USING GPS MONITORING SYSTEM TO ENHANCE PRODUCTIVITY OF CONSTRUCTION EQUIPMENT IN LARGE-SCALE CONSTRUCTION COMPANIES IN SRI LANKA

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DECLARATION

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The above candidate has carried out research for the Masters Thesis under my supervision.

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Prof. A.A.D.A.J. Perera

ABSTRACT

USING GPS MONITORING SYSTEM TO ENHANCE PRODUCTIVITY OF CONSTRUCTION EQUIPMENT IN LARGE-SCALE CONSTRUCTION COMPANIES IN SRI LANKA

Productivity of construction equipment refers to the value of work done in a period as a piece of individual equipment or as a fleet of equipment. Estimating the actual productivity of construction equipment requires tracking and monitoring. Manual data collection methods and data input procedures restrict access to precise and real-time performance data. This limitation creates a need for GPS tracking, eliminating human reporting errors and increasing productivity. GPS-based equipment tracking and monitoring systems are more efficient than traditional performance estimating systems on productivity assessment. Therefore, the main objectives of this study will be to i) Identify current issues in tracking and monitoring the construction equipment, ii) Investigate the tracking and monitoring information needed to enhance the productivity of construction equipment, and iii) Analyse the impact of GPS monitoring systems on the productivity of construction equipment. Relatively important issues in construction equipment tracking and monitoring were prioritized based on questionnaire responses. Using relative important index, tracking information needed to enhance productivity was prioritized based on questionnaire responses. The current equipment monitoring process of the selected construction company for the dump trucks was mapped and analyzed. The production of the dump truck is based on truckload, the number of trucks used for the operation, truckload time, truck haul time, dump time, and return time. The areas for process improvement for the dump trucks were identified using the prioritized outputs of the GPS monitoring system, which are machine location tracking, fuel consumption, trip history, idling trends, and route optimization. Finally, realistic recommendations for identified issues and future developments were suggested.

Key Words: GPS, Tracking and Monitoring, Telematics, Equipment Productivity, Hauling Equipment, Dump Trucks, Process Mapping

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LIST OF ABBREVIATIONS

Abbreviation	Description
GPS	Global Positioning System
OBD	On-Board Diagnostics
GNSS	Global Navigation Satellite System
RTK	Real-Time Kinematic
CORS	Continuously Operating Reference Stations
NRTK	Network Real Time Kinematic
US	United States
A-GNSS	Assisted Global Navigation System
API	Application Programming Interface
CIDA	Construction Industry Development Authority, Sri Lanka
CS1 (CIDA)	Contractor organization registered with CIDA, Sri Lanka, with a financial limit between LKR 3000 to 1500 million per year
CS2 (CIDA)	Contractor organization registered with CIDA, Sri Lanka, with a financial limit of more than LKR 3000 million per year
C1 (CIDA)	Contractor organization registered with CIDA, Sri Lanka, with a financial limit between LKR 1500 to 600 million per year

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1. INTRODUCTION

1.1 Background of the Study

The ultimate purpose of a structural design is construction, and people and construction equipment accomplish the transformation of a design into a functional structure. (Peurifoy, Schexnayder, & Shapira, 2017). The construction industry hinges on the construction equipment industry, and earthmoving equipment is just a segment. It includes loaders, dozers, scrapers, graders, hydraulic excavators, backhoes, Trucks, and Hauling Equipment (Arditi, Kale, & Tangkar, 1997). This study will focus on earthmoving construction equipment, but the generic term "construction equipment" will be used in describing them.

Productivity of construction equipment refers to the value of work done in a period as a piece of individual equipment or as a fleet of equipment (Kannan, 2011). Estimating the actual productivity of construction equipment requires tracking and monitoring (Alshibani & Moselhi, 2016). Equipment users need to consider multiple variables related to the operational condition of the equipment and allow maximum utilization of equipment towards achieving overall project productivity (Oloufa, Ikeda, & Oda, 2003). Alshibani and Moselhi (2016) presented that conventional productivity estimating was dependent on performance tables given by equipment manufacturers, which did not represent the factual site circumstances, resulting in the overestimation of productivity. In comparing actual to the estimated productivity, the construction equipment tracking process goes through a process of data gathering from a construction site, analyzing the collected data, calculating actual productivity, and comparing the estimated and the actual.

As information technology has advanced in recent years, spatial technologies, particularly GPS, have drastically contributed to tracking and monitoring equipment (Alshibani & Moselhi, 2016). A global Positioning System, or in short form GPS, is a navigation system based on a satellite radio system using 24 GPS satellites orbiting the Earth and transmitting radio signs (Oloufa et al., 2003). GPS systems calculate longitude, latitude, and altitude to establish an exact position with high precision based on the time it takes for satellite radio signals to be received by GPS receivers. (Oloufa et al., 2003). GPS tracking and monitoring is a new technology for the Sri Lankan construction industry. However, over the previous three decades, it has been employed worldwide for a wide range of applications in the construction sector. Because of the threat of lava, Japanese contractor Fujita utilized GPS technology in 1994 to remotely manage dozers, backhoes, trucks, and other auxiliary vehicles and equipment at the erupted Mount Fugen volcanic site. (Oloufa et al., 2003).

As Alshibani and Moselhi (2016) explained, estimating the actual productivity of construction equipment requires tracking and monitoring. GPS tracking makes it simple to track construction equipment, and we can utilize the GPS tracking data to monitor the construction equipment and, ultimately, assess productivity. Monitoring the equipment and evaluating productivity monthly or daily can have an impact on the actual productivity of the equipment and operator. In a global context, many researchers such as Pradhananga and Teizer (2012), Alshibani and Moselhi (2016); Han, Lee, Hong, and Chang (2006), and many other researchers have studied referring to GPS tracking and productivity. However, there is relatively little study on equipment productivity or GPS tracking and monitoring of construction equipment in the Sri Lankan context.

1.2 Problem Background

The Sri Lankan construction industry has many construction equipment-related and productivity issues. It is challenging to track and monitor the equipment manually by using the machine's meter readings using information from supervisors and operators. Time taken to transfer the information is lengthy, which only allows preventive actions for the future, and it is challenging to apply corrective measures for the ongoing problem. Manual data collection methods and input procedures restrict access to precise and real-time performance data, resulting in ineptitude in project management (Aslan & Koo, 2012). This constraint necessitates using GPS Vehicle Tracking, a procedure that can remove human reporting mistakes while increasing field operation productivity. (Aslan & Koo, 2012).

Large vehicle fleets frequently necessitate efficient fleet management to improve overall productivity, and efficient equipment fleet management is crucial. GPS vehicle tracking can ensure that the vehicle fleet is operating efficiently (Jagushte, 2017). Inadequate equipment monitoring accounts for 30-40% of construction cost overruns (Ranjithapriya & Arulselvan, 2020).

Most construction companies in Sri Lanka have kept records on fuel and oil usage(Bogahawatta & Amarathunge, 2019). Bogahawatta and Amarathunge (2019) found that just 56.3 % have digitized their equipment records, and some enterprises did not keep track of operating hours, operator salaries, and repair information.

1.3 Problem of the Study

My study's research problems are,

1. What are the current issues in tracking and monitoring the construction equipment?
2. What is the tracking and monitoring information needed to enhance the productivity of construction equipment?
3. What is the impact of GPS monitoring systems on the productivity of construction equipment?

1.4 Objectives of the Study

GPS-based equipment tracking and monitoring systems are more efficient than traditional performance estimating methods for assessing productivity (Han, Lee, & Halpin, 2005). Han et al. (2005) further elaborate that decision-makers need to determine the feasibility of implementing a high initial investment cost on GPS tracking and monitoring system compared with potential profit and cost savings.

Therefore, the main objective of my study will be to,

1. Identify current issues in tracking and monitoring the construction equipment.
2. Investigate the tracking and monitoring information needed to enhance the productivity of construction equipment.
3. Analyze the impact of GPS monitoring systems on the productivity of construction equipment

1.5 Significance of the Study

As there was little research on GPS tracking and monitoring of construction equipment in the Sri Lankan context, this study will have a theoretical significance in filling the research gap.

The construction industry in Sri Lanka would benefit from the results of this study on determining the potential benefits and impact of implementing a GPS system on the productivity of construction equipment.

1.6 Methodology

This research is Applied Research as it seeks to answer a problem in the real world and solve it.

Information for the following research questions will be found using a questionnaire survey

1) What are the issues in tracking and monitoring construction equipment?

2) What is the tracking and monitoring information needed to enhance the productivity of construction equipment?

Information for the following research question will be found using a field study.

3) What is the impact of GPS monitoring systems on the productivity of construction equipment?

Caldas, Torrent, and Haas (2006) have studied using a GPS monitoring system to improve the material locating process in industrial projects by mapping the existing material finding process. Since the locating procedure is typical for most other projects' material handling, this process's efficiency is based on the ability to gather, retrieve, and communicate the proper position and identification codes for construction components at any given time.

Similar to the methodology used by Caldas et al. (2006) current equipment monitoring process of the selected construction company will be analyzed and mapped. Areas for process improvement will be identified using the outputs of the GPS monitoring system.

1.7 Structure of the Report

The research study was divided into six chapters. The first chapter is devoted to the report's introduction, and it goes on to discuss the research's history, research problem, research objectives, research methodology, and research limitations.

Chapter two will be the literature review. It systematically identifies, evaluates, and interprets the work produced by researchers, scholars, and practitioners under the interested research area.

The study's methodology is covered in the Third chapter. Research design, methodology, demographic and sample methods, data collection methods, measurement methods, and data analysis procedures are all included.

Chapter four contains the data presentation and analysis. It entails an evaluation of the reliability and validity of the tools used to gather data.

The data analysis outcomes described in chapter four are compared to the chapter two findings in the fifth chapter. This chapter concludes with conclusions and recommendations.

References are mentioned in sixth Chapter.

2. LITERATURE REVIEW

2.1 Introduction

2.1.1 History of Global Positioning Systems

Significant milestones in the history of Global Positioning Systems can be summarized as follows.

- 1957: Sputnik I satellite was launched by the Soviet Union
- 1959: The United States Navy Constructs Transit system satellites to begin detecting submarines.
- 1963: The Aerospace Corporation completes military research that serves as the foundation for today's GPS system.
- 1974: The United States launches the first NAVSTAR test satellite
- 1978: As part of its Block I GPS program, the United States initiated the launch of 11 test satellites.
- 1983: Following the accident of Korean Air Lines Flight 007, the United States declared that GPS would be made available for public use to enhance navigation and promote air traffic safety.
- 1985: The United States government awards contracts to commercial businesses to develop portable GPS receivers.
- 1989: Magellan, a GPS manufacturer, presents the NAV 1000, the first handheld GPS device. The United States Air Force launched the first fully functioning satellite as part of its Block II program.
- 1990: The United States Department of Defense began to reduce the accuracy of GPS readings for non-military usage, citing a concern of rivals acquiring military advantages as the basis for the action. This was dubbed Selective Availability.
- 1991: Regardless of the fact that the GPS system is not completely operational, it plays an important part in US actions throughout the Gulf War.

- 1995: All 24 satellites in the GPS constellation have been certified fully operational by the United States military.
- 1998: Vice President Al Gore of the United States says that GPS III satellites would transmit two more signals for civilian and aviation usage.
- 1999: Benefon, a mobile phone maker, released the first commercial GPS phone.
- 2000: Selective Availability in the United States is no longer in effect, enabling more commercial GPS use and innovation.
- 2004: Qualcomm, a US electronics firm, has completed a test of live-aided GPS on a mobile phone, which combines mobile and GPS signals for improved precision.
- 2005: The first of the Block IIR satellites are launched, allowing a dedicated civilian GPS channel to be established.
- 2010: The first of 12 Block IIF satellites were launched by the United States. Block IIF satellites are the first satellites to be deployed by a modernized rocket, the Evolved Expendable Launch Vehicle.
- 2016: The final of the Block IIF satellites is launched, bringing the Block II program, which lasted from 1989 to 2016, to a close.
- 2018: The first GPS III satellite was successfully launched by the United States Air Force.
- 2019: A SpaceX Falcon 9 launches the second GPS III satellite from Cape Canaveral.
- 2020: United States Space Force has announced that the launch of the GPS III-3 satellite by SpaceX has been postponed owing to the COVID-19 outbreak.

(Ravikumar, 2020)

Commercial GPS Technology came into the industry in late 1980, and The first consumer-grade portable GPS receiver was NAV 1000 by Magellan (Ravikumar, 2020). Ravikumar (2020) further states that the NAV 1000, which weighed in at 1.5 pounds, cost about $3,000 and could only run on battery power for a few hours at a time.

With the improvement of technology, GPS devices have become more affordable and very small in size, which can fit in the palm of our hands (Ravikumar, 2020). Today GPS is essential for real-time bus tracking, fleet management, telematics, routing, and dispatching (Minni, 2013).

2.1.2 GPS Tracking Techniques

Point positioning and relative positioning are used in GPS to calculate location. The coordinates of points are determined with regard to a precise coordinate system by three coordinate values in point placement. (Berber, Ustun, & Yetkin, 2012). On the other hand, Berber et al. (2012) demonstrated that relative positioning determines point coordinates by comparing them to another point, using a point as the origin of a local coordinate system and that relative positioning is the most accurate GPS positioning technique because it eliminates the majority of errors by integrating differences in code or carrier phase ranges.

Relative positioning techniques presently being used in surveying include the following methods (Berber et al., 2012).

