queries it using PostGIS, and returns the results in a GeoJSON format, an open standard geospatial data interchange format. These results can then be passed to the client to be viewed in a map rendered by Leaflet. Data in GeoJSON format can be used to represent geographic features with their non-spatial attributes (properties).

The 'Leaflet Routing Machine' library available in Leaflet enables the identification of routes between the recorded points, calculates the distance between the points, and allows color-coding of routes based on the route properties.

Pug template engine was used for creating the view of the map. Code was written to create filters that work based on the properties of the data in the database.

A table was designed to display all the required information from the database on the tool interface. The columns of this table were chosen from those in the table created on the database. Code was written in Pug for creating this table, and the GeoJSON data fetched after querying enables the table to be filled with appropriate data. The working of the developed Web-based GIS tool is presented in the next section.

5 Experimental Work and Results

This Web-based tool is capable of displaying the progress of two types of projects:

1. Projects like transmission line projects, where the shortest distance between the points is considered as the route length (referred to as Type I projects)
2. Projects like cable laying, road laying, and pipeline projects, where the distance between the points along specific routes is considered the route length (referred to as Type II projects).

Each project stage can be represented in different colors as shown in Figure 3 – where red, blue and, green colors indicate routes along which work has not yet started, work is in progress, and work has been completed, respectively or as shown in Figure 4 – where black, and blue routes indicate planned work and completed work along that route, respectively. The placemarks indicate the intermediate points as per the collected data.

The main activities in the execution of a typical cable laying project include A1: transportation of cables to the site, A2: site clearing, A3: trench excavation or road cutting for laying the cables, A4: laying of a sand bed, A5: cable laying, A6: covering the trench with cover tiles, A7: installation of warning tape, A8: backfilling the trench or road restoration works, A9: repair of damaged underground utility (if any), and A10: shifting of excess soil and installation of related electrical equipment. Figure 5 shows the images representing some of the stages indicated above. Each of these stages can be represented in a different color on the Web-based tool.

Using the ODK Tools, data related to the work executed in a project was collected in Google Sheets. This sheet was then downloaded in CSV format and uploaded to the PostgreSQL database. Using NodeJS and Leaflet, a webpage that functions as the proposed web-based GIS monitoring tool was developed. The resulting webpage, shown in Figure 6, has features to display progress on a map and its tabular representation. This table has been designed to display the route's name, starting and ending points, the status of work execution, the planned and the actual executed length along these routes, and the percentage of work completed along these routes.

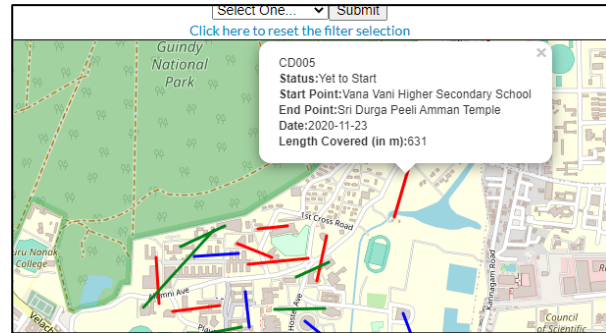


Figure 3. Web-Based GIS Tool for Type I Project

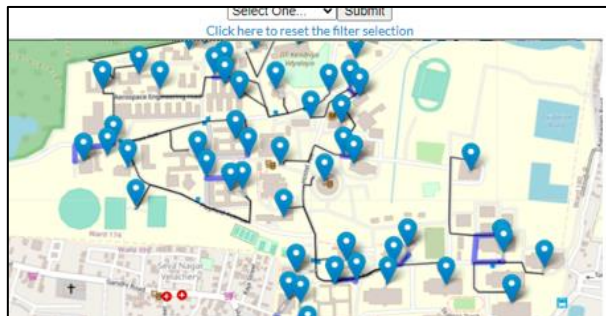


Figure 4. Web-Based GIS Tool for Type II Project

The filters at the top of the page allow the user to choose routes based on any predetermined criteria. For example, filters were created in this study to enable users to select routes based on their execution status or name.

The code can be modified to create as many filters as required to suit the project monitoring requirements (E.g., based on the reason for delay). The filters used in this study have been shown in Figure 7 and Figure 8. Here the cable drum number indicates the name of the routes in the project. On selecting the status as 'Yet to Start' in the first filter, the result is as shown in Figure 7. Only black lines displayed indicate that no work has started yet. Figure 9 also shows the result of choosing 'CD016' in the route name filter. The black path is the planned route, and the blue path (along with the marker) indicates the completed work. On clicking on any placemark, the corresponding route details are displayed in a pop-up. In this study, the pop-up has the route name, execution status, the name of the start and endpoints, and the date on which the route was last modified. The details for the routes CD016 can be seen by clicking on the placemarks on the route.

