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RESEARCH ARTICLE

A Framework for Integrating Green Highway Performance Data with the Carbon Footprint Calculator in Malaysia

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Abstract

Highway concessionaires in Malaysia spend considerable assets in collecting, analysing and controlling different forms of data during highway projects' life cycle. Considering this massive investment, nowadays the data use and information system reliability is becoming the key concern in terms of delivering value to consumers as opposed to the amount generated. The data generated is extensive and heterogeneous. This paper provides a new paradigm for integrating green highway performance data with carbon footprint data for green highway assessment. This framework is used to improve the active use of data in the generation of information and to assist comprehensively in decision-making at all levels of management. The network approach used in this study is the main component for interlinking data with knowledge and decisions, identifying the parameters of data integration for green highway assessment, determining the criteria data for integration, and assessing the overall performance of data usage. Real-time green highway data scenarios are used to demonstrate the applicability of this framework. A new monitoring performance measure called the MyGHI-Dashboard is proposed to control green highway assessment processes and evaluate the level of data usage, which will serve as a green highway performance scorecard. Through data-driven insights, this new paradigm can be used as a benchmarking model by highway authorities to make efficient and accurate decisions. This study is expected to become the central reference to mitigate the challenge associated with the use of highway performance data in real-time for Malaysian highway development.

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Keywords

Big Data Integration; Carbon Footprint; Decision Making; Framework Development; Green Highway Rating System

Introduction

Malaysia together with other world leaders adopted the 2030 agenda for sustainable development, the agenda has highlighted the importance of sustainability in infrastructure (Mahidin, 2016). Besides that, with the revolution of industry 4.0 has emerged the advancement of technology which offers advanced data storage, management, and analysis (Prabowo, Rustendi and Nurbaiti, 2020; Yousif, et al., 2022b). With the extensive use of recent technology, the amount of data produced by the construction industry increased significantly. The massive explosion of information, therefore, leads to the trend of big data integration which is intended to reshape the construction like never before (Wang and Kim, 2019). As the industry is focused on increasing efficiency and sustainable practices, despite the value it provides, there is a certain appeal to accept data integration (Ismail, Bandi and Maaz, 2018).

Malaysia has become a high-income nation, so national development strategies and plans must be synchronized and driven with the global major wave, especially climate change (Wahid, et al., 2019). Research aimed at contributing to the country's rewards in particular towards the country's carbon reduction, which was expected to reduce by 45% by 2030 (Yousif, et al., 2018). With increasing urbanization and living standards of people in Malaysia, there is a certainty that there will be a substantial increase in human activities hence mobility via highway networks (Ramlia, et al., 2019).

Highways are among the country's most crucial infrastructures, and they play a critical function in a country's social and economic growth. Malaysian Highway Authority (MHA) is the highways authority served under the government and is committed to contributing to the Government's target for Greenhouse Gas (GHG) emissions reductions (Mohamed, et al., 2017). The introduction of the "Malaysian Green Highway Index (MyGHI scoring)" in 2014 outlines in-depth the scope of points for sustainable practices. However, MHA, concessionaire, and University Technology Malaysia (UTM) extend their study to a holistic assessment of the impact of Malaysian highways on the environment. They establish the Carbon Footprint Calculator (CFC) to calculate the greenhouse gases emissions and to assess the impact on the national environment. In 2017, 150 governments signed the Paris Climate Agreement. This proves that environmental awareness and preservation have become the agenda in developed countries. These initiatives have been adopted in line with the National Green Technology Strategy to ensure that the path to sustainable growth will make substantial progress in addition to the existing reforms, especially in the construction industry (Wahid, et al., 2019).

Highways are also among the facilities that help with human mobility. Malaysia has 31 tolled highways with an overall length of 1,988.6 kilometres, according to statistics provided by the (MHA, 2016). To meet the growing demand from road users, it is expected that the number of highways and overall length covered would expand, resulting in an increase of highway building operations and corresponding additional carbon emissions in the environment.

Once the number of building projects increased over time, a large amount of data was generated. Because the data from MyGHI scoring and CFC are varied and extensive, evidence suggests they need to be integrated, managed, and analysed (Yousif, et al., 2022a). Data integration and its implementation are among the fastest-growing developments in many sectors (Guo, et al., 2021). Data integration can be described as a set of digital technology that can manage, analyse, and maintain more data than was previously managed. With this innovative new generation, data can be effectively collected and analysed (Sjarov and Franke, 2022). The adoption of data integration technologies in an optimum manner would indisputably be the next frontier of innovation in the construction industry. It is difficult to manage these data efficiently using the current data collection and processing techniques, hence data integration technology needs to be implemented (Foote, 2019).

Recently, the digital technology boom has reached Malaysia. Subramaniam, Ismail and Mohd Rani (2021) suggest this has encouraged the government to ensure that Malaysia will be one of the world's biggest information systems competitors during the next century. In this era, the accelerated advancement of Information and Communication Technology (ICT) is very important due to the growing number of users sharing data (Yousif and Zakaria, 2022a). The Construction Industry Transformation Plan 2016-2020 defines the Malaysian construction industry's scope, aiming to increase productivity via the use of data technologies. Consequently, this author notes the need for substantial research in this field. Despite its importance, data analytics and integration are still novel, expanding topics in the Architecture, Engineering, and Construction (AEC) industry. With the growing digitalization of sustainable construction projects, data integration and analytics are unavoidable in the AEC to reap the full advantages of digitization initiatives. Historically, the AEC industry has struggled with several barriers to the implementation of information technology solutions, including cultural resistance to change, cost, and data-sharing concerns (Elhendawi, et al., 2019). Dealing with the data for both projects MyGHI scoring and CFC from the thirty-one highway concessionaires is dealing with substantial heterogeneous data. The data from concessionaires regarding CO2 emissions from each element of CFC plus the scoring obtained for each category, criterion, sub-criteria, and super sub-criteria of MyGHI scoring, are all individual and not easy nor simple to access. As a result, both projects are independent of each other and work as separate entities, despite the need to work as a single entity. Therefore, data integration and visualization will be a critical organizational issue to derive benefit from the data. This research aims to integrate MyGHI scoring and CFC for green highway performance management. To achieve the research aim, the following objectives have been set: identify the parameters of data integration for green highway assessment, determine the criteria data for integration from MyGHI scoring and the CFC, and establish the framework of green highway data integration for web-based programming development. This data integration would include insight on GHG pollution levels to enable the establishment of a stronger pollution management strategy. The data integration for MyGHI scoring and CFC is useful for highway assessment and visualizing performance. It has the power to manage highway data efficiently and has the potential to further reduce energy and carbon emissions. Furthermore, if implemented, it will help to monitor the amount of carbon emission before and after the reduction action.