1) Static
2) Rapid static
3) Pseudo-kinematic
4) Kinematic
5) Real-time kinematic

2.1.2.1 Static GPS Technique

Two or more receivers are used in this operation. One receiver (named the base receiver) is placed on an existing control station, while the remaining receivers (called roaming receivers) are placed on stations with undetermined coordinates. For the initial observing session, observations are taken simultaneously from all stations to four or more satellites for an hour or longer, based on the baseline length. Greater baselines necessitate prolonged observation intervals. Besides one, all of the receivers are relocated once the session is over. The surviving receiver now functions as the observing session's base station. Any of the receivers used in the initial inspection period can be utilized. The practice is continued until all stations are engaged, and the observed baselines form geometrically closed figures at the end of the second session (Berber et al., 2012).

2.1.2.2 Rapid Static Technique

This approach is identical to static surveying, with the exception that one receiver is constantly stationed at a control station while the other(s) are moved from one unknown site to the next. For each point, an observation session is held; however, the sessions are smaller than in the static technique (Berber et al., 2012).

The quick static approach may be used to observe baselines up to 25 kilometers long. Rapid static produces accuracies comparable to the static approach; however, ideal satellite setups and good air conditions are required to attain these accuracy rates. Typical observation periods range from 5 to 20 minutes, depending on the baseline (Berber et al., 2012).

2.1.2.3 Pseudo-kinematic Technique

This technique, like other static methods, needs a minimum of two receivers. The base receiver stays on a control station in pseudo-kinematic surveying, which is also known as broken static (or intermittent static) surveying (Berber et al., 2012). The rover moves to each point of uncertain position, and at each station, the rover conducts two relatively brief observation sessions (about 5 minutes each) (Berber et al., 2012). The interval between the first and second sessions at a station must not be shorter than one hour, and due to the change in satellite geometry that happens throughout the time-lapse interval, the geometric intensity of the observations increases (Berber et al., 2012).

The necessity to revisit the stations is a downside of this strategy compared to other static solutions. This necessitates meticulous pre-survey preparation to ensure that enough time is set out for site revisitation and the most effective travel route (Berber et al., 2012).

2.1.2.4 Kinematic Technique

Two or more receivers are required for this process, and the numerical discrepancy for each pseudorange is determined in this way (Berber et al., 2012). One receiver, known as the base, stays at the control station when setup is finished, whereas the other, known as the rover, travels from location to location or along a line (Berber et al., 2012). At periods as small as 0.2 seconds, the antenna locations of the rover may be established, and throughout the whole session, both receivers must keep the lock on at least four satellites (Berber et al., 2012).

2.1.2.5 Real-Time Kinematic (RTK)

The data collected during kinematic surveying is temporarily retained until the field activity is concluded. After then, the data was post-processed to determine the locations of the surveyed spots (Berber et al., 2012). RTK, on the other hand, allows the locations of points to be calculated instantly as the wandering receiver(s) occupies each one (Berber et al., 2012). RTK, like other kinematic approaches, necessitates the use of two or more receivers at the same time (Berber et al., 2012). The employment of radios to broadcast adjustments and observations to the roaming receivers is a distinctive characteristic of this approach (Berber et al., 2012). A reference station is occupied by one receiver, which sends raw GPS observations to the wandering units. The onboard computer of the rover processes the GPS measurements from both receivers in real-time to give an instant location determination (Berber et al., 2012).

Improved GNSS signal quality, current GNSS positioning technology (e.g., CORS, network, NRTK, etc.), and growing interest from user groups and major players in the application of these technologies for high-quality precise positioning are all contributing to the development and enhancement of accuracy. (Dabove, Di Pietra, & Piras, 2020).

2.1.3 GPS in Mobile Devices

The ability to obtain and apply GNSS pseudo-range and carrier-phase measurements on mobile devices such as smartphones and tablets running the Android operating system has revolutionized the idea of accurate location using mobile devices (Dabove et al., 2020).

Smartphone technology has become very popular in recent years. Nowadays, almost everyone has a smartphone. It's used for more than simply communication; it's also used to guide users to their destinations and, on occasion, to broadcast their whereabouts. As a result, navigation systems have become a necessary part of everyday life. In the absence of global navigation satellite system (GNSS) signals or in any circumstance where the signal is disturbed or shielded, such as an urban canyon or partially indoors, other sensors embedded in smartphone devices provide accurate information for performing navigation and positioning using assisted GNSS (A-GNSS) systems, which can obtain the required data from other GNSS fixed stations or from a world wide web server (Dabove et al., 2020). Every current smartphone includes an integrated GNSS receiver, and it has been possible to obtain GNSS raw data through mobile platforms since 2017, as well as high-level Application Programming Interface (API), which implies that raw measurements from GNSS receivers may be obtained for exact location (Dabove et al., 2020).

2.1.4 Construction Equipment

The construction equipment industry is classified as a "mature industry," which refers to a sector that has transitioned from fast expansion to moderate growth Maturity indicates features such as increased rivalry for market share and additional product and manufacturing process advancements (Arditi et al., 1997).

The construction equipment sector includes a wide variety of equipment. Crawler loaders and dozers, wheel loaders and dozers, scrapers, graders, hydraulic excavators and backhoes, trenchers, pipe layers, and off-highway vehicles are all examples of earthmoving equipment. Although this may be a more specific word for these items, the generic phrase "construction equipment" is used throughout this research (Arditi et al., 1997).

The construction equipment sector is obviously influenced by market conditions, such as construction activity highs and lows, as well as the type and size of construction projects done (Arditi et al., 1997). Arditi et al. (1997) further explained that the technical advances in domains like materials, metallurgy, mechanical systems, electrical sensors, and hydraulic controls have an impact on them.

The Economics of construction equipment depends on ownership cost, including purchase cost, operating cost, residual value, the economic life of the equipment, repair and maintenance cost, and availability (Kannan, 2011).

The construction equipment industry relies on ongoing product development by combining new technologies, such as electronics, and enhanced fluid and mechanical power actuation for rapid reaction, greater operational efficiencies, and diagnostic methods (Arditi et al., 1997). Construction businesses will reap significant benefits from introducing new technology and innovation in construction equipment, such as increased site productivity and safety, improved working conditions, and increased cost-efficiency and competitiveness (Arditi et al., 1997). The development in information technology associated with the digital age has advanced construction earthmoving to the same magnitude that they have revolutionized other industries (Koehrsen, Sahm, & Keefer, 2001).

According to the studies, labor variables, late inspection, soil characteristics, operator efficiency, and the availability of replacement parts are the most important elements influencing equipment management in the construction industry (Ranjithapriya & Arulselvan, 2020).

A user interface for manual and automatic work zone identification was developed, and Manual and automated work zone identification methodologies were used to gather and evaluate data related to equipment cycles (Pradhananga & Teizer, 2012). Additionally, the position and speed of the equipment were evaluated to assess its closeness to adjacent equipment (Pradhananga & Teizer, 2012). Based on the research finding of Pradhananga and Teizer (2012), proactive actions can be used to improve job site layout, equipment operation and utilization, and job site safety.

2.1.5 Telematics

Telematics is a phrase that refers to the process of tracking vehicles and equipment using GPS and onboard diagnostics (OBD) to detect and record their movements on a digital map. Many public and private fleets use telematics, often known as fleet monitoring or GPS vehicle monitoring, as an important management instrument today. (Geotab, 2021).

Using various wireless methods, telematics collects and transmits diverse real-time data from distantly positioned devices to a centrally connected database system. (Aslan & Koo, 2012).

The logistics and transportation industries have experienced significant growth in the usage of fleet telematics, which conducts fleet management securely and efficiently by exchanging information about vehicle fleet whereabouts, operational conditions, and control and dispatching plans in real time (Lee, Park, & Seo, 2018).

Figure 2.1 Use of Telematics (Geotab, 2021)

2.1.6 Geofencing

Reclus and Drouard (2009) elaborated that geofencing, a cutting-edge system based on telematics and satellite location, allows for remote surveillance of geographic regions encircled by a virtual barrier.

Geofencing is a GPS-based strategy for tracking moveable items (vehicles, people, containers, etc.). The topographical coordinates of the observed item are automatically and on a regular basis sent to a command center through mobile networks. (Reclus & Drouard, 2009).

2.2 GPS and Construction Equipment

Han et al. (2005) stated that a GPS-based system is more efficient than traditional techniques based on assessing hourly productivity and unit costs, and profit should be calculated with increased performance and compared to the high initial investment cost of GPS devices before implementation.

In a study conducted by Han et al. (2006) showed that When compared to the conventional system, a GPS-based system may boost productivity by 21.74 percent and reduce costs by 12.92 percent in a short-haul distance project, and can increase productivity by 5.67 percent, and reduce costs by 4.79 percent in a long-haul distance project.

A construction company desires to know how many hours its equipment is running in order to enhance equipment utilization at each worksite. It is essential for Construction fleets to understand the following,

1. Is excess equipment on site?
2. Is equipment on site not adequate?
3. Is one piece of equipment doing excess work compared to others?
4. Is equipment idling for a significant period of time?

(Rauhof, 2020)

2.2.1 Logistics

Having a complete view of where the equipment is located using the GPS Tracking and Monitoring System allows the decision-makers to plan travel schedules and allows technicians to know the location of the equipment if a repair is needed (Rauhof, 2020). Rauhof (2020) explains further that GPS Tracking and Monitoring System also helps avoid the delays caused by locating equipment on large construction sites, reducing downtime.

In terms of equipment failures, it was discovered that the placement of the equipment and the waiting for spare parts are the most significant sources of downtime. (Bogahawatta & Amarathunge, 2019).

2.2.2 Utilization

Managers can monitor the usage of equipment on-site, and they can allocate equipment to each job based on current work. With real-time utilization data, managers have the ability to properly disperse equipment (Rauhof, 2020).

Pradhananga and Teizer (2012) demonstrated that once GPS data is processed, it could be utilized to comprehend the utilization of construction equipment as well as analyze the work environment on a job site.

2.2.3 Allocation

GPS monitoring systems allow the company as a whole to see what equipment they need and base their purchasing budget on actual and accurate usage data (Rauhof, 2020).

2.2.4 Maintenance and Repair Schedules

Ranjithapriya and Arulselvan (2020) explain that an important aspect of good construction equipment management is defensive maintenance, which may assist in saving time, and money and decreasing project delays.

Telematics can provide information and work collaboratively with maintenance programs of a company with data directly from the equipment. This saves time and effort for manual data entry and guarantees the accuracy of the data used in the maintenance program (Rauhof, 2020).

2.2.5 Theft

By tracking an equipment's location, using geofencing, and getting alerts when a device is stopped, managers can monitor the real-time location of the equipment and if they are traveling without consent or scheduled path (Rauhof, 2020).

2.2.6 Fuel Consumption

By monitoring idling patterns and machine usage patterns, managers can determine how to save fuel (Rauhof, 2020).

2.2.7 Job Estimates

With the actual data from GPS monitoring equipment used to carry out a task, contractors can accurately bid for construction jobs. Knowing the actual usage will allow bidders to estimate the job properly and not overbid or underbid (Rauhof, 2020).

2.2.8 Operating Expenses

Information on equipment usage, transport history, and maintenance details allows companies to adjust their budgets consequently and reduce fuel and other costs (Rauhof, 2020).

2.3 Assigning and Monitoring Equipment

In reality, selecting, assigning, and continuously monitoring equipment of a project is one of the most important decisions in a construction project since it impacts how the project is completed, the time and resources required to complete the task, and the cost that will be incurred (Tatari & Skibniewski, 2006).

2.4 Productivity

Improving logistics, utilization, and maintenance of equipment will enhance productivity (Rauhof, 2020). Because of the difficulties of construction, the investment for these projects is highly costly, and a variety of factors such as Factors like as labor, late inspection, soil condition, operator efficiency, and spare component availability can all have a substantial influence on Equipment productivity (Ranjithapriya & Arulselvan, 2020).

2.4.1 What is Equipment Productivity?

It is often expressed in internationally created statistics as a constant in-place value divided by inputs such as worker-hour (Ok & Sinha, 2006). Ok and Sinha (2006) explained that it might be the cost of production generated by the facility for the owner of an existing or planned plant, other assets, or equipment. Ok and Sinha (2006) presented a simple explanation for productivity for a contractor, which is presented as the quantity or proportion by which expenses are less than (or more than) the income flows from the owner.

Since this study is focused on earthmoving construction equipment (dump trucks), productivity related to trucks and hauling equipment is estimated in the literature in various methods.

2.4.2 Productivity in Dump Trucks

A truck's productivity is determined by the size of its payload and the number of trips it can make in a given timeframe, where the number of trips performed per hour varies with cycle time. (Peurifoy et al., 2017). As Peurifoy et al. (2017) elaborated further, a dump truck's cycle type is determined by four factors.

(i) Load time
(ii) Haul time
(iii) Dump time
(iv) Return Time

Peurifoy et al. (2017) have explained the truck cycle time as follows.

$$Truck\ Cycle\ Time\ =\ Load\ Time + Haul\ Time + Dump\ Time + Return\ Time$$

2.4.2.1 Load time

The first step in evaluating truck production is determining how many excavator bucket loads are required to load the truck (Peurifoy et al., 2017).

$$Balanced\ number\ of\ Bucket\ Loads\ = \frac{Truck\ Capacity\ (lcy)}{Bucket\ Capacity\ (lcy)}$$

The number of bucket loads loaded into the vehicle must be an integer. It is common not to entirely fill the bucket in order to balance the bucket volume to the truck volume, although this is typically inefficient because it causes wasted load time (Peurifoy et al., 2017).

If one fewer bucket load is loaded into the truck, the loading time is decreased, but so is the weight on the truck. Job requirements may require that fewer bucket loads be loaded onto the vehicle at times (Peurifoy et al., 2017). For example, if the transport roads are in bad condition or the trucks must climb steep gradients, the load size is changed, and in such cases, the truckload will be equal to the bucket volume multiplied by the number of bucket loads (Peurifoy et al., 2017).

