IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

CONSTRUCTION EQUIPMENT SELECTION AND OBJECT DETECTION FOR COLLISION PREVENTION USING DEEPLEARNING

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Abstract: The selection of equipment for a project is one of the key decisions in planning and executing a construction project as it affects how efficiently the work will be done, the time required to completethe work and the total cost that will be accrued. This study identified 48 factors influencing constructionequipment selection in the construction industries through literature review. The questionnaire was sent to various construction professionals directly involved with construction industries. The responses were checked for internal consistency reliability, then analyzed using SPSS software and ranked considering Relative Importance Index method to identify the dominating factor influencing equipment selection. The findings revealed that the three major influencing factors project and site-specific factors, engineering criteria and equipment specific factors. Two SEM models were developed: the first model relating most contributing and least contributing factor and the second model relating all the factors affecting construction equipment selection. A construction object detection model was developed using deep learning to detect construction objects. Construction objects here refer to construction equipment and construction workers. The types of construction equipment considered were 'truck', 'dozer', 'excavator', and 'crane'. The developed model also works as an automated collision detection system and detects any impending collision between a construction worker and a piece of construction equipment

KEYWORDS: Construction equipment, Selection, Reliability, RII, SEM, Detecting model, Collisiondetection

I.INTRODUCTION

Any organization tends to gain benefit through effective use of resources and converting them into marketable products. One such industry is the construction industry which can be benefitted from proper material management and equipment management. The role of effective equipment utilization in construction projects is of great concern. Construction equipment usually constitutes about 10-35% of the total cost in a building construction project. Choosing the best alternative for obtaining equipment is one of the prime issues to gain profit for the construction industry. Construction projects are highly mechanized and becoming more so every day. With the growing industrialization of construction work, the role of onsite equipment and machinery is vital in achieving productivity and efficiency. During the construction phase, the selection of the right equipment leads to the success of any construction project. This decision is often made by matching equipment available in a fleet with the tasks to be carried out. Such analysis accounts for equipment productivity, equipment capacity, and cost. Construction equipment planning and selection play a crucial role in the success of construction firms. Manual processes of equipment planning and selection that are insufficient along with the subjective decisions of equipment managers usually result in considerable losses in construction firms. Being a crucial item of resource, it produces output at an accelerated speed and allows the task to be completed within a limited period. Manpower is becoming costly and more demanding nowadays. So, the use of equipment can save manpower. The use of equipment enhances quality, productivity, and safety.

Construction equipment planning aims at identifying construction equipment for executing project tasks, evaluating equipment performance capability, forecasting date-wise requirement of number and type of equipment, and finally participating in the selection of equipment to be acquired. A particular method for selecting equipment has to be adopted which will be more productive and less expensive and more profitable. Equipment selection is a critical factor in the execution of many construction projects. In heavy construction projects this becomes a much more critical factor where the equipment fleet plays a vital role in performing the work. Proper selection and better planning of the operations help to derive full benefits from the equipment. The planning and selection procedure that a company adopts for its equipment to achieve its objective of meeting the project deadline is essential. This research work is aiming to develop a deep learning-based construction object detection model to detect 'trucks','dozer', 'excavator', 'crane', and construction workers as well as a model for automated detection of collision between construction equipment andconstruction workers at construction sites.

1.1. Construction Equipment

"Construction equipment" (CE) or "Heavy equipment" refers to heavy-duty self-propelled vehicles that are specially designed to accomplish various construction tasks. Most huge construction projects require different types of construction equipment to perform various tasks. It not only enhances operational efficiency but also the use of construction equipment helps to achieve project targets and contractors' goals. It is of significant importance in the successful completion of construction projects. With the advent of new equipment and innovative methods, some wholesale changes have become possible in construction technologies in recent decades. It is therefore crucial for the site managers and construction planners to be familiar with the characteristics of the major types of equipment most commonly used in construction. Therefore, it serves as a major capital investment in the construction industry. The term CE here refers to the machinery that is used especially for earth-moving operations (excavators, dump trucks, loaders, compaction rollers, graders, scrapers, etc.). Those earthworks mainly consist of four basic processes: excavating, hauling, spreading, and compacting.