Along with the representation of the route data on a map, the progress is quantified as well. The progress in the percentage of work complete for the selection using filters or for all the routes is presented in the table below the map as illustrated and highlighted in Figure 6. The percentage of work done along each route is calculated using Equation 1.

$$\text{Percentage completion along each route} = \frac{\text{Work completed along the specific route}}{\text{Total work planned along the same route}} \times 100 \quad (1)$$

Similarly, the overall percentage of work done along all routes is calculated using Equation 2.

$$\text{Project level percentage completion of work} = \frac{\text{Work completed along all the routes}}{\text{Total work planned along all the routes}} \times 100 \quad (2)$$

This calculation enables the user to understand the level of work completed at the project level and identify the pace of execution.

The Web-based GIS monitoring tool, thus developed, provides information to enable the project managers or monitoring team to make several kinds of decisions, as elaborated in the following section.

6 Discussion

This section of the paper deals with the functions and evaluation of the developed tool. The tool has been designed to display information to cater to various monitoring requirements of any linear project.

6.1 The Web-based GIS Tool as a Decision Support System

The possible decisions that can be taken based on the visual and the tabular representation of site data on the tool, followed by related communication with execution

and planning teams from the site, can be regarding management of (i) materials, (ii) manpower, (iii) machinery, (iv) project budget, (v) schedules, and (vi) project scope.

Appropriate interpretation of data on the tool can facilitate better material handling. For example, in areas where delays are due to shortage or where there are excess materials, the team can direct more materials for work completion or redistribute them to other areas to avoid wastage, respectively.

Identification of the areas requiring immediate action has been facilitated on the tool using filters based on the status of work execution. The monitoring team can focus on these areas to determine the exact reason for the delay and take necessary actions to expedite the project execution.

Also, based on the actual progress, updated cost estimates can be prepared to indicate the need for any changes in budget allocation of project resources for successful completion.

Manpower and machinery can also be reallocated based on the current requirements at the site, from the routes along which work is completed to other routes depending on the requirements, i.e., strategic placement of resources is enabled.

Updated schedules can be prepared, and the revised deadlines can be decided based on the responses from the site to ensure that project milestones are met on time.

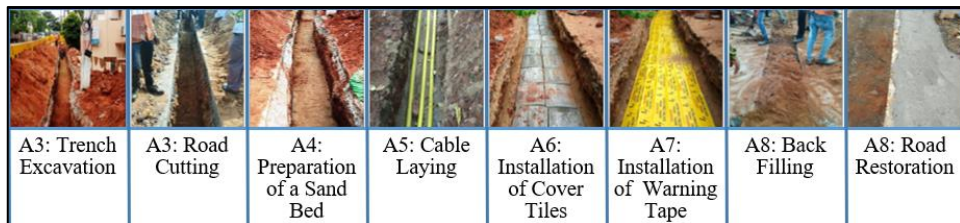


Figure 5. Stages in the Execution of a Typical Cable Laying Project

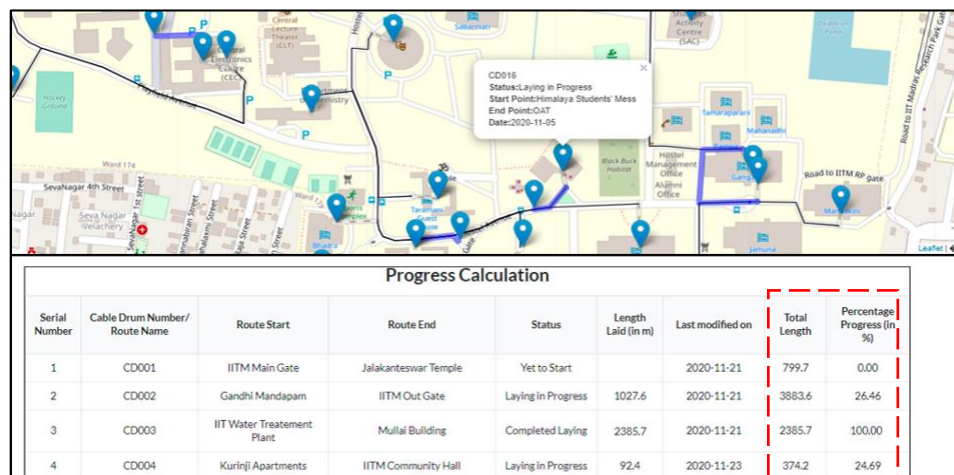


Figure 6. Visual Representation along with the Numeric Representation of Work Progress for a Type II Project