Peurifoy et al. (2017) explain circumstances where the amount of bucket loads is rounded down to an integer less than the total number of loads or lowered due to work conditions.

$$Load\ time\ =\ Number\ of\ bucket\ loads\ \times\ Bucket\ Cycle\ Time$$

$$Truck\ load\ LI\ (volumetric)\ =\ Number\ of\ Bucket\ loads\ \ \times Bucket\ Volume$$

Furthermore, excess material will be automatically fallen off the truck if the truck cargo body volume divided by the bucket volume is rounded up to the next higher integer and that number of bucket loads is loaded to the truck; in this case, the loading time equals the bucket cycle time multiplying the number of bucket shifts, and the volume of the load on the truck represents its truck capacity. (Peurifoy et al., 2017)

$$Truck\ Load\ HI\ (Volumetric)\ = Truck\ Volume$$

2.4.2.2 Haul Time

To maximize the efficiency of one-way traffic patterns, hauling should be done at the greatest safe speed and in the right gear (Peurifoy et al., 2017).

$$Haul\ time\ (Min) = \frac{Haul\ Distance\ (ft)}{88\frac{fpm}{mph} \times Haul\ Speed\ (mph)}$$

Haul travel speeds may be predicted using truck manufacturer's performance tables based on the gross weight of the vehicle with the load and incorporating rolling and grade resistance from the loading spot to the dump site (Peurifoy et al., 2017)

2.4.2.3 Dump Time

Dump time will be determined by the type of hauling vehicle used and the amount of traffic in the dump region. A rear dump can dump and turn in 0.7 minutes under ideal conditions, while the average unfavorable time is around 1.5 minutes (Peurifoy et al., 2017). When predicting the dump time, the estimator must always imagine the characteristics of the dump region.

2.4.2.4 Return Time

Return trip speeds may be approximated using the vehicle manufacturer's performance tables, relying on the emptied weight of the vehicle and also the rolling and grade resistance from the disposal facility to the loading location (Peurifoy et al., 2017).

$$Return\ Time(Min) = \frac{Return\ Distance\ (ft)}{88\frac{fpm}{mph} \times Haul\ Speed\ (Mph)}$$

2.4.2.5 Number of Trucks Required

Peurifoy et al. (2017) have demonstrated the process to calculate the number of trucks required to occupy the loading equipment working at the capacity as follows.

$$Balanced\ number\ of\ trucks = \frac{Truck\ cycle\ time\ (Minutes)}{Excavator\ Cycle\ Time\ (Minutes)}$$

2.4.2.6 Calculating the Productivity

If the number of trucks used in operation is less than the balanced number of trucks, the trucks are a limited resource, and it will control the production of the operation (Peurifoy et al., 2017). Hence the productivity is calculated as follows,

$$Production\ (lcy/hr) = Truck\ Load\ (lcy) \times Number\ of\ trucks\ \times \frac{60\ min}{Truck\ Cycle\ time\ (Min)}$$

If the number of trucks used in loading, hauling, and unloading operations is higher than the Balanced number of trucks, the production of the operation will be controlled by the loading equipment (Peurifoy et al., 2017). Hence the production of the operation is calculated as follows.

$$Production\ (lcy/hr) = Truck\ Load\ (lcy) \times \frac{60min}{Excavator\ cycle\ time\ (Minutes)}$$

2.5 Studies in Sri Lanka on Using GPS to Enhance Productivity

In the Sri Lankan context, Medagama et al. (2008) have conducted research on how to track vehicle fleets using Geographical Information Systems (GIS), the Global Positioning System (GPS), the General Packet Radio Service (GPRS), and the World wide web. But little to no literature was published on the application of GPS for construction equipment in the Sri Lankan context. Moreover, there is a research gap in the area of the impact of GPS tracking and monitoring on the productivity of construction equipment in the Sri Lankan context. Supplementary literature searching shall be done in this study to understand the Sri Lankan context and also by searching the studies which were not published.

2.6 Dimensions of Construction Equipment Management

Construction equipment management is a subject associated with construction operations such as selection, maintenance, replacement, and cost recovery utilization and operations control (Bogahawatta & Amarathunge, 2019).

The following dimensions of construction equipment management were identified by analyzing the literature. Every dimension has direct or indirect links to the productivity of equipment and will be considered in improving the equipment management process using GPS monitoring.

- Equipment selection Practices
  - Type of financing used to acquire equipment(Gransberg, Popescu, & Ryan, 2006)
  - Acquisition policy (Amirkhanain & Baker, 1992)
  - Authority of acquisition (Gransberg et al., 2006)
  - Assignment of the equipment (Gransberg et al., 2006)
  - Authority of assignment (Gransberg et al., 2006)
- Cost management of equipment
  - Ownership costs(Gransberg et al., 2006)
  - Operating costs (Gunawardena, 1990)
  - Equipment Hiring Rates (Gransberg et al., 2006)
- Equipment maintenance practices
  - Types of maintenance (Harris & McCaffer, 1982)
  - The time between maintenance (Yip, Fan, & Chiang, 2014)
  - Training and experience in maintenance (Gransberg et al., 2006)
  - Availability of resources(Yip et al., 2014)
- Equipment replacement practices
  - Authority in replacement (Eilon, King, & Hutchinson, 1966)
  - Disposing of used equipment (Gransberg et al., 2006)
  - Time of replacement (Jaafari & Mateffy, 1990)
  - Reasons for replacement decision (Jaafari & Mateffy, 1990)
- Failure of equipment
  - Causes for failure (Gransberg et al., 2006)
  - Downtime of equipment (Vorster & De La Garza, 1990)

3. RESEARCH METHODOLOGY

3.1 Introduction

The study's research methodology is described in this chapter. It consists of mainly three parts which are research design, research method, and summary.

3.2 Research Design

Purpose of this research is to identify issues in tracking and monitoring and identify and analyse the impact of GPS monitoring system on the productivity of construction equipment. Hence this research can be considered as applied research as it seeks to answer a problem in the real world and solve it.

The research strategy will be a questionnaire survey strategy for following objectives one and two for and case study strategy for the objective three.

The construction equipment monitoring process is typical to construction equipment monitoring operations in the majority of other large-scale companies in Sri Lanka. This research maps the existing equipment monitoring process and analyses the impact GPS monitoring systems can be made the productivity of construction equipment.

3.3 Research Method

3.3.1 Questionnaire Survey

Information for the following research questions will be found using a questionnaire survey

1) What are the issues in tracking and monitoring construction equipment?
2) What is the tracking and monitoring information needed to enhance the productivity of construction equipment?

Questionnaire survey was targeted to large scale construction companies in Sri Lanka who are having CIDA grading C1 or above.

There were three sections to the questionnaire. The first section collected general information about the respondent and the company, while the second section gathered information about issues they've had with tracking and monitoring equipment, as well as tracking and monitoring information respondents prefer to have in a GPS tracking and monitoring system to improve productivity. 3rd section comprised questions to gather data related to initial and monthly investment feasible for a GPS monitoring system and the respondent's preference for the conventional GPS system or smartphone-based GPS Monitoring system.

3.3.2 Case Study

Information for the following research question will be found using a case study.

3) What is the impact of GPS monitoring systems on the productivity of construction equipment?

The current equipment monitoring process of the selected construction company was mapped and analyzed as this system is typical of construction equipment monitoring operations in Sri Lankan Construction Projects. Areas for process improvement were identified using the outputs of the GPS monitoring system incorporating the outputs from questionnaire survey results related to Objective 1 and Objective 2.

For the case study, process of monitoring, dump trucks were selected to map the process and identify process improvements.

3.3.3 Population and Sampling

This part will cover the population, sample, data collection, validity and reliability of the questionnaire, the degree of measurement of the variables, and data analysis techniques.

3.3.3.1 Research Population

The research Population for this research is considered as large construction companies in Sri Lanka. The working definition of a large construction company for this research is taken as Grade C1 and above construction companies in Sri Lanka listed in Construction Industry Development Authority (CIDA).

As per Construction Industry Development Authority, there are 78 construction companies with grades C1, CS1, and CS2 (CIDA, 2022).

3.3.3.2 Sampling

The convenience sampling method was used when selecting the sample. Ongoing construction companies with CIDA registration C1 and above were the study sample, and companies were chosen based on their accessible availability. For the survey questionnaire, one individual from each managerial level was chosen. More than 40% of the research population was targeted for the data collection sample.

3.3.4 Data Collection

The data gathering process was broken down into numerous parts. The current literature, expert opinions, and the authors' experience were analyzed to identify issues in construction equipment management and information utilized in GPS Equipment tracking to increase construction equipment productivity.

Following that, a thorough questionnaire was created based on the information gathered from various sources and was designed to be filled out online, aiming the objectives i) Identify current issues in tracking and monitoring the construction equipment and ii) Investigate the tracking and monitoring information needed to enhance the productivity of construction equipment.

Questionnaire Survey data collection was done using google forms tool as it is possible to fill the questionnaire using smart phone or using a computer.

Data was collected from 20th January 2022 to 28th January 2022 using the Google Forms questionnaire survey.

In case study, meetings were arranged with the Chief Mechanical Engineer and Transport Manager of the selected company to map the existing dump truck monitoring process. It was transferred in to a flow charts to better understanding and reviewed with the Chief Mechanical Engineer and Transport Manager. Copies of new and filled documents in the monitoring process was checked to get a clear understanding about the process.

Data was collected from 20th January 2022 to 30th April 2022 for the mapping existing equipment monitoring process.

3.3.5 Methods of Measurement

3.3.5.1 Method of Measuring General Information

Identity information and the initial two questions were arranged to gather information about the candidate's name (Not Mandatory), Name of the Company, Job Position of the respondent, and CIDA grade of the company.

Questions 3,4 and 5 collect general information about following

- Who has the authority to assign particular construction equipment for a specific task?
- Who is responsible for monitoring the productivity of Heavy Construction Equipment?
- Does the company have a GPS Tracking and Monitoring System for Construction Equipment?

3.3.5.2 Identifying Current Issues in Tracking and Monitoring the Construction Equipment

In question 6 of the questionnaire, Respondents were requested to rate the issues identified in literature from Very Important to Unimportant, 5: Very Impotent, 4: Important, 3: Moderately Important, 2: Slightly Important, and 1: Unimportant.

In question 7 of the survey, respondents were asked to submit a descriptive answer if they have any other critical issues in tracking and monitoring construction equipment other than the issues mentioned in question 6.

3.3.5.3 Investigating the Tracking and Monitoring Information Needed to Enhance the Productivity of Construction Equipment

In question 8 of the questionnaire, Respondents were requested to rate the tracking information they prefer to have in a GPS Monitoring system to enhance the productivity of construction equipment. Respondents were requested to rate the information that could be obtained from a GPS Monitoring system which was identified in literature from Very Important to Unimportant, 5: Very Impotent, 4: Important, 3: Moderately Important, 2: Slightly Important, and 1: Unimportant.

In question 9, respondents were requested to provide a descriptive answer explaining any other information they would prefer to have in a GPS monitoring system.

3.3.5.4 Potential Initial Investment and Monthly Investment

Respondents were given initial investment ranges, and monthly subscription ranges to analyze the financial feasibility of integrating preferred information into a GPS system.

3.3.5.5 Method of Receiving GPS Location

Participants for the questionnaire survey were asked to select a preferred method of receiving the GPS location either by a GPS tracking receiver where the driver cannot see or input anything or by a smartphone application-based GPS receiver where the driver can see and input.

3.3.6 Methods of Data Analysis and Evaluations

Questionnaire responses were collected using Google Forms, and Data analysis of 12 questions in the questionnaire was done using Microsoft Excel.

3.3.6.1 Data Analysis

The following tools were used to represent general data for better understanding and for interpretation purposes.

- Percentages for each option
- Bar charts representing each option in a column
- Pie charts
- Relative importance index (RII)

3.3.6.2 Relative Importance Index (RII)

Ranjithapriya and Arulselvan (2020) carried out a study on Factors Affecting Equipment Management and its Effect on Productivity in Building Construction, and they used the Relative importance index (RII) method for data analysis. Similar data analysis is used to analyze Questions 6 and 8. The RII technique is used to calculate relative indices between 0 and 1, making it simple to compare various variables (Gurmu & Aibinu, 2017). Many construction management academics choose RII because the relative comparison of variables with indices less than or equal to one is simpler to comprehend (Gurmu & Aibinu, 2017). Means and standard deviations are unreliable statistics for judging the overall order. Hence the relative relevance weights were employed as input for factor and regression analysis (Gurmu & Aibinu, 2017). The RII approach was used in this study since it is appropriate for ranking purposes and is suggested for inferential statistical analysis.

3.3.6.2.1 Objective 1: Identify current issues in tracking and monitoring the construction equipment.

By analyzing Questions 6 and 7, in the questionnaire, The data was analyzed using the Relative Importance Index (RII) approach. This approach was used to rate the overall concerns and determine the viewpoints of various professionals in construction. The RII is computed as follows:

RII = $\sum W/(A*N)$

Where W is the weight given by each factor, W ranges 5: Very Important 4: Important 3: Moderately Important 2: Slightly Important 1: Unimportant. A is the highest weight, five, and N is the total number of responses.

3.3.6.2.2 Objective 2: Investigate the tracking and monitoring information needed to enhance the productivity of construction equipment.

By analyzing Questions 8 and 9, in the questionnaire, The data will be analyzed using the relative importance index (RII) approach. This approach will be used to rate the overall GPS System Information and to determine the opinions of various professionals. The RII is computed as follows:

RII = $\sum W/(A*N)$

Where W is the weight given by each factor, W ranges 5: Very Important 4: Important 3: Moderately Important 2: Slightly Important 1: Unimportant. A is the highest weight, five, and N is the total number of responses.