Background of Research

Trustworthy, high-quality, integrated data is now needed to comply with Malaysia's Construction Industry Development Board (CIDB, 2016) initiatives and the Construction Industry Transformation Program (CITP) aspiration (Portela, Lima and Santos, 2016). Climate change has been recognized as a global problem that requires a comprehensive and up-to-date assessment. This is likely to contribute significantly to the high risk of carbon emission and a big amount of disparate data (Rehman, et al., 2021).

The industry manages important data from various fields during the project life cycle. The primary issue and concerns are, what the definition of this data is, where to extract them, how to process them, and finally how to represent them so that they may be integrated into one platform. What metrics may be used to evaluate this data integration? The capacity to manage vast volumes of data and derive relevant insights from it has transformed society and innovation, resulting in long-term growth. The use of big data analysis in the construction sector is not uncommon, but the use of these technologies in this sector is still in its infancy and lags the widespread use of such technologies in other sectors (Bilal, et al., 2016).

Continuous access to reliable project data is critical to project success. Changing the method of data and information exchange between users is essential for the success of any project. A highway construction project produces a massive amount of complicated, detailed, and professional data. While much effort has been made to address these problems, weak coordination and information uncertainty in the construction industry remains an unsolved issue (Yousif, et al., 2018).

This time of uncertainty has led to increasing calls to put forth data management for Malaysian highway as a core development concern. In these emerging days of technological achievement, it is mandatory to develop data-driven decision-making and green assessment tools for highway projects by using the data integration framework. The current scenario of the type of problems that related to data management in highway projects is the lack of data storage, management, and analysis for the past decade. There have been several suggested ways to organize data for decision-making benefit (Ekambaram, et al., 2018; Abdul Rahman, et al., 2022). According to Burger (2019), data processing inefficiencies are related to the restricted capacity of working with unstructured data. That is where data integration can be the key to enhancing data use. To this regard, this research focuses on a framework for data integration of the two green highway assessment tools (MyGHI scoring and CFC).

MALAYSIAN GREEN HIGHWAY RATING SYSTEM

On the journey to achieve a green highway, research and efforts to identify the relevant green highway elements and the possibility to apply the green concept in highway development have been undertaken. There are several green rating systems developed like Green Roads, Leadership in Energy and Environmental Design (LEED), Illinois Liveable and Sustainable Transportation (I-LAST) and Green Leadership in Transportation Environmental Sustainability (GreenLITES), (FMLink, 2012). In addition, Malaysia conjointly has the green road rating system that is Malaysian Green Highway Index (MyGHI scoring). It is the rating system that proposed sustainable highways and an assessment framework to measure the green performance of highways (Zakaria, et al., 2012). The tool also covers the fundamental elements of green highway development that are suitable for the tropical region. Ismail et al. (2013) investigated the essential aspects of Malaysia's green highway. Twenty-five green highway elements were identified and grouped in six categories, these being energy efficiency, water preservation, waste minimization, materials, landscaping, and ecology.

The formation of MyGHI scoring in 2014 was well-suited to the situation and attributes of Malaysian highways, as it compensates for other global highway green tools. Malaysia's highway authority has achieved a significant move forward in green technology by launching a series of projects aimed at making highways more sustainable (Gara, et al., 2021). There are five main categories in MyGHI scoring: Energy Efficiency, Social and Safety, Environmental and Water Management, Sustainable Design and Construction Activities, and Material and Technology. The establishment of the scorecard certification and the carbon footprint calculator may be used to assess the green performance of the highway (Seng, 2018).

Data management is an indispensable requirement to enhance the evaluation of data efficiency. At present, MyGHI scoring data in different structural forms are stored in different databases, including formatted report data stored in the system, text data stored on the computer, tabular data, picture data, and various project data stored in papers (Adzar, et al., 2019b). This assessment uses a different procedure than CFC, is presented in a hard copy format, and takes a long time to complete. The evaluation documents, as well as all other information, must be completed in both hardcopy and softcopy and delivered to the authorities.

MALAYSIAN HIGHWAY CARBON FOOTPRINT CALCULATOR

A carbon footprint calculator is commonly used to calculate the total amount of Carbon Dioxide (CO2). It can be defined as the total amount of GHGs (direct and indirect) emitted over the life cycle of the highway

(Asian Development Bank, 2010). Carbon dioxide is considered a dominant factor in climate change (Hulail, Ayob and Omar, 2016). The transport industry releases significant volumes of GHG during the life cycle of highway projects, including the manufacture of materials, construction, operation, and maintenance of the highways. The emission of these gases is caused by human activities that are intensely harmful to the environment such as the burning of fossil fuels to produce new material, transportation fuel combustion, and electricity generation (Chen, et al., 2017).

Carbon footprint technology is still emerging as a means of benchmarking and comparison, especially regarding the precision of calculations and the consistency of measurement methods (Li, et al., 2021; Valls-Val and Bovea, 2021). Nevertheless, the implications of personal decisions must be discussed in further depth until a normative definition of responsible action towards emission reductions is developed (Kar, et al., 2015). The CFC will calculate carbon footprint pollution in the unit of tons of equivalent carbon dioxide (t CO2-eq / km-lane). This instrument will also provide a viewpoint on GHG pollution trends that can be used to develop a better strategy for managing green highways in Malaysia (Adzar, et al., 2019a).

Various strategies for lowering pollutant emissions such as the use of eco-tax and carbon tax have been introduced in different countries to encourage low environmental impact practices. Such methods of reducing emissions require accurate calculation (Chong and Wang, 2017). Therefore, the development of MyGHI scoring and the CFC tools allow each participant (investor, concessionaire, and authority) to measure, manage and obtain reports on their highways' green performances.