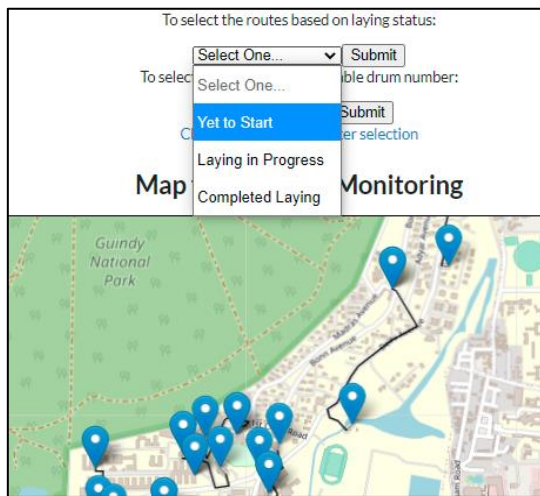


Figure 7. Results for Choosing 'Yet to Start' in the First Filter

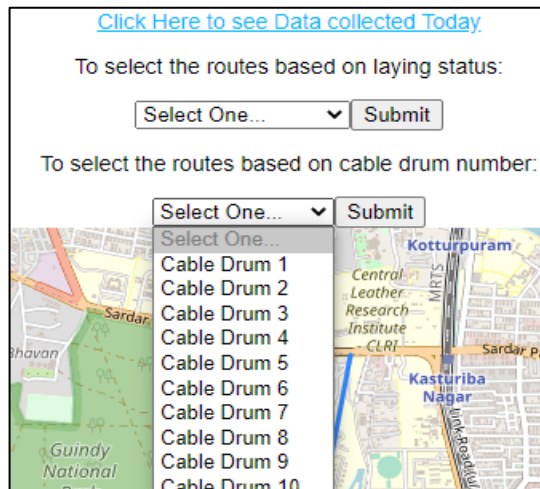


Figure 8. Filter based on Route Name

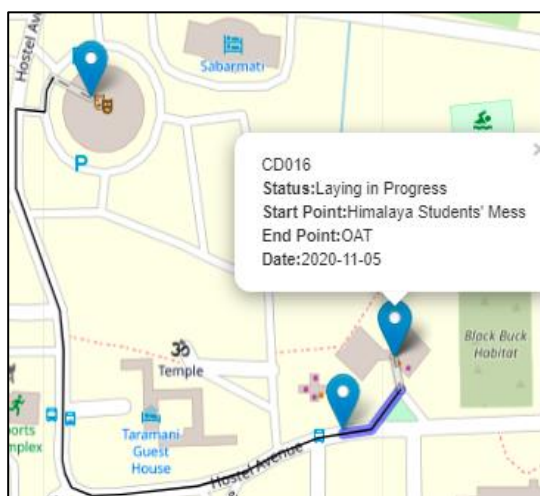


Figure 9. Results for Choosing 'CD016' in the Second Filter

Scope management is facilitated since any deviations in executed routes can be identified from the map and checked immediately to ensure that the work executed aligns with the project scope. If these deviations are not as agreed, the site personnel can be instructed immediately to undertake the route corrections required to meet the project scope.

Hence, the Web-based GIS monitoring tool provides information about various project management aspects.

6.2 Advantages and challenges of using the tool over conventional methods

- The tool and open-source applications are easy to use, and users can quickly be trained to use the tool.
- Data for progress monitoring can be recorded by the site personnel on the application, even in the absence of Wi-Fi or mobile data, making data collection robust.
- Progress of the project can be seen both in visual and numeric forms and at route level and overall project level on a single interface.
- Due to the inclusion of the spatial aspect in the management tool, all the project participants can have the same interpretation of the project work done.

The tool, hence, increases the reliability and robustness of the progress monitoring process.

The developed tool, at the current stage of development, has few limitations as well. Currently, the data is manually downloaded from Google Sheets and imported into the PostgreSQL database to visualize and analyze it. This process can be automated in the future.

Thus, this tool would serve as a quick guide to the project management teams to monitor the project progress. Its functions provide the possibility of overcoming the existing shortcomings with the current techniques of progress monitoring.

7 Conclusion

Since proper progress monitoring of projects would aid effective utilization and distribution of project resources, it is essential for construction projects. So, this study focussed on developing a process involving the management, monitoring team, and site personnel to improve progress monitoring, specifically for linear construction projects.

The potential of GIS for monitoring was explored, and a web-based GIS tool for progress monitoring of linear construction projects was designed and developed. The potential uses and outcomes of the tool have been explored by providing an illustration of the tool.

The key finding of this study is that by integrating existing technologies like Web-based interface and GIS, progress, of linear projects in particular, can be monitored in a systematic manner. A realistic perspective of the executed work is provided by the tool, along with support for decision-making by providing accurate information. Various open-source resources have made the development of this tool possible.

An inexpensive, fast, and accurate tool that can serve as an information system for decision-making has been developed. This information system can assist project managers in making the required decisions regarding supply chain management, resource allocation, cost analysis, schedule analysis, and scope management.

Consolidated project data for all the projects undertaken by a contractor can be maintained at a single interface using the tool. The data related to each project can be accessed using a filter indicating the project they belong to. Monitoring at the project level and the organization level would, thus, be facilitated.

In the future, the study aims to make the tool completely automated to increase the tool's efficiency for progress monitoring of linear projects. In addition, the integration of data collected from the site and data from management teams at the office, such as reports for resource planning and allocation, would enable the transformation of this information system into a decision support system.

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