3.3.7 Evaluations and Interpretations

Evaluations are done based on results obtained from data analysis. Then a comparison will be made between the results and the finding in the literature.

3.4 Summary

Through this chapter, The Research design is made up of the type of study, research strategy and research setting. And then, in the research method, it described about questionnaire survey, case study, population and sampling and data collection methods. Finally, methods of data analysis and evaluations were discussed with interpretations.

4. DATA ANALYSIS AND DATA PRESENTATION

4.1 Introduction

This chapter presents the data gathered in the study, and then it moves to the Data Analysis.

4.2 General Data Regarding Companies and Respondents

The population for the data collection study is taken as 78 Companies who are C1 or above in the CIDA Contractor grading system as of January 2022 (CIDA, 2022). The collected sample is 32, and it amounts to 42% of the population.

Data was collected from 20th January 2022 to 28th January 2022 using the Google Forms questionnaire survey.

Respondent's name, Name of the Company, and Job Position was collected to make sure the response could be taken as a sample of the population and for the validity of data. Some respondent's requested not to record their names in the questionnaire, and it was allowed.

Confidentiality of the respondent's Name, Position, and Company Name will be protected and not disclosed with this report.

4.2.1 CIDA Grade of the Responded Construction Companies

The CIDA grade of participating companies in the questionnaire survey is shown in Figure 4.1.

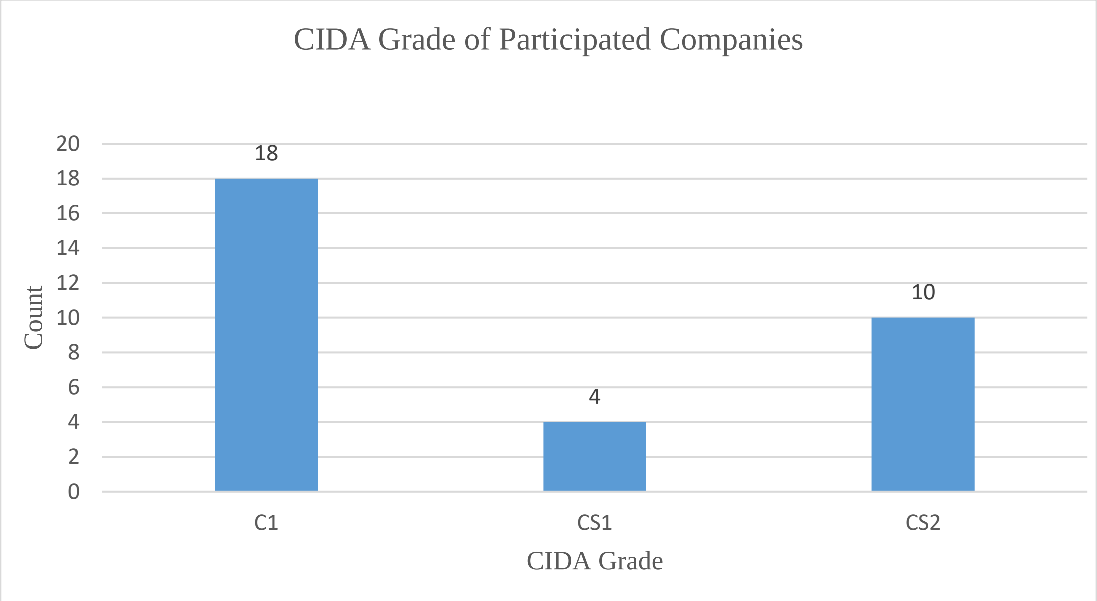

Figure 4. 1 CIDA Grade of the Responded Construction Companies

CIDA grade of the respondent's company was collected to shortlist the responses received to match the population. Out of 44 responses received, only 32 responses matched the population criteria of being a C1 or above construction company.

4.2.2 Types of Construction Equipment owned by the company

The percentage of equipment was calculated as follows,

$$\frac{Number\ of\ companies\ that\ own\ a\ \text{specific}\ equipment}{Total\ number\ of\ companies}$$

The percentage of equipment owned by responded organizations is shown in Figure 4.2 below.

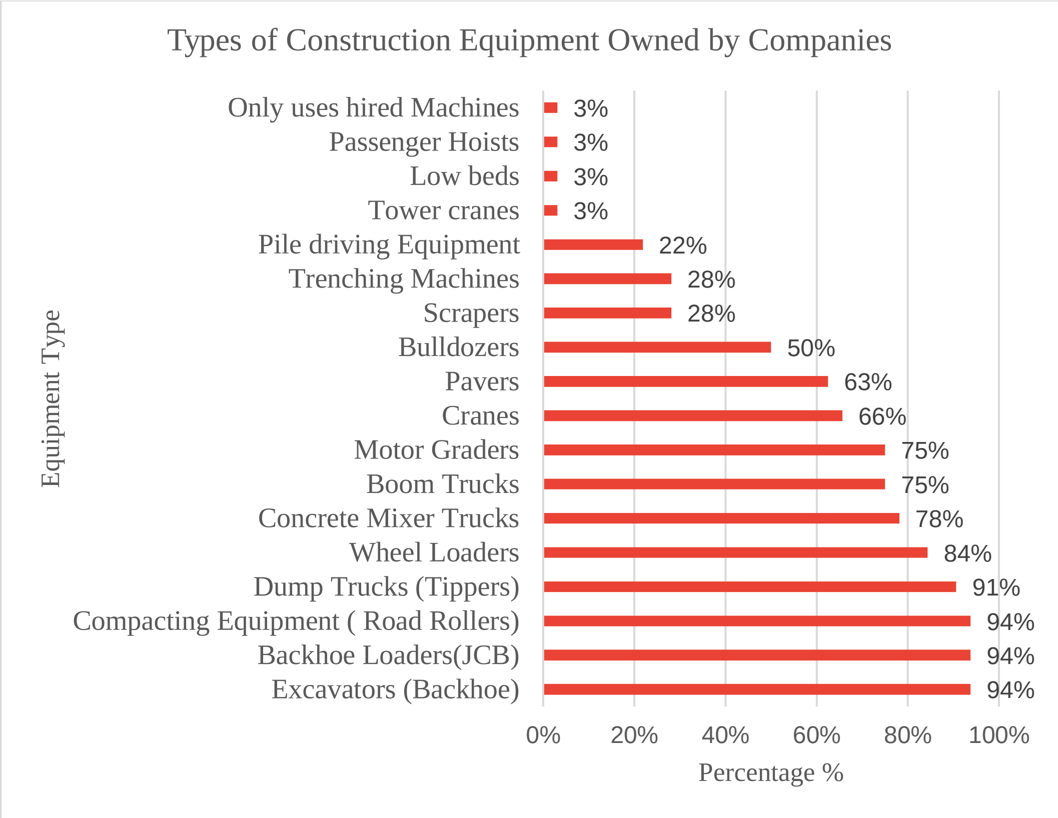

Figure 4. 2 Types of Construction Equipment Owned by Companies

4.2.3 Authority to Assign Equipment and Responsibility for Monitoring Equipment

In the sample, organizations that hold the authority to assign particular construction equipment for a specific task in a project were recorded in the survey. Similarly, who holds the responsibility of monitoring the assigned construction equipment was also recorded. This information was plotted in the following pivot chart in Figure 5.3 for better understanding.

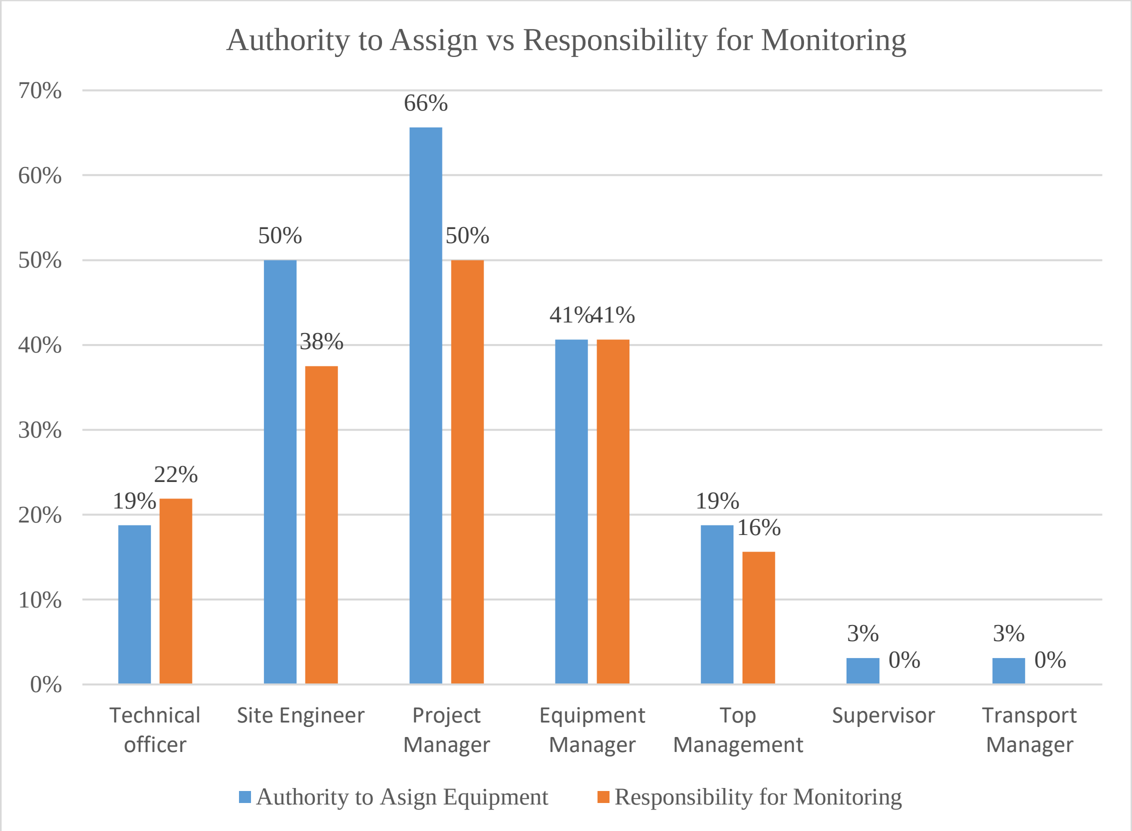

Figure 4. 3 Authority to Assign Equipment and Responsibility of Monitoring Equipment

In Figure 4.3, the Project Manager, Site Engineer, and Equipment Manager hold the authority to assign equipment to the majority of the sample. But in 66% of responding organizations, the Project Manager has the authority to assign equipment, but 50% of the sample organizations' Project Managers are responsible for monitoring construction equipment. Similarly, 50% of respondent organizations' Site Engineers have the authority to assign, but 38% only have the responsibility to monitor.

On the other hand, 41% of sample organizations' Equipment Managers had the authority to assign, and 41% were considered responsible for monitoring.

4.2.4 Availability of a GPS Tracking and Monitoring System

In the questionnaire survey, it was checked to gather information from respondents about the availability of an existing GPS tracking and monitoring system. In the study, if a company has implemented a GPS tracking system for a selected group of construction machines answer was taken as yes, as many firms have not completely integrated GPS equipment into their whole fleet of machines. Hence if a company has implemented a GPS system for some of their vehicles, answers were taken as yes.

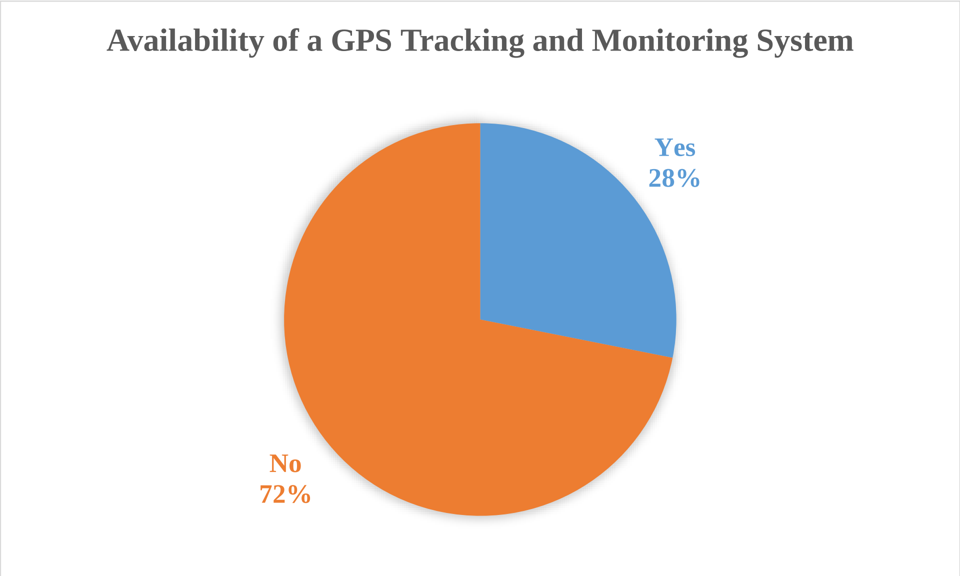

Figure 4. 4 Availability of a GPS Tracking and Monitoring System

As per Figure 4.4, It was noted that 28% of the responded organizations have existing GPS systems, and 72% of the organizations do not have a GPS tracking and monitoring system in their organizations.