In this regard, MHA is becoming more accountable for the social and environmental issues that arise as a result of its concessionaire's and subcontractors' operations inside the logistics chain. Globalization and industrialization are continually rising, putting substantial pressures on ecological and sustainable logistics. Nowadays, the focus is mostly on minimizing the carbon footprint of the highway lifecycle to enhance supply chain performance (Ren, et al., 2020). An example of sustainable logistics is the analysis and support of sustainable initiatives, sustainable transportation, sustainable construction, sustainable operation, reverse logistics, and design and control of sustainable supply chain activities (Wang, et al., 2018). Green logistics is the key feature and primary structure of the circular economy. Green logistics is a paradigm that integrates resources with projects, as well as projects with customers. Integrating green logistics with digitization would result in the country's long-term growth, with benefits such as minimizing carbon emissions and more effective data optimization. Digital logistics is an effective and risk-free approach to incorporating sustainability components into highway development supply chain management (Richnák and Gubová, 2021) and Construction Management.

Data Integration of Green Highway Assessment

Understanding and evaluating data relationships by integration, is important because the use and meaning of data and information often intersect and are used interchangeable. Hence the need to make a distinction in the research should be addressed. Data hierarchy, often recognized as the data, information, knowledge and wisdom is among the crucial systems used in the literature on data and information management. It explains the hierarchical and practical relationship between data and information with the simple premise that data is the backbone to produce information, and therefore information is utilized to produce knowledge. Consequently, in effect, knowledge finally establishes wisdom (Lytras, et al., 2021). Depending on the definition of the structure of knowledge adapted from Peiffer (2016); Berengueres (2020); Yasaka (2020), the hierarchy of information in this research is adjusted into three categories, as shown in Table 1.

A three-tiered structure is built using the categories above to clarify the principle of data integration in the processing and analysis of data relationships, by combining and integrating data into tangible information and insights. This in turn encourages decision-making in a series of graded steps. The structure comprises Tier I raw data (D), Tier II information (I), and Tier III decisions (DM). These three categories

Table 1. Information Hierarchy Entities

Data	Information	Decision
Primary data is obtained during a highway project's life cycle and preserved in datasets.	Data is transmitted, organized, and produced by the standard methods of data analytics. The key performance indicator or extracted results from data analysis is defined as the Information.	The process of selecting or deciding the collection methods builds on the "data-driven" approach, using specific data gathered and information produced from relevant data.

are combined and analysed using centralized collaboration and integrated relationships based on the criteria of the decision-makers. Analysing these categories causes active routes that indicate the extensive use of data that is now being used by highway concessionaires for information generation and decision making.

During analyses, a "bottom-up" and "top-down" approach is applied to evaluate the system using indicators. A bottom-up technique is used as an internal metric to give visibility into how the three-tiered system integrates raw data, sets of information, and decisions. The top-down technique is utilized as an external metric to clarify the entire system and can be indicative of the nature of the data and information route. The technique will define and evaluate the overall content of the process for data and information by recognizing the interrelation of the routes as one system. Based on this framework and using the routes defined from data and information analysis and integration system, a performance metric, the MyGHI Dashboard, was developed. This Dashboard assists strategic decision-makers at the management level, and users, to determine the efficiency of data use and envision the overall system.

This research strategically implements the network approach as an analytical tool for experimentally evaluating the relationships and their related advantages and influencing data and information for green highway assessment to eventually find solutions to improve decision-making system efficiency and green performance through data-driven perspectives. The research can help determine the most important facts and information or important participant in the decision-making system, analyse the connections and evaluate the green data on highway management.

In the truest sense, data integration requires the deliberate and methodical combining of data from multiple sources, making it more usable and beneficial than ever (Pastore y Piontti, et al., 2019). IBM offers a clear concept that data integration is a mixture of technology and processes utilized to integrate data from different sources into practical and useful information (IBM, 2020). The main concept is that data is transformed into usable and useful information. It is not just about transferring data from one location to another or dumping many avenues of data into a single database. This is about making the data accessible and more functional.

PARAMETERS IDENTIFICATION OF DATA INTEGRATION

Data integration is a little more involved, as it entails making the data useful and common throughout the process. Usually, data ingestion, cleansing, and standardization integrate the data into the process (Sharma, Kumar and Kaswan, 2021; Yousif, et al., 2021). Data integration has five parameters:

- Data velocity: refers to the rate at which new data is produced and the speed at which data flows. This flow can be huge or constant. Velocity indicates the rate of incoming data demanding to be processed.

Data integration now enables data to be analysed while it is being generated, without ever being placed into databases.

- Data veracity: refers to the messiness or trustworthiness of the data. With many forms of data, quality and accuracy are less controllable, but data integration and analytics technology now provides the confidence to work with this type of data.
- Data volume: refers to the vast amounts of data generated. The volume of this data is measured in terabytes, zettabytes, and exabytes. Such significantly large data sets are difficult to preserve and analyse using conventional database technologies. Using data integration technologies, enables the preservation and utilization of these data sets using distributed systems, where bits of the data are processed through various locations and software platforms.
- Data variety: refers to the different types of useable data, whether structured, semi-structured or even unstructured data formats. Many sorts of data can now be harnessed and combined with more conventional, organized data using data integration technologies.
- Data value: refers to the importance of data to the company. The ultimate objective of any data integration project should be to generate value for the company through the analysis.

Given the above parameters, consideration must be given to the method of integration and type of database that will be dealt with. Database integration alternatives include two main approaches, the first one is a fused database and the second is interoperable databases. The first option, the integration approach leads to the establishment of a single database containing all the integrated data; second, the current or newly established databases are connected, and the integration of the data is accomplished using queries offering a view of the connected data. Selection between the two integration approaches is based on several factors and the choice must be made exclusive according to the characteristics of each data integration project. The factors to be addressed include, but according to Durham, Ashuri and Shannon (2018), are not limited to:

- Intentional use of integrated data (to who and to what use).
- Features in current databases and/or information systems.
- Data form and quantity to be integrated.
- Information technology is today available.
- The extent of information technology worker's experience work.
- Distribution of resources that will be allocated to the project.
- Organizational architecture (functional organizational structure).

Another benefit of database integration and consistency is the use of widely agreed data descriptions and standardized system-wide formats. Regardless of the integration approach implemented, a common data dictionary or global standard for data interpretation, representation, distribution, and communication may be essential for data integration (Karanam, et al., 2021). Nonetheless, concessionaires have found several problems in creating and applying data standards and adapting existing legacy data to these new standards. Such challenges include deciding on appropriate data formats, templates, and protocols as there is significant variation in existing databases; getting help from the concessionaire's staff and getting people to adhere to the new standard; and minimizing as much time and money as possible, and enforcing the standards.