To further analyze the availability of GPS tracking and Monitoring systems, Data was arranged based on CIDA grading as per Figure 4.5. It is observed that 50% of the CIDA CS2 and CS1 companies have implemented GPS tracking and monitoring systems, and in the C1 grade, only 10.7% have implemented GPS Systems in construction equipment tracking.

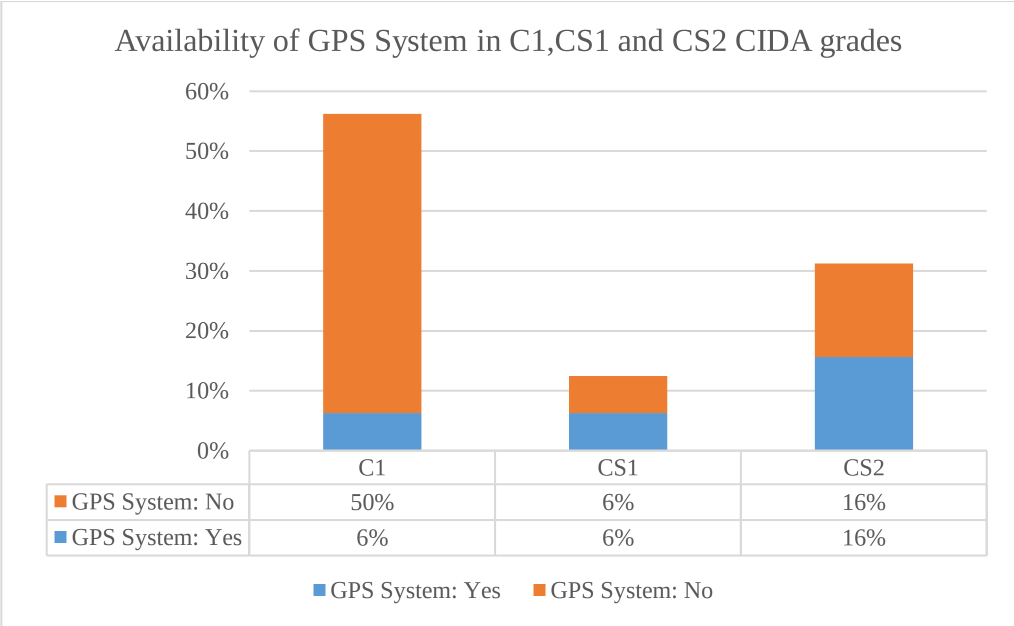

Figure 4. 5 Availability of GPS System in C1, CS1, and CS2 CIDA Grades

4.3 Issues in Construction Equipment Tracking and Monitoring

To achieve the objective of identifying current issues in tracking and monitoring the construction equipment, based on the Relative Important Index, issues identified in the literature were prioritized. Relative Important Index is a value between 0 to 1. Results of the data analysis of question no. 6 of the questionnaire survey are summarized in Table 4.1.

Table 4. 1 Issues in Construction Equipment Tracking

Issues in Construction Equipment Tracking and Monitoring	Relative Importance Index
High Fuel Consumption	0.875
Unable to monitor the usage/idling of equipment on site	0.838
Unavailability of Information on Operating Costs (Fuel, Oils, Grease, Repair, Maintenance)	0.838
Unable to monitor the equipment idling with the engine powered on	0.813
Theft or unauthorized usage of Equipment for fraudulent work	0.806
Unable to locate the equipment Realtime	0.800
Unavailability of Actual cost information for bidding	0.800
Unavailability of correct Usage/ Millage data for plan for Maintenance/Repairs	0.781
Unable to identify Machines needed to allocate to the project	0.756

As per Table 4.1, It can be identified that high fuel consumption of construction equipment is the topmost relatively important issue in large-scale construction companies in Sri Lanka, having an RII of 0.875.

Issues of being unable to monitor the usage or idling of equipment at the site and unavailability of information on operating costs have the same RII of 0.838.

Issue of unable to locate the equipment Real-time stands at 6th rank in Relative Importance Index. Even though Locating the equipment is the main function of the GPS monitoring system, it is not prioritized as an issue.

4.3.1 Other Critical Issues

Respondents were asked to explain any other critical issues based on their experience. The following main issues were identified

- Manual machine meter readings could be erroneous and manual meters could be broken.
- Shortages of skilled operators for construction Equipment and shortage of quality spare parts
- Construction equipment may take time more than the allocated time
- Fuel consumption varies with the allocated work of the construction equipment
- It's difficult to allocate actual costs and work done to each machine
- The problem in measuring machine efficiency when more than one operator is used on the same machine
- Safety issues related to construction equipment usage
- False Overtime of operators without productive work
- Calculating machine idle time is difficult when needed information is not available

4.4 Tracking and Monitoring Information Prefer to have in a GPS Tracking and Monitoring System to Enhance the Productivity

In order to achieve the objective of investigating the tracking and monitoring information needed to enhance the productivity of construction equipment, based on literature, cutting-edge GPS tracking system facilities and other basic facilities provided are prioritized using RII. Results of the data analysis of question no. Eight of the questionnaire survey are summarized in Table 4.2.

Table 4. 2 Tracking and Monitoring Information Prefer to have in a GPS Tracking and Monitoring System to Enhance the Productivity

Tracking and monitoring information prefer to have in a GPS Tracking and Monitoring System to enhance the productivity	Relative Importance Index
Machine Location Tracking	0.931
Fuel Consumption	0.919
Trips History	0.906
Idling Trends	0.888
Route Optimization	0.844
Predictive Maintenance	0.844
Cameras	0.819
Engine Faults	0.806
Remote Diagnosis	0.806
Dispatch Nearest Driver to the Equipment	0.800
Roadside Assistance	0.800
Remote Diagnosis	0.794
Driver Scorecards	0.788
Geofencing (Setting Boundaries to travel)	0.763
Weather Hazard Alerts	0.750

With relative importance of 0.931, Machine location tracking information is prioritized by respondents as per table 4.2. Based on table 4.1, even though respondents did not recognize being unable to track the real-time location of equipment as a major issue, respondents have recognized location tracking information as the most important information in a GPS tracking system.

4.4.1 Other Important Features Respondents Wanted in an Equipment Tracking and Monitoring System to Enhance the Productivity

- Some respondents recommended the GPS system shall have a good GPS and Internet Signal strength without disruptions to continuous tracking
- Some recommended that the GPS user interface shall be in the local language
- There shall be two categories of GPS System monitoring. i) Heavy construction equipment, ii) Tipper Trucks and other vehicles
- Monitor the health condition of drivers and operators was a good suggestion received by a respondent considering the COVID 19 pandemic

4.4.2 Issues Identified in GPS Tracking and Monitoring Systems

- Many mobile networks in Sri Lanka have internet connectivity issues when it comes to rural and poor signal areas.
- Poor familiarity with usage of GPS monitoring system for decision making and record-keeping

4.5 Initial Investment for a GPS Tracking and Monitoring System

Large-scale construction companies were asked to select the most preferred initial investment for a GPS tracking and monitoring system per vehicle. Data analysis is summarized in Figure 4.6. As per Figure 4.6 majority of 50% have selected the option for less than 20,000 per machine initial investment option.

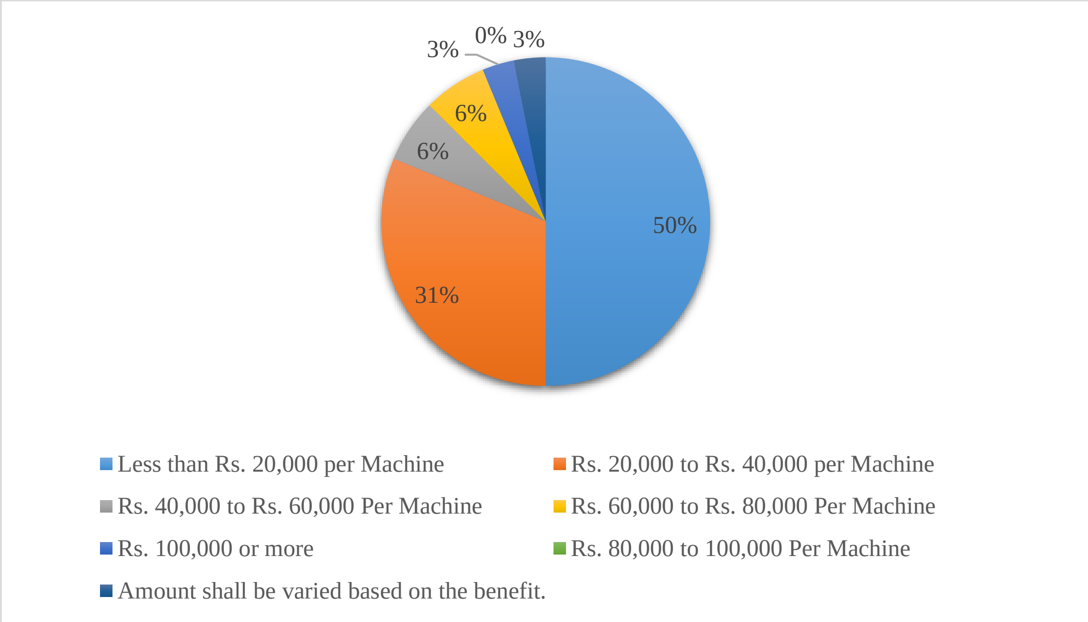

Figure 4. 6 Initial Investment for a GPS Tracking and Monitoring System

Secondly, 31% have selected 20,000 to 40,000 initial investments. It shows that more than 80% of the large construction companies are willing to spend less than 40,000 initial investments for the GPS Monitoring system per vehicle.

4.6 Monthly Subscription for a GPS Tracking and Monitoring System per Machine

Figure 4.7 summarizes the analysis of the response to question number 11 in the survey, which got the feedback of the respondents on the monthly payment they would like to incur to maintain the GPS tracking and Monitoring system per machine.

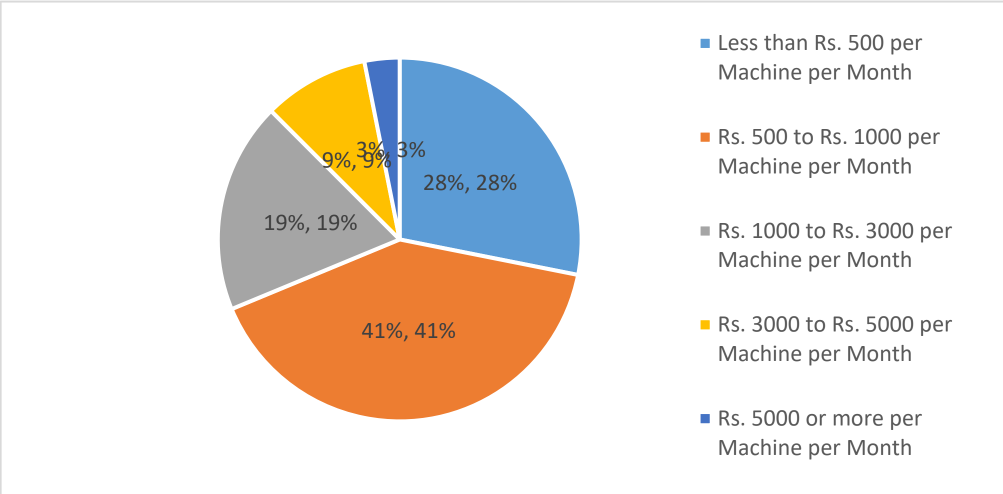

Figure 4. 7 Monthly Subscription for a GPS Tracking and Monitoring System

4.7 Method of Receiving the GPS Location

Question No. 12 of the questionnaire collected the preference of the respondents concerning the method of receiving the GPS location if the respondents were to implement a GPS tracking and monitoring system.

The results of the data analysis are summarized in Figure 4.8. As per the analysis, 56% of the sample preferred smartphone-based GPS location receiving GPS systems. Out of that, 56%, 3% of the sample preferred a smartphone-based system where the driver or operator could not see or input anything.

44% of the sample preferred GPS tracking receivers where the driver cannot see or input anything.

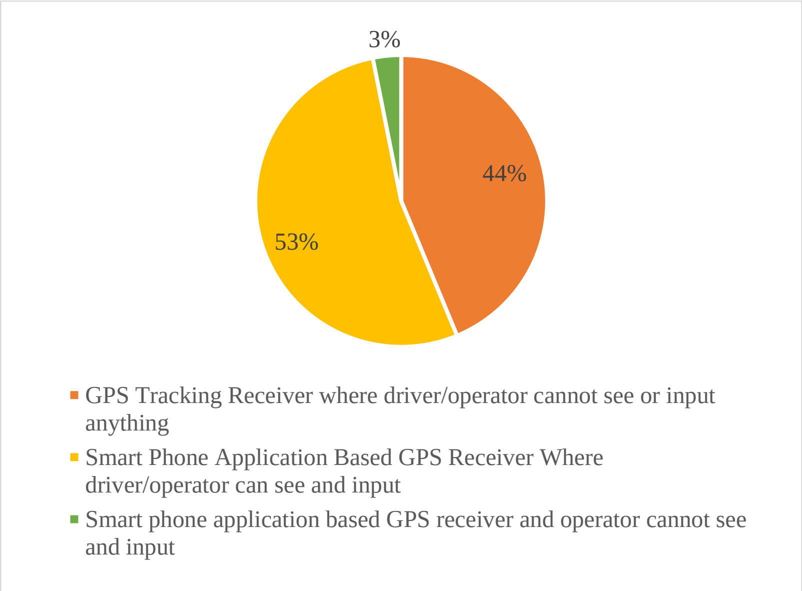

Figure 4. 8 Method of Receiving the GPS Location

4.8 Case Study Results

The selected construction company's current equipment monitoring process was mapped and analyzed since this system is representative of the construction equipment monitoring process in Sri Lankan construction projects. Areas for process improvement were identified utilizing GPS monitoring system outputs along with questionnaire survey findings.

For the case study planning, loading, hauling and unloading, returning, and monitoring processes related to dump trucks were considered. The current process followed by the company was mapped.

Process improvements were identified using the outputs of a GPS monitoring system to enhance the productivity of dump trucks, considering the following aspects.

- Improve the weekly transport plan process
- Reducing the loading time and increasing the efficiency
- Reducing the hauling time and increasing the efficiency
- Reducing the unloading time and increasing the efficiency
- Reducing the returning time and increasing the efficiency
- Improve the Monitoring Process

4.8.1 Mapping and Analysing Current Dump Truck Monitoring Process

4.8.1.1 Weekly Transport Plan

When there is a material requirement for construction work, the initial step would be to raise the Material Request. It is done in the selected company using a Material Request Note (MRN) which is sent to main stores. Figure 4.9 shows the process diagram of the transformation of a Material Request into a weekly transport plan for dump trucks.

After the receipt of the Material Request, stock availability will be checked, and if the material is not in the stock purchasing process will initiate, which will not be discussed in this study. Available material will be checked for bulk material or not. If it is a bulk material like gravel, sand, or Aggregates prioritizing material requests will be done by the transport manager while discussing with the Project Managers. If it is not a bulk material, Material Requests will be prioritized by the transport manager in collaboration with Stores Manager while discussing with the Project Managers. Based on the information, a priority list will be created based on the above information. After the priority list is prepared, there could be urgent material requests which are approved by the Top Management of the selected company that needs to be prioritized. Priority List would be changed based on the urgent material request. Based on the priority list weekly transport plan is created by the Transport Manager.

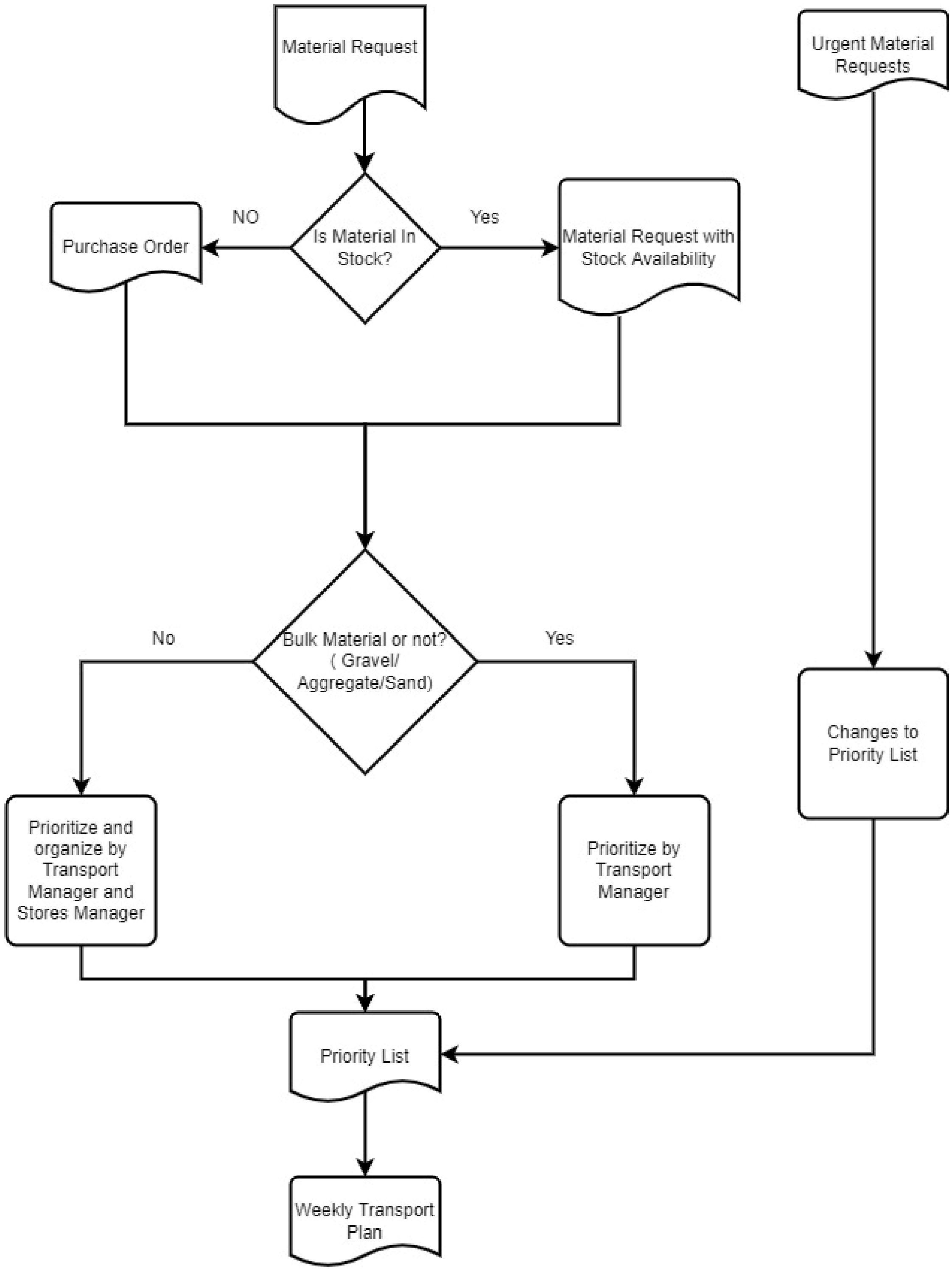

Figure 4. 9 Process of Creating the Weekly Transport Plan

4.8.1.2 Selection of Routes and Material Loading Process

Based on the Weekly Transport Plan, the next step in the process would be the selection of routes, assigning tasks to dump truck drivers, and deciding on the amount of fuel to be issued for each hauling operation. This process is shown in Figure 4.10.

Selection of the route for the transporting process would be made initially using google maps by the Transport Manager. If the transport operation is continuous, generally more than 100 loads route will be observed by a representative from the transport department in the first vehicle. If there is an economical route, it will be selected based on expert judgment. Hauling speed is estimated based on the average speed traveled in the trip.

Assigning tasks for dump truck operators is done by the transport manager. Fuel needed for the daily operation is estimated based on average consumption. After estimating fuel quantity, fuel was allocated to each job.

In the loading process for Bulk Material, a visual check is done for the truckload determination. Full truck loads are checked visually with a minimum spill from the loading. If there is a need for a partial truckload needed quantity will be measured using tape measuring the truck capacity.

If there is a weighbridge available weighbridge report will be sent with the transfer docket. A visual check will be done by the security officer before releasing the truck from the loading site.

If the material is not bulk material, transfer notes have to be issued from Stores Manager, and the material is loaded as per the transfer notes. A visual check of the loaded material will be done by the security officer and storekeeper. After checking, the gate pass is signed and released from the main stores.

Figure 4.10 illustrates the flow of the process.

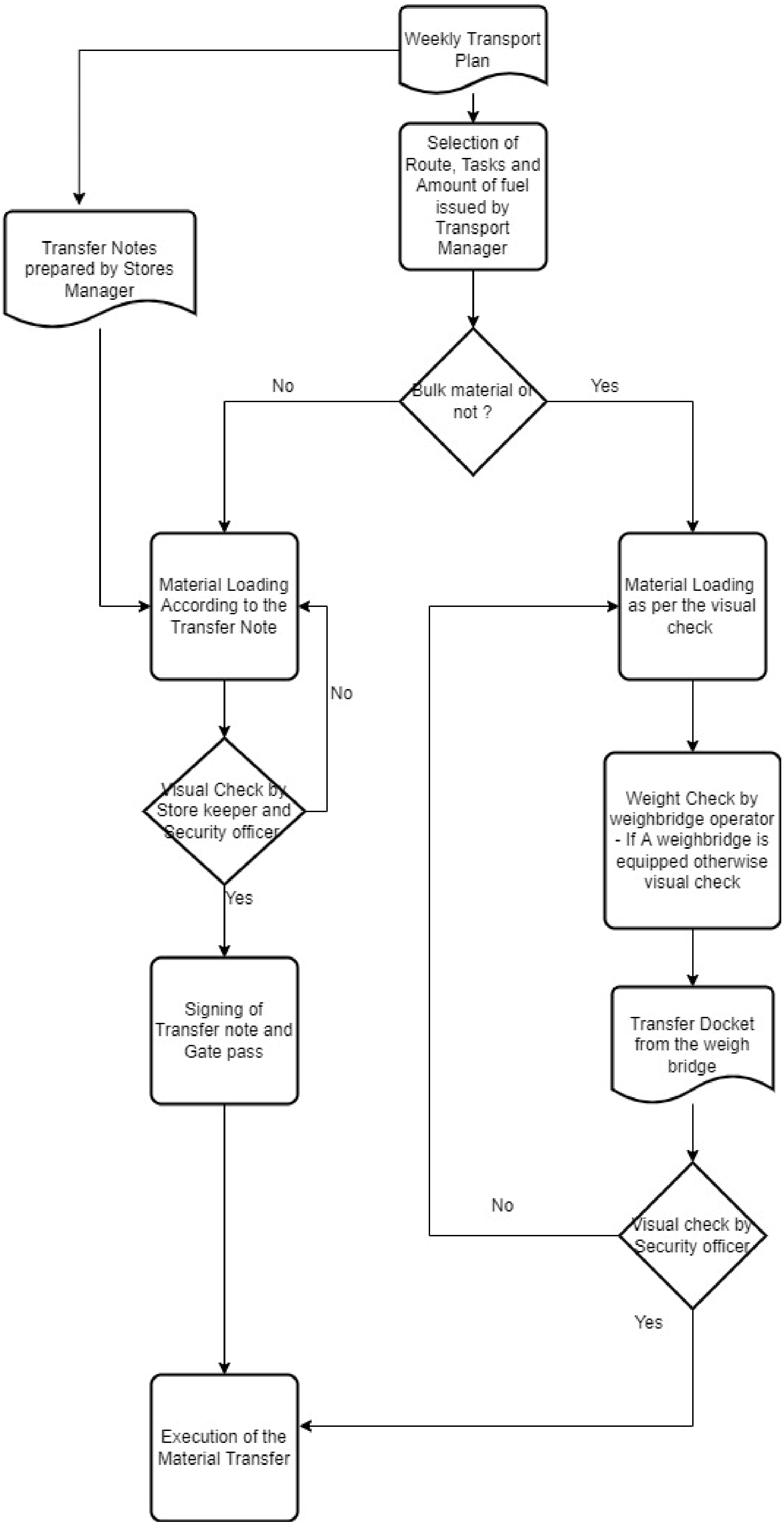

Figure 4. 10 Planning to Loading Process

4.8.1.3 Hauling and Unloading

Before initiating the material transfer Vehicle Running Chart is filled by the dump truck operator. The selected company uses a triplicate running chart book. The truck operator has to complete the trips for the day and fill the running chart and submit the 1st copy of the running chart daily with signed dockets or material transfer notes. Figure 4.11 illustrates the process followed in hauling and unloading.

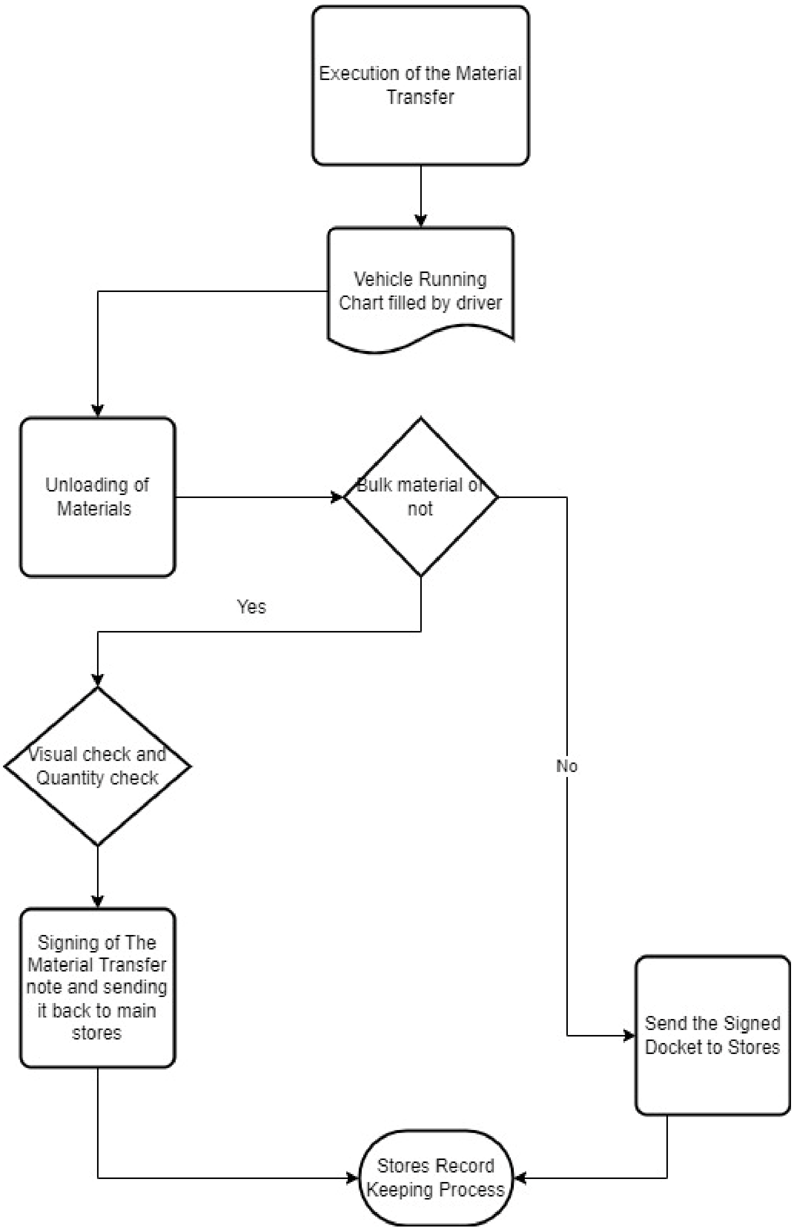

Figure 4. 11 Hauling to Unloading Process

4.8.1.4 Monitoring Process

The monitoring process of hauling trucks in the selected company is illustrated in Figure 4.12. After completing the daily trips, the first copy of the running chart is collected from Drivers. Running chart distances from the meter readings are compared with the planned trip distances. If there is a deviation explanation is asked from the drivers, and if the explanation is satisfactory, the explanation is mentioned as remarks in the running chart checking. If the explanation for the deviation is not satisfactory, an initial warning is issued, and if the deviation happens, continuously punitive action is taken.