DATA INTEGRATION ARCHITECTURE AND PROCESS

The issues of data integration can be properly understood using a layered architecture. The architecture of data integration consists of various layers, so each layer executes a particular function (Vetova, 2021). Data integration architecture comprises 6 layers:

- Ingestion layer: data is given priority and classified in this layer. This layer maintains data flows seamlessly in the layers below.
- Collector layer: this layer carries data from the ingestion layer to the remainder of the data system.
- Processing layer: within this layer, data is interpreted to direct the information towards the intended location.
- Storage layer: the data being analysed is housed in this layer.
- Query layer: the effective analytical analysis occurs in this layer. This layer simply helps to collect the information from the data.
- Visualization layer: users discover the true value of data in this layer through the display method.

The MHA and highway concessionaires play a significant role in collecting and analysing data by conducting research and designing programs to support decisions in highway management. For example, Malaysian Green Highway Index is one of the prominent studies carried out by MHA and UTM (MHA, 2014). The system provides a guideline for collection or main actions to be implemented in the collection, storage, and management of data to help decisions making. As part of data integration, the process sums up five primary tasks and these steps are most compatible with this project as shown in Figure 1. This process has proven its suitability for highway data integration from case studies in the United State of America (USA) (Woldesenbet, Jeong and Park, 2016).

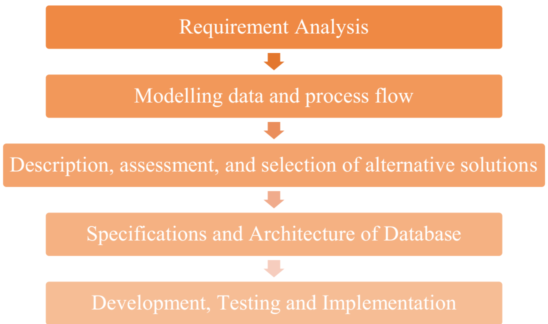

Figure 1. Data integration process (adapted from Woldesenbet, Jeong and Park, 2016)

DETERMINATION OF CRITERIA DATA FOR INTEGRATION

The approach to achieving the determination is demonstrated by assessing real data management. The study utilizes MyGHI scoring and CFC data, information obtained from such data, and green highway management decisions as a conceptual decision-making mechanism for the highway infrastructure.

Development of the integration system and research by MHA and concessionaires together with industry experts, academics, and engineering companies will encourage the MHA to store and maintain highway data. For Malaysian highways authority, green highway data management systems encompass two programs (MyGHI scoring and CFC). Each one of them is unique and both obtain their characteristics, spreadsheets, and databases using conventional and computerized data gathering over the management of the highway infrastructure.

The highway concessionaire collects many sorts of data during the project lifecycle. These data are used for green highway assessment and are generally gathered and analysed by the MHA management system as part of the highway management scheme. The analysis was done by identifying the criteria data of Malaysia's green highway index and CFC. By comparative review, the green assessment data that are relevant to the green highway have been identified in this research. The content analysis was done to understand the variety of data and information on green highway assessment.

In this study, 34 sub-elements of data from MyGHI scoring and CFC were classified into 8 main categories of data sources. A range of information and a representative decision such as project selection, technology implementation, project prioritization, budget allocation, new Policies, etc. are listed as possible players in the MyGHI Fundamental Framework.

Figure 2 and Figure 3 show a summarized overview of the data managed by MHA. In green highway management, these green assessment data will be translated into a functional form and accurate information. The functional form of this information is to assist in the decision-making process and monitor green performance to guide appropriate actions after green initiatives have been implemented. Many of these types of data include the amount of GHG emission, source of emission, the technology utilized in highway construction, sustainable design implementation, and environmental management. Such information is used to help several decisions at different stages and phases during a highway project's life cycle. Accordingly, after identifying the parameters of data integration and determining the criteria data for integration, the next phase of the research is to establish the framework for integrating green highway data.

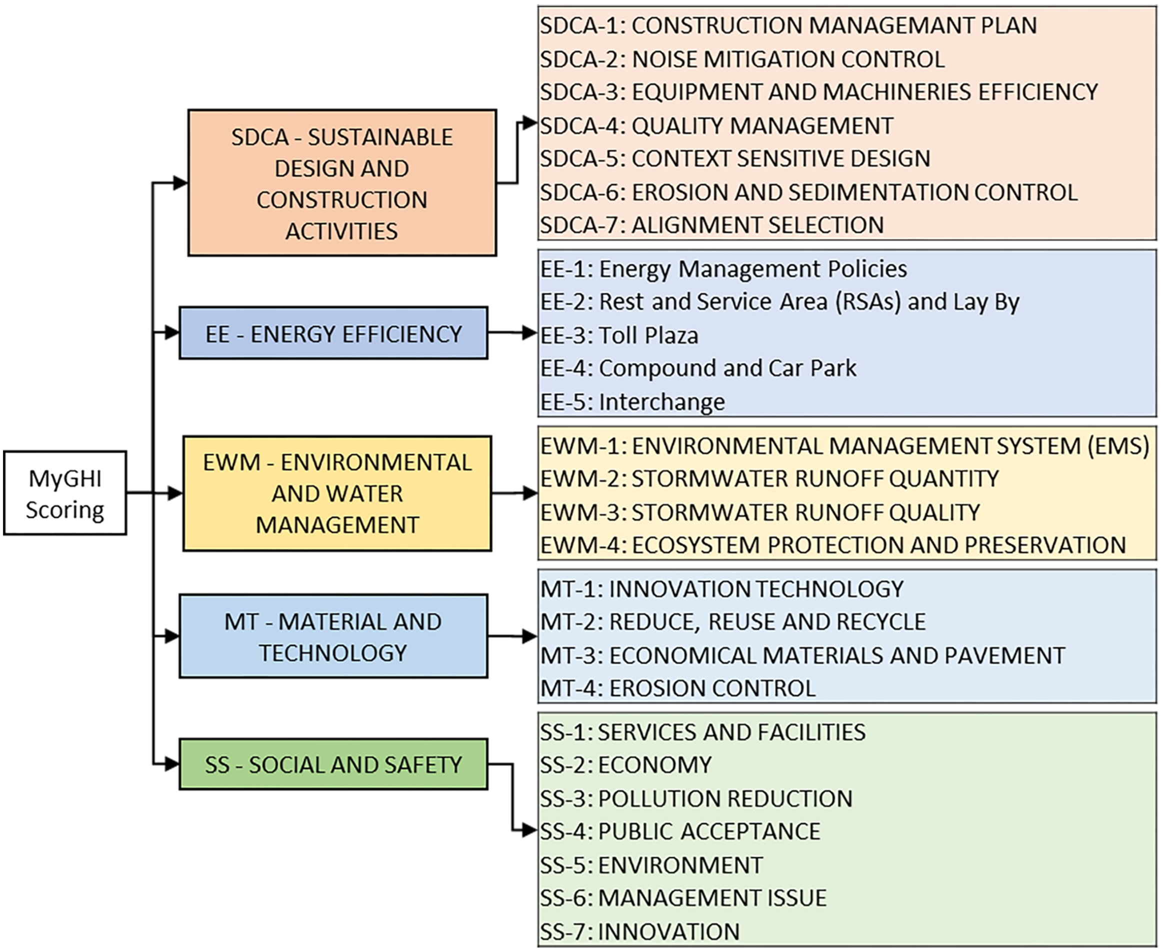

Figure 2. Data for integration from MyGHI scoring

THE FRAMEWORK OF GREEN HIGHWAY DATA INTEGRATION

At the time of writing, diverse data are gathered through project life cycles, placed in various databases, and handled by several highway divisions. Moreover, different forms of decisions are taken through various hierarchies of decision-making and various stages of the project. Meanwhile, data are generated and

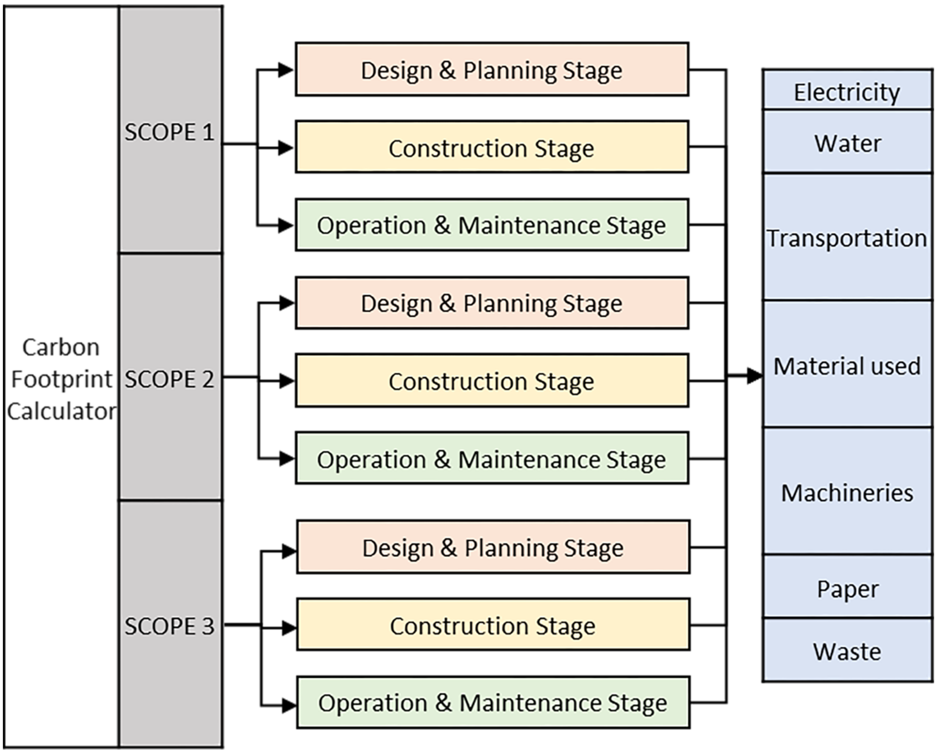

Figure 3. Data for integration from CFC

processed by various divisions or users to match the needs of specific divisions or departments, which causes data and information to be dispersed and sometimes lost or unidentified. However, this research describes the data by its relationships, how the data is linked to other data, whether and how it connects with information in a network system instead of a private network where data are no longer recognized to be autonomous. The data connection can be acquired and evaluated by data integration and visualization with processes of information and decision making.

To clarify the principle of data integration in communication and data analysis, and to support the decision-making process, a three-tiered system for linking and transforming data into useful information is established. The three tiers framework comprises data, information, and decision-making. Using hierarchical collaboration and inclusive relations based on decision makers' requirements, these levels are integrated and interlinked as indicated in Figure 4.

Once these three levels of linking entities have been set up, the framework is utilized as a principle for evaluating the concessioner's highway green performance. As an internal indicator, a bottom-up method is used to get information into how specific data and information are integrated into the framework. This method identifies users' requirements at various levels through the definition of the application and significance of data in enhancing the process of decision making.

Once data are collected and stored, the next step is to accurately analyse and treat them to meet their purpose. Data is intended to create information and take decisions throughout the project's life. This purpose can be reinforced by using applicable and efficient data analysis techniques (Yousif and Zakaria, 2022b). Highway information comprises pavement assessment, financial assessment, carbon footprint, and more (Ait-Lamallam, et al., 2021). Table 2 shows a variety of highways information generated from raw data along with project life.