As a secondary check, Google Map distance between trip locations is checked and similar to above. If there are significant deviations, explanations are requested.

For checking the fuel consumption, the fuel tank was made full, and the average fuel consumption was calculated. Fuel consumption is checked with benchmarks. The selected company uses the following benchmark based on historical information.

- For 6-wheel dump trucks, the benchmark for fuel consumption was taken as 3.5km/l
- For 10-wheel dump trucks, the benchmark for fuel consumption was taken as 2.5 km/l

When actual fuel consumption is compared with the benchmarks if there is a significant deviation, an explanation from the driver is requested.

Figure 4.12 illustrates the process which is followed by the selected company and the steps taken to monitor the trucks.

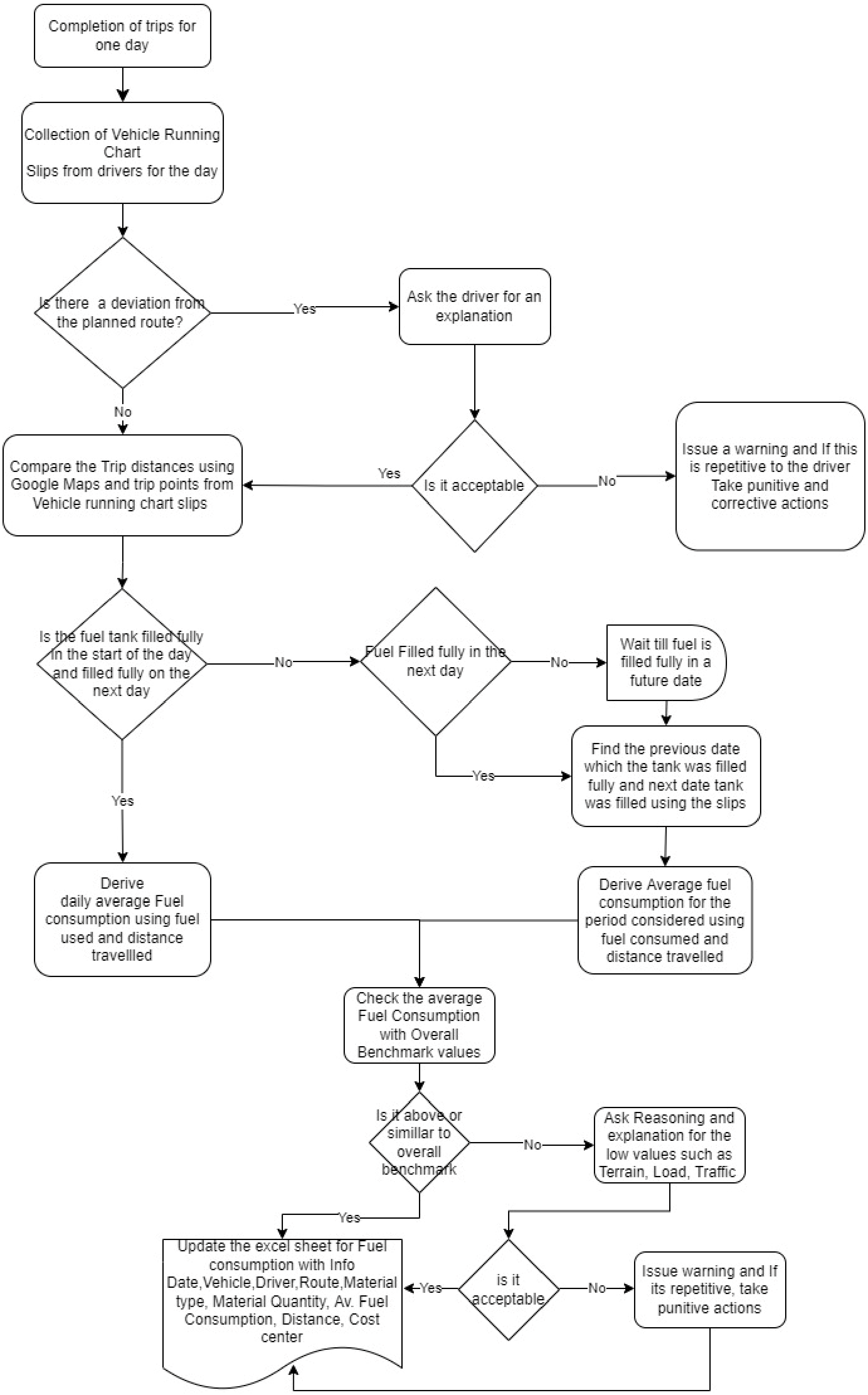

Figure 4. 12 Monitoring Process

4.8.2 Identifying Process Improvements

Top 5 tracking and monitoring information preferred to have in a GPS tracking and monitoring system based on the data analysis of question no. Eight of the questionnaire survey are prioritized based on Relative Importance Index results.

Table 4. 3 Prioritized Tracking and Monitoring Information

	Tracking and monitoring information prefer to have in a GPS Tracking and Monitoring System	Relative Importance Index
1	Machine Location Tracking	0.931
2	Fuel Consumption	0.919
3	Trips History	0.906
4	Idling Trends	0.888
5	Route Optimization	0.844

4.8.2.1 Improvements to Preparation of Transport Plan

The process of preparation of transport plan could be improved by following outputs of the GPS Monitoring System.

- Machine Location Tracking
- Fuel Consumption
- Trips History
- Idling trends

When creating the Weekly Transport Plan, the Machine location is collected by available trucks in a project and by coordinating over the phone with drivers by Transport Manager. This process could be improved by Locating the machines in real-time using the GPS Monitoring System and deciding what the most cost-effective option in assigning a task for a dump truck is.

In the current planning process, fuel consumption, trip history, and idling trends for an individual truck are not considered in creating the transport plan. With the actual fuel consumption records available with the GPS Monitoring System, it is recommended to use vehicles with better fuel consumption for long hauling trips. It is very important to consider the trip history and idling trends to assign work evenly among vehicles. The improved process is illustrated in Figure 4.13.

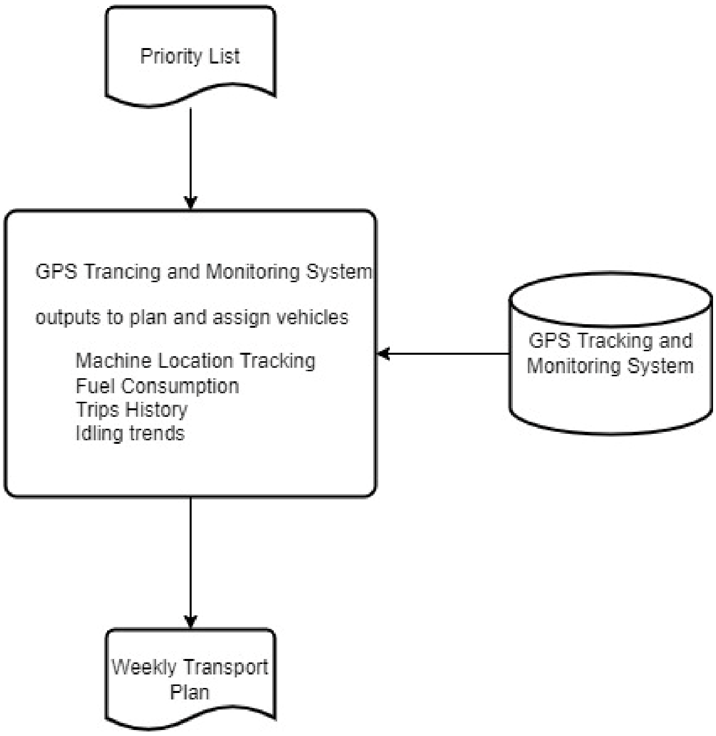

Figure 4. 13 Improvements to Transport Planning Process

4.8.2.2 Improvements to Selection of Routes, Assigning Tasks, and Allocating Fuel

In the current process, the selection of routes is initially made by google maps manually by adding the point of vehicle location and adding the delivery location, and getting directions from google maps. With the GPS Tracking and monitoring system with route optimization, vehicle location will also be taken accurately, and transport routes could be optimized using the GPS tracking monitoring system.

Based on the machine location, fuel consumption, trip history, and idling trends could be used in assigning trucks to specific works. The process of allocating fuel could be improved significantly with the actual fuel consumption historical information from the Monitoring System and available fuel quantity information. Available fuel quantity and the ability to check it remotely will be a piece of very helpful information in deciding the amount of fuel to be allocated.

4.8.2.3 Improvements to Monitoring Process

The current Monitoring Process of the selected company is only focused on checking trip distance and fuel consumption after the trip is completed. The monitoring process is not arranged in a way to monitor the trips in real-time, but it is focused on evaluating the performance and taking corrective actions.

Historical information related to vehicles such as Date, vehicle Number, Driver, Route, Material Type, Material Quantity, Average Fuel Consumption, Distance, and cost center is recorded in a Microsoft excel file. There could be backlogs accumulated due to delays in manually entering information.

The monitoring Process could be improved with outputs from GPS Tracking and Monitoring System, as illustrated in Figure 4.14.

The current Monitoring process of the Selected company is mainly designed to monitor actual trip distance against planned trip distance and monitor actual fuel consumption against planned fuel consumption.

Production is based on Truck Load, Number of Trucks, and Truck Cycle Time. Truck Cycle time is dependent on load time, haul time, dump time, and return time.

In the selected company load time, dump time is not recorded but monitored and controlled by the supervisor overseeing the process. Haul time and return time are recorded in the running chart. With a GPS Monitoring system, the monitoring process shall be improved to capture the following.

- Truckload
- Number of trucks used for the operation
- Truckload time
- Truck haul time
- Dump time
- Return time

As per the method mentioned in section 2.3.2, production can be calculated using the GPS Monitoring System with the above inputs.

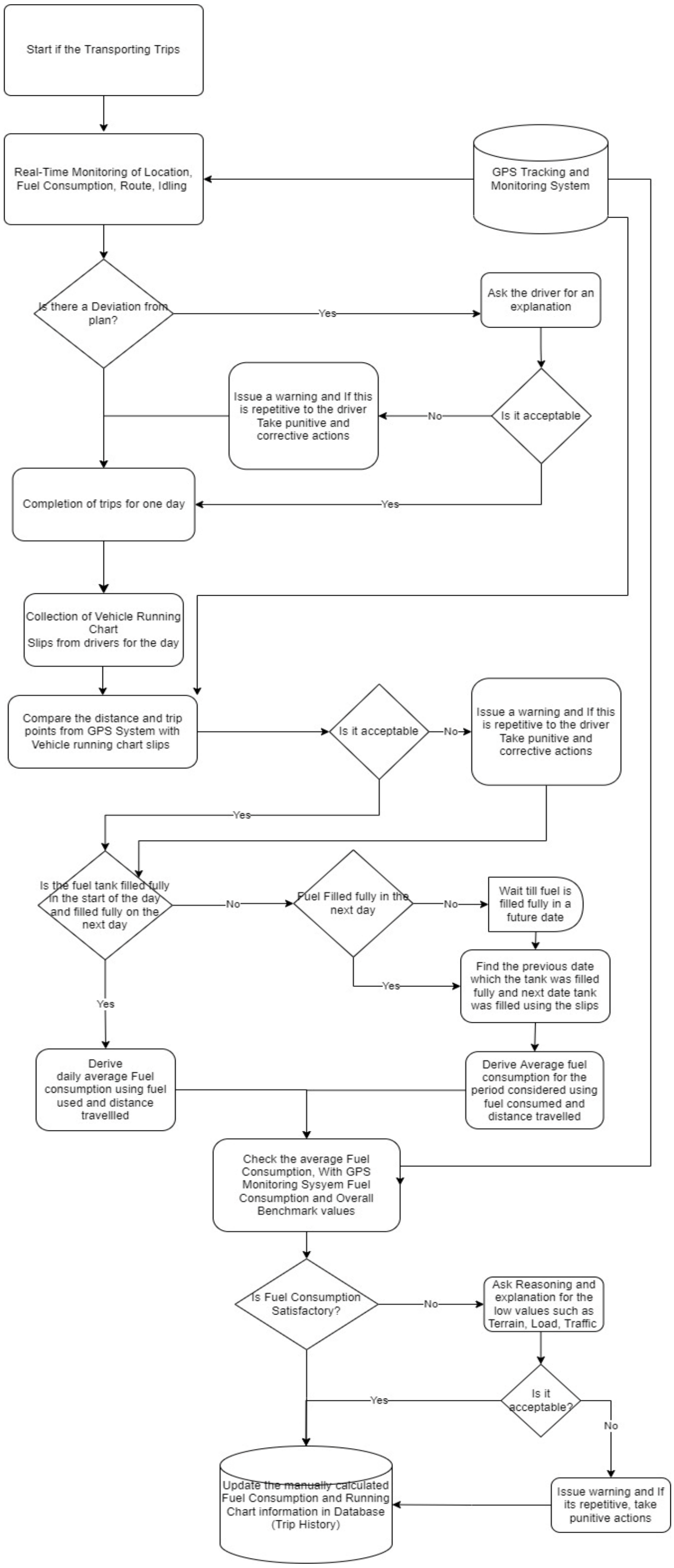

Figure 4. 14 Improved Monitoring Process

5. DISCUSSION, CONCLUSION, AND RECOMMENDATION

5.1 Introduction

The outcomes of the data analysis reported in Chapter 4 are discussed in this chapter. It covers a discussion of the recognized issues in tracking and monitoring construction equipment, as well as an investigation of the tracking and monitoring information required to improve construction equipment productivity. The mapping and analysis of processes followed by the selected organization were done. Improvements were proposed to the processes using outputs of GPS tracking and monitoring system to enhance productivity.