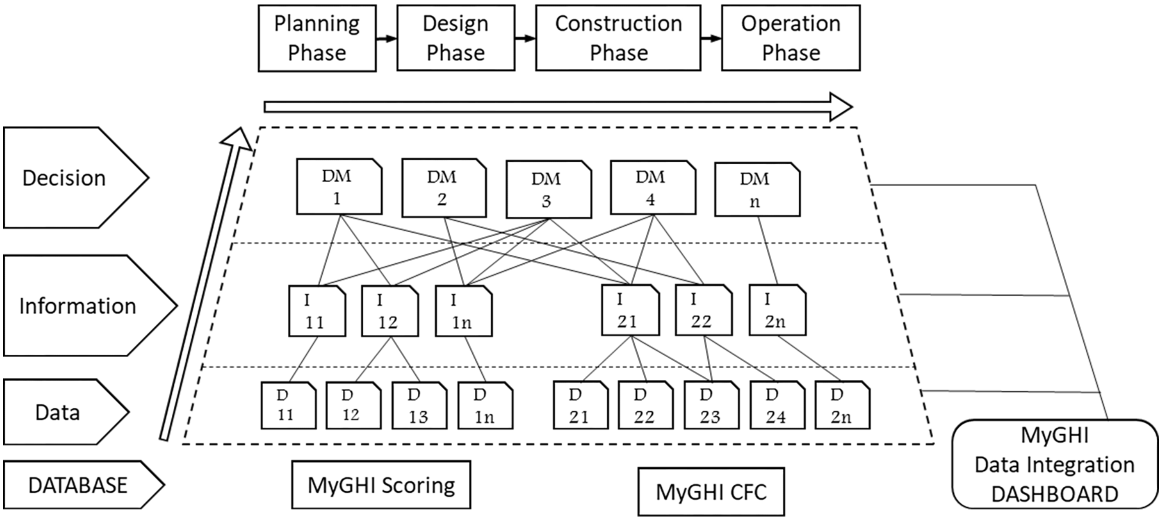

Figure 4. Data, information and decision-making integration framework

Table 2. Example entities of highway infrastructure information

Phase	Information
Planning	Carbon footprint, capacity analysis, financial assessment, transportation traffic assessment, ecological assessment, etc.
Design	Design evaluation, safety and risk assessment, budget allocation, etc.
Construction	Quality assurance, machinery usage, productivity rates, progress reports, variations, etc.
Operation & Maintenance	Green performance, electrical consumption, water consumption, pavement assessment, expenses assessment, benefit assessment, etc.

The information is obtained from highways data, for use in decision support. The principles of decision-making commence with the determination of ways to enhance the highway network by the implementation of green strategies. Vital factors vary, however the growth of the economy, population, transportation, and carbon footprint, are the basis for highway designs. These factors are transformed into long and short highway plans based on available data and information.

Malaysia's national goal from 2016 to 2020 is the Construction Industry Transformation Program (CITP). Its strategic directions are Quality, Safety, Professionalism, Environmental Sustainability, Productivity, and Internationalization, all of which are aimed at transforming the construction sector. In this process, The MHA and concessioners make various decisions ranging from carbon emissions reduction plans to the application of sustainable practices and many more, too extensive to list for their diversity and details. The illustration of decisions made through the highway's project lifetime can be shown in Figure 5. The decisions vary depending on the phase of the project, ranging from the planning phase to the maintenance and operation phase.

To understand the entire integration process, a top-down method is utilized as an external indicator capable of analysing the complexities of the data and information paths. The method is used as a key tool to determine and evaluate the actual performance of the data integration framework by recognizing the interrelationship and connection of the routes as a unified network. A performance indicator, the MyGHI

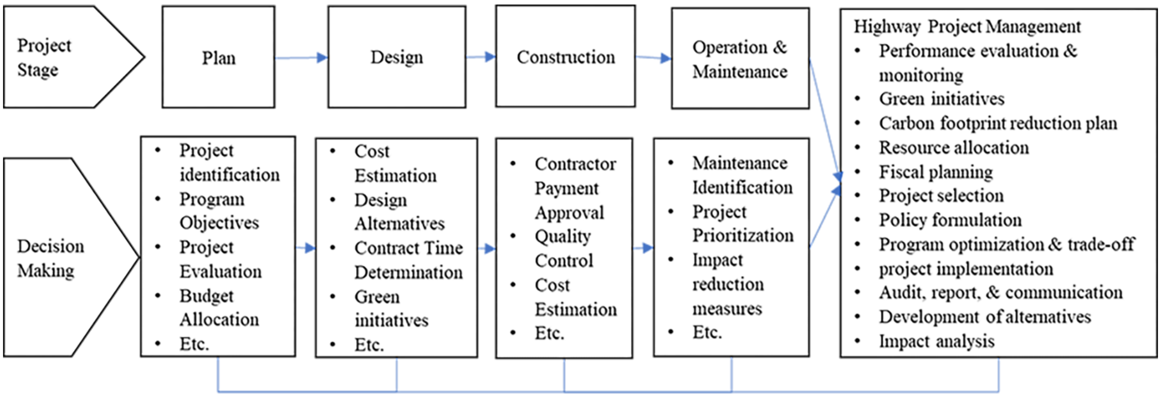

Figure 5. Highway development decisions map

Dashboard, has been established based on the framework developed. MyGHI Dashboard can support the decisions process, efficiently manage highway information, and provide a visualizer to display highway green performance. This dashboard is an information management tool that visually tracks, analyses, and displays key performance indicators, metrics, and key data points to monitor the highway performance, department, or specific process. It is customizable to meet the specific needs of the Malaysian highways authority to effectively manage the green highway development.

Data-driven decision-making through the integration of both projects is the catalyst of making organizational decisions based on actual data rather than intuition or observation alone. When used, the data and information integration will lead to a solid decision through the project lifecycle as shown in Figure 6.

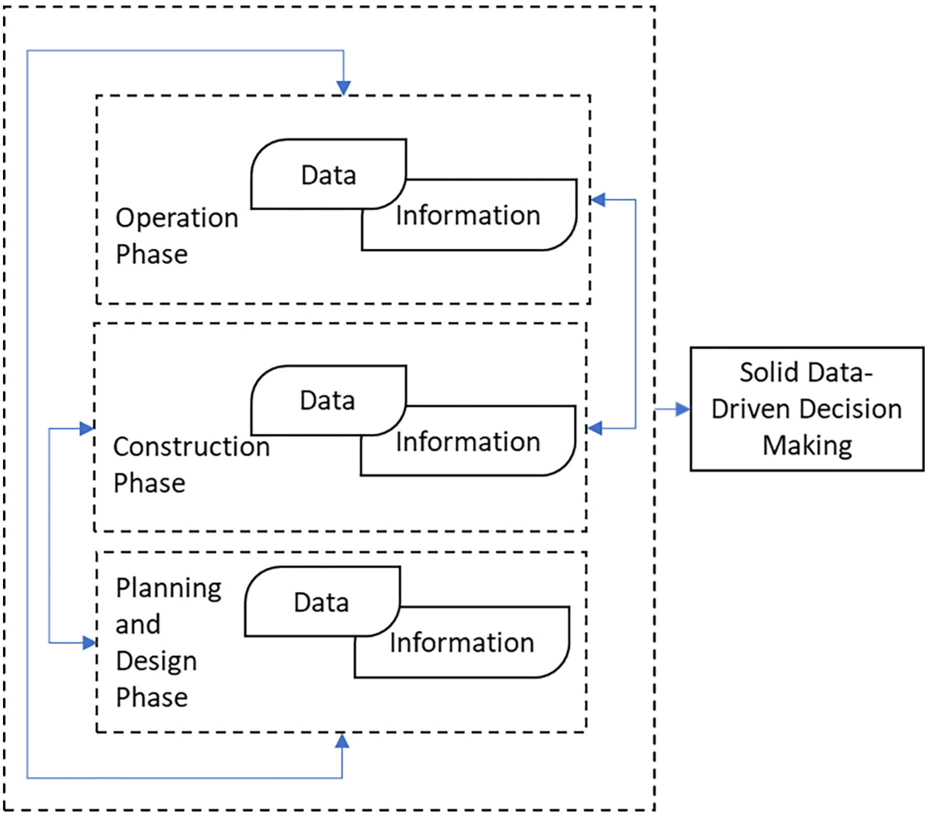

Figure 6. Project Data Information Decision Making Cycle

The framework also covers data management strategies to aid decision-making, as well as best practices and guidelines for data governance, performance metrics, and dashboard creation. Each facet of performance evaluation, such as data quality, data administration, analytic tools and methodologies, distribution, and application in the business operations, is critical to the effort's overall success. Figure 7 depicts the existing data flow of the MyGHI performance measures data system as well as the proposed setup for the future.

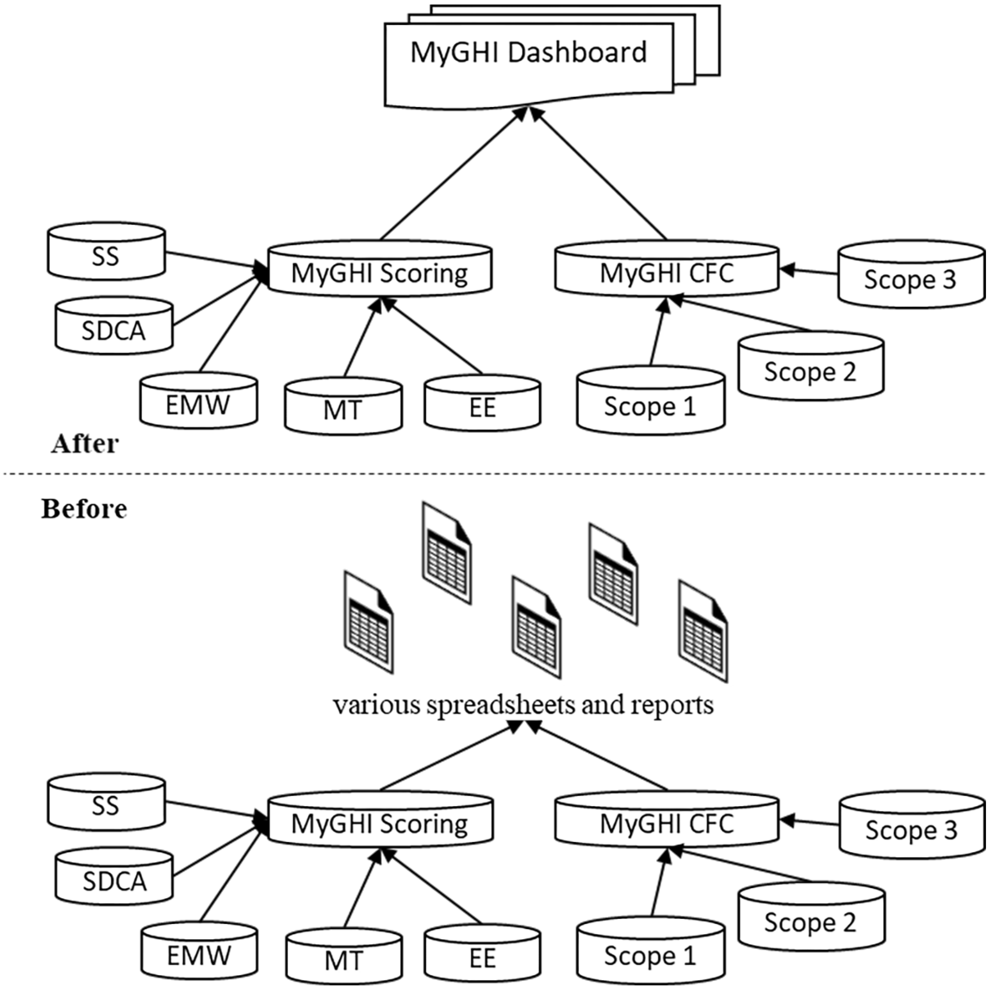

Figure 7. MyGHI performance measures data system configuration

This diagram shows how the bottom-up data system configuration, and its elements, correspond to specific performance measures under both current and future configuration conditions. For the current condition, data flows from all criteria and elements of both projects. All these feed data into various spreadsheets and reports. For the recommended future configuration, again working from the bottom up, data flows directly into the dashboard.

Assessment and Validation

This section addresses the validity of the framework, using a particular data management system as a case study. In this research, green highway assessment real data from MyGHI scoring and carbon footprint data were used to assess the effectiveness of the data integration framework. The main task of the case study is to specify the data and information to be used in the framework. Data analysis is performed to interlink the components. This helps identify the relationship between the existing green performance assessment by applying the integration system. The network approach is utilized to determine the data and information and execute the integration parameters in the framework. The foundation stone was laid to develop the MyGHI Dashboard to evaluate green performance of the highway system.

Diverse decisions are taken throughout the project's life that can affect the project's budget, program, productivity, and integrity. Such decisions vary from the identification of viability choices and allocation of funds at a structural level to the identification of design solutions and project-specific decision details. Various construction management plans, waste management, air pollutant control, innovation, quality management, energy management policy, energy efficiency performance, environmental management system, business enhancement, intelligent traffic systems, and renewable energy sources and fuel consumption are also some of the decisions made through highway lifecycle.

To make accurate decisions these decisions need specific types of information as feedback. In addition, these types of information need specific data as inputs. The data from MyGHI scoring and CFC were classified into two parts to avoid confusion between the data, where each has its unique characteristics and has its evaluation method. MyGHI, evaluates multiple criteria and then gives points (ratings) for each criterion achieved, while CFC, calculates the amount of carbon dioxide emissions from the activities along the project's lifetime. Leveraging this combination of classifications, allowed for collection and storage in one database, which was then analysed and integrated to finally be displayed in one interface, thus providing a comprehensive platform for evaluating green highway performance.

Based on the network approach, the conceptual design of data integration in Figure 8 has been validated through an expert group discussion with highway professionals from the industry and academia. By following this flowchart users can view and navigate between all parts of the application and get a comprehensive view of the evaluation process.