5.2 Findings of the Study

Authority to assign construction equipment and responsibility to monitor construction equipment was analyzed to identify who should be given the monitoring access of a GPS Monitoring System outputs. 66% of responding organizations, the Project Manager has the authority to assign equipment, but 50% of the sample organizations' Project Managers are responsible for monitoring construction equipment. Similarly, 50% of respondent organizations' Site Engineers have the authority to assign, but 38% only have the responsibility to monitor. There is a gap in authority to assign and responsibility to monitor. In contrast, 41% of sample organizations' Equipment Managers had the authority to assign, and 41% were considered responsible for monitoring. This information shows there are several employees with the authority to assign equipment, but they have not been given the responsibility to monitor and impact the productivity of construction equipment. When an employee has the authority to assign equipment, he shall be given access and responsibility to monitor the assigned equipment to have better equipment management.

28% of the responding organizations have current GPS systems, whereas 72% of the organizations do not have a GPS tracking and monitoring system. Data were grouped based on CIDA grading further to analyze the availability of GPS tracking and monitoring devices. It has been discovered that 50% of CIDA CS2 and CS1 enterprises have adopted GPS tracking and monitoring systems, whereas just 10.7% of C1 companies have deployed GPS systems for construction equipment tracking. When a C1 company develops to the CS1 and CS2 levels, the need for better management of construction equipment becomes essential due to the equipment management process becoming too complex to monitor manually.

With an RII of 0.875, it can be determined that excessive fuel consumption of construction equipment is the topmost relatively critical concern in big-scale construction enterprises in Sri Lanka. The top 5 relatively critical issues related to tracking and monitoring construction equipment that was found in the study were as follows.

1. High Fuel Consumption
2. Unable to monitor the usage/idling of equipment on site
3. Unavailability of Information on Operating Costs (Fuel, Oils, Grease, Repair, Maintenance)
4. Unable to monitor the equipment idling with the engine powered on
5. Theft or unauthorized usage of Equipment for fraudulent work

With relative importance of 0.931, respondents did identify location tracking information as the most critical information in a GPS tracking system. The top 5 relatively important Tracking and monitoring information preferred to have in a GPS Tracking and Monitoring System to enhance productivity was used in the case study to improve the monitoring process of the selected organization. They were as follows,

1. Machine Location Tracking
2. Fuel Consumption
3. Trips History
4. Idling Trends
5. Route Optimization

The process of creating the transport plan in the selected organization for the case study was mapped, and improvements to the transport plan were identified using prioritized information from a GPS tracking and monitoring system.

Production of a dump truck is dependent on truckload, the number of trucks, and truck cycle time. Truck cycle time is a function of load time, haul time, dump time, and return time. When creating a transport plan above parameters shall be taken into account. Since the transport plan is prepared by the transport manager, real-time information on excess equipment on-site or shortage of assigned equipment could be identified using the outputs of the GPS tracking and monitoring system. Without a GPS system, it would require getting a physical update about available equipment and its condition. With trip history and idling trends, it is easy to identify equipment that does excess work compared to others, and priority could be given to the idling construction equipment.

In selecting the best route for hauling and return, route optimization could be done from the software platform for monitoring the equipment. It would convert the existing manual method of route selection into a more systematic process and less time-consuming process.

Fuel consumption could be measured by having a fuel gauge in the fuel tank and meter readings from the truck. Available fuel levels also could be taken as an output. This parameter would be helpful in determining the fuel allocation for the vehicle. Managers can conserve fuel by analyzing idling trends and machine usage patterns.

The monitoring process of the organization in the case study was mapped, and it was identified that trip distance, and fuel consumption was checked by the transport manager by the current process. Productivity was checked but not formally recorded by the project management staff. The transport manager was more focused on identifying deviations from the plan after the trips had been completed and corrective action was taken. It was proposed to monitor the location, the route being used, fuel consumption, and idling in real-time and address the issue in real-time. This could prevent the wastage of resources before it happens. The process of checking the vehicle running charts was also proposed to improve using accurate and organized information from GPS tracking and monitoring system. Record keeping manually was one of the concerns identified by the transport manager as it is likely to have a backlog due to the large about of information to sort and enter in to excel data sheet manually. Record keeping process also could be improved by automatically recording the information from the GPS tracking and monitoring system, and if needed, manually calculated inputs could also be added. Since the productivity of a dump truck is based on the truckload, the number of trucks used for the operation, Truckload time, a truck traveling time with load, Allowance for the dumping time, the truck return time, and manufacturers parameters. I was proposed to track and monitor the above information as it will contribute to overall productivity. Because reducing the overall cost will not always increase productivity. Managers shall be focused on reducing the cost of unit output for a task that was done within the allocated time frame.

Sixty-six percent of respondents chose smartphone-based GPS location receiving GPS devices. Forty-four percent of those polled favored GPS tracking receivers that did not allow the driver to see or input anything. The majority of respondents preferred having a smartphone-based GPS tracking and monitoring system. Using a smartphone-based system with driver input would be able to capture actual loading time, hauling time, dumping time, and return time with the inputs from the drivers. Results could be compared with the estimated parameters, and it could be helpful in identifying deviations.

In the matter of initial investment per vehicle, the majority have chosen the option for an initial expenditure of less than LKR 20,000 per machine and a monthly subscription between LKR 500 to 1000. The majority of vehicle telematics devices in Sri Lanka in 2021 could be fitted with less than 20,000 budget without fuel monitoring. Vehicle telematics devices with fuel gauges and other features would cost more based on the features preferred in the system. It is recommended to do an initial test run and compare costs and benefits before implementing a GPS tracking and Monitoring System in a fleet of construction equipment.

5.3 Conclusion and Recommendations

It could be recommended that when an employee has the authority to assign construction equipment, they shall have responsibility and access to monitoring the assigned equipment. Outputs from a GPS tracking and monitoring system could improve the planning process, the process of assigning jobs, selecting the best route to travel, and the monitoring process of the organization. Using telematics, organizations could identify issues and deviations from the plan while the trip is ongoing and implement corrective actions, which will save cost, time, and resources compared to conventional post-trip checking.

The literature highlighted various flaws in construction equipment simulation, such as the lack of realistic evidence to support a simulation framework, and underlined the necessity for incorporating real-time field data into simulations. Hence a field study is proposed as the future development of the research to evaluate the potential benefits of a GPS monitoring system on the productivity of construction equipment.

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Appendix – A

Sample Questionnaire

Questionnaire on GPS Tracking and Monitoring Heavy Construction Equipment

Dear Sir/Madam,

I am carrying out a research on Using GPS Monitoring System to Enhance Productivity of Heavy Construction Equipment. This questionnaire survey is done to collect data to identify issues in tracking and monitoring heavy construction equipment and identify the tracking information required by experts in the construction industry to enhance the productivity of heavy construction equipment.

This questionnaire survey will take less than 5 minutes to complete. I respectfully ask you to take few minutes out of your busy schedules and complete the following questionnaire survey. By answering this survey, you are supporting the University of Moratuwa Research and contributing to the pursuit of knowledge. My research findings will be summarized and communicated back to you. All efforts have been taken to maintain confidentiality. Thank you for your participation.

Janith Bogahawatta,
Postgraduate Student of MSc in Construction Project Management,
University of Moratuwa.
0779483388

* Required

1. Name:

____

2. Name of the Company: *

____

3. Your Position: *

____

Please select one or more appropriate answers for following questions and specify any thing that is not included as an answer in the other selection.

4. 1. Please select the CIDA grade of your construction company. *

Check all that apply.

- [ ] CS2
- [ ] CS1
- [ ] C1
- [ ] C2
- [ ] C3
- [ ] Other: ______________________

5. 2. What are the types of construction equipment owned by your company? *

Check all that apply.

- [ ] Dump Trucks (Tippers)
- [ ] Bulldozers
- [ ] Excavators (Backhoe)
- [ ] Backhoe Loaders(JCB)
- [ ] Motor Graders
- [ ] Compacting Equipment (Road Rollers)
- [ ] Pavers
- [ ] Wheel Loaders
- [ ] Cranes
- [ ] Scrapers
- [ ] Trenching Machines
- [ ] Boom Trucks
- [ ] Pile driving Equipment
- [ ] Concrete Mixer Trucks
- [ ] Other: ______________________

6. 3. Who has the authority of assigning a particular Construction Equipment for a specific task? *

Check all that apply.

- [ ] Technical officer
- [ ] Site Engineer
- [ ] Project Manager
- [ ] Equipment Manager
- [ ] Top Management
- [ ] Other: ______________________

7. 4. Who is responsible for monitoring productivity of Heavy Construction Equipment (Machines)?

Check all that apply.

- [ ] Technical Officer
- [ ] Site Engineer
- [ ] Project Manager
- [ ] Equipment Manager
- [ ] Top Management
- [ ] Other: ______________________________

8. 5. Does your company have a GPS Tracking and Monitoring System for Construction Equipment? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Other: ______________________________

9. 6. Please rate the issues you have experienced in tracking and monitoring equipment based based on imporatnce *

5: Very Important 4: Important 3: Moderately Important 2: Slightly Important 1: Unimportant

Mark only one oval per row.

	5: Very Important	4: Important	3: Moderately Important	2: Slightly Important	1: Unimportant
Unable to locate the equipment realtime					
Unable to monitor the usage/idling of equipment on site					
Unable to identify Machines needed to allocate to the project					
Unavailability of correct Usage/ Millage data for plan for Maintenance/Repairs					
Theft or unauthorized usage of Equipment for fraudulent work					
High Fuel Consumption					
Unable to monitor the equipment idling with the engine powered on					
Unavailability of Actual cost information for bidding					
Unavailability of Information on Operating Costs (Fuel, Oils, Grease, Repair, Maintenance)					

10. 7. What are the other critical issues in tracking and monitoring construction equipment based on your expertise?

11. 8. What are the tracking and monitoring information you prefer to have in a GPS Tracking and Monitoring System to enhance the productivity of construction equipment?

5: Very Important 4: Important 3: Moderately Important 2: Slightly Important 1: Unimportant

Mark only one oval per row.

	5: Very Important	4: Important	3: Moderately Important	2: Slightly Important	1: Unimportant
Machine Location Traking	⬭	⬭	⬭	⬭	⬭
Geofencing (Setting Boundaries to travel)	⬭	⬭	⬭	⬭	⬭
Trips History	⬭	⬭	⬭	⬭	⬭
Dispatch Nearest Driver to the Equipment	⬭	⬭	⬭	⬭	⬭
Roadside Assistance	⬭	⬭	⬭	⬭	⬭
Fuel Consumption	⬭	⬭	⬭	⬭	⬭
Idling Trends	⬭	⬭	⬭	⬭	⬭
Route Optimisation	⬭	⬭	⬭	⬭	⬭
Engine Faults	⬭	⬭	⬭	⬭	⬭
Predictive Maintenance (Predict when failures will occur and maintain accordingly)	⬭	⬭	⬭	⬭	⬭
Remote Diagnosis	⬭	⬭	⬭	⬭	⬭
Accident Detection	⬭	⬭	⬭	⬭	⬭
Driver Scorecards	⬭	⬭	⬭	⬭	⬭
Weather Hazard Alerts	⬭	⬭	⬭	⬭	⬭
Cameras	⬭	⬭	⬭	⬭	⬭

12. 9. What are the other important features you would want in a Equipment tracking and Monitoring System to enhance the productivity?

13. 10. What is the initial investment you would prefer to do to set up a GPS tracking and Monitoring System per Machine? *

Mark only one oval.

- Less than Rs. 20,000 per Machine
- Rs. 20,000 to Rs. 40,000 per Machine
- Rs. 40,000 to Rs. 60,000 Per Machine
- Rs. 60,000 to Rs. 80,000 Per Machine
- Rs. 80,000 to 100,000 Per Machine
- Rs. 100,000 or more
- Other:

14. 11. What is the monthly payment would you like to incur to maintain the GPS Tracking and Monitoring System per Machine *

Mark only one oval.

- Less than Rs. 500 per Machine per Month
- Rs. 500 to Rs. 1000 per Machine per Month
- Rs. 1000 to Rs. 3000 per Machine per Month
- Rs. 3000 to Rs. 5000 per Machine per Month
- Rs. 5000 or more per Machine per Month

15. 12. What is your prefered method of Receiving the GPS Location if you were to implement a GPS tracking and Monitoring System? *

Mark only one oval.

- GPS Tracking Receiver where driver/operator cannot see or input anything
- Smart Phone Application Based GPS Receiver Where driver/operator can see and input
- Other: ____________________