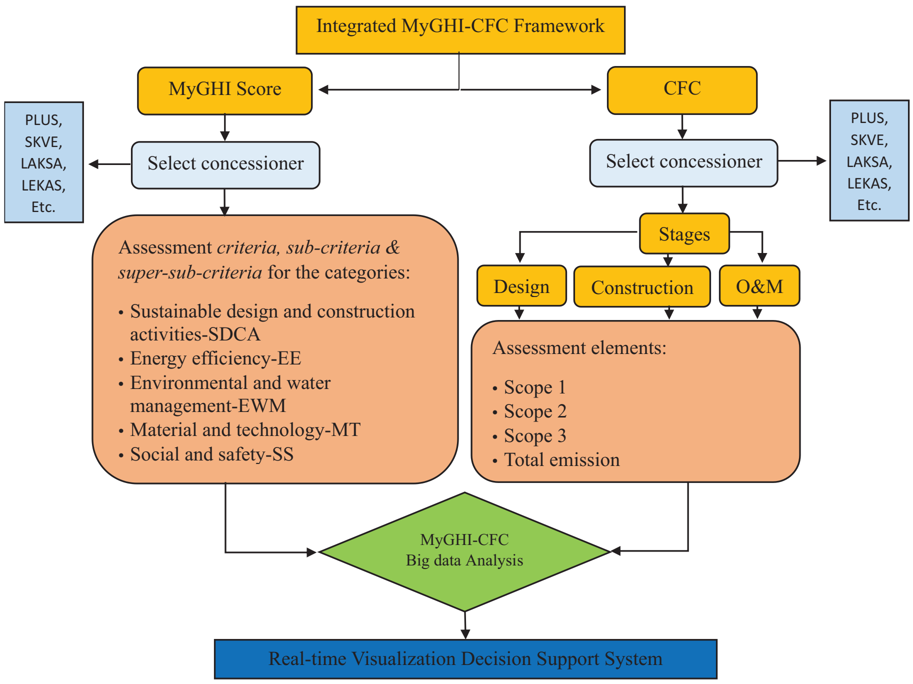

Figure 8. Conceptual design of the integration dashboard

Based on the integration system architecture, it was found that such data are used specifically as sources in the decision-making process since there is no application developed to monitor the green performance of each concessioner in terms of the score of green points that were achieved in every evaluation criterion of MyGHI scoring. At the same time, monitoring the amount of carbon dioxide emissions during the planning, construction and operation phases of the project for each concessioner was undertaken separately.

This proposed framework will achieve two key objectives: first of all, the administrative users or informed decision-makers in the highway industry can evaluate the data needs of future users for enhancing information processing and offering decision support by finding new connections among data and information; and second, authorized users will be willing to determine the state of the concessioner's data collection and processing initiatives by evaluating the difference between current data processing state and optimal data processing, which may act as a frequent report-card for data integration. As stakeholders, government and society have the right to understand how the highway performs and what its environmental impact is; they also have the right to know the plans and investments made in this sector and whether they are supported by affective and sufficient data.

This integration will also achieve that aim by assisting to validate the effectiveness of data management processes and create trust in the decision-making processes of concessionaires. It must be remembered that the degree of sophistication of the data collection system ranges from a concessioner to the other concerning the volume, nature, and degree of complexity of the data gathered in addition to the technology and processing techniques used to help decisions.

Anecdotal evidence suggests, with the industry's new transition toward investment management and performance-based program, highway concessionaires need to assess their success and clarify how decisions are taken. Data plays a crucial role in the accountability and integrity of performance assessment and decision-making frameworks. A concessionaire with such a high degree of success or a concessioner who has reached the optimal data usage outcomes could be a possible source of experience and good practices for other concessionaires. This will potentially increase the transparency and sharing of data. The data will remain stored in the databases of the Highway Authority, as the governing body for all data, characterized by its high level of security.

Finally, the development of visualization technologies aims at anticipating the growth of data. Large volumes of data are collected, processed, and exchanged between stakeholders as part of highway construction. For design, estimation, and operation, even small businesses and projects might generate Gigabytes of data. As the scope of the initiatives expands, so does the amount of data associated with it. Effective predictive analytics and Web-based data visualization technologies are necessary to extract valuable insights from the data. The new developed visualization dashboard provides several advantages, including performance evaluation and multidimensional data representation. It also provides a real-time solution and strength. To assure the accuracy and completeness of the new established Dashboard, it has been presented to the authorities to check the User Acceptance (UAT) to assure that users can view and navigate between all parts of the application and get a comprehensive view of the evaluation process easily and effectively. These web-based applications are expected to increase the level of confidence in terms of web-aided decision making which can reflect positively on comprehensive data analysis, data diagnosis, and data assessments and treatment.

Conclusion

This research provides a new framework that will consistently combine and connect green data with information to generate decisions on highways by incorporating a creative and constructive technique for performance evaluation. The methodology utilized mixing of "top-down" and "bottom-up" techniques by integrating quantitative and specific approaches for interlinking, with analysing data and information to enable evaluating the efficiency of data employed in highway decision making. The research uses data integration parameters as primary dimensions for the implementation of this framework. Its application is used to determine data and information by defining the link among them to maximize the degree of data use and enhance the decision process.

A concessioner's real-time green performance and carbon footprint data for the highway management system are utilized to clarify the implementation of the framework. The developed MyGHI dashboard will visualize green highway performance and work as a decisions support system that can serve as a real-time monitoring system. This research built a bridge between the MyGHI scoring and the CFC and works as an important decision support system. The decisions that will be aided are wide-ranging; from implementing green initiatives to help reduce the GHGs emissions from highways lifecycle, to strategies to increase their green scores for all MyGHI criteria.

The benefits of this framework include a better understanding of the return on investment for concessionaires' efforts to collect and analyse data. Currently, many concessionaires may fail to substantiate and demonstrate to their managers the reasons why modern IT and data analysis and integration techniques should be applied. By specifying the data and information relationships and what decisions will gain from this implementation, the framework will assist concessionaires to protect their data collection initiatives and reduce expenditures. This new framework would greatly enhance how data is gathered, analysed, and controlled. It can also be used to improve decision-making systems for concessionaires and fulfil their sustainable targets by addressing the demands of authorities and the goals of governments. This research can be extended in the future to integrate green highway assessment data with highway traffic management systems as well as with the pavement management system, to have a fully comprehensive monitoring dashboard for better highway management.

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