The three main inputs in construction practice include labor, materials, and construction equipment. So, construction equipment is a significant factor to run the project more successfully. High standards can be attained through the use of construction equipment which also makes the construction process more economical. A wide variety of portable or movable items ranging from hand tools to heavy equipment like cranes, trucks, dozers, excavators, etc., are classified as machinery or equipment. Construction costs can be reduced and productivity can be increased through the effective utilization of construction equipment. It also helps to reduce wastage of construction materials resulting from handling and placing. Effective equipment management paves way for the successful completion of construction projects.

II. LITERATURE REVIEW

Chinda, Thanwadee, and Pimnapa Pongsayaporn. "Relationships among factorsaffecting construction safety equipment selection: Structural equation modelling approach." Civil Engineering and Environmental Systems 37.1-2 (2020): 28-47, utilizes the structural equation modelling to examine relationships among key factors affecting construction safety equipment selection. The approach considers measurement- and structural-models. The measurement-model confirms key factors and their relationships, while the structural model examines relationships directions. Questionnaire survey is utilized to collect data. Respondents include managers and operators from medium- and large-sized construction companies. Six key factors are confirmed with the measurement-model results, including (1) Safety-related Policy, (2) Equipment Design, (3) Personal, (4) Supplier Agreement, (5) Supplier Support, and (6) Cost Value factors. They relate with employers, employees, and suppliers to select construction safety equipment that match with company's policy and employees' need to reduce chances of accidents. The structural-model results reveal directionsof relationships among key factors. Safety-related Policy is the most important factor, as it influences other factors. Equipment Design and Personal factors are crucial when selecting construction safety equipment, as they influence Supplier Agreement and Supplier Support factors, which in turn, affect Cost Value factor. Construction companies can utilize the results to understand key factors affecting construction safety equipment selection, and make better decisions.

Dang, Khang, and Tuyen Le. "A Novel Audio-Based Machine Learning Model for Automated Detection of Collision Hazards at Construction Sites." ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction. Vol. 37. IAARC Publications, 2020, presents a newly developed auditory surveillance framework using convolutional neural networks (CNNs) that can detect collision hazards by processing acoustic signals in construction sites. The study specifically has two primary contributions :a new labeled dataset of normal and abnormal sound events relating to collision hazards in the construction site, and a novel audio-based machine learning model for automated detection of collision hazards. The model was trained with different network architectures, and its performance was evaluated using various measures, including accuracy, recall, precision, and combined F-measure. The research is expected to help increase the auditory situational awareness of construction workers and consequently enhance construction safety.

Gurmu, Argaw Tarekegn, and Ajibade Ayodeji Aibinu. "Construction equipment management practices for improving labor productivity in multistory building construction projects." ***Journal of Construction Engineering and Management*** **143.10 (2017): 04017081,** adopted a two-phase exploratory sequential mixed-methods design. During Phase I, 19 experts were interviewed. The qualitative data were analyzed, and construction equipment management practices that have the potential to improve productivity were identified. In Phase II, data were collected from 39 principal contractors on 39 projects using questionnaires. A scoring tool for measuring the practices was developed; a logistic regression model was also developed for predicting the probability of exceeding baseline productivity factor using a sigmoid graph when the score of the practices is known. This research contributes to the body of knowledge by developing a construction equipment management practice measuring, planning, monitoring, and evaluating tool in the context of multistory building projects. Also, the logistic regression model can be used to test whether a certain level of implementation of a construction equipment management practice might be associated with higher or lower productivity compared to the baseline.

Naskoudakis, Ilias, and Kleopatra Petroutsatou. "A thematic review of main researches on construction equipment over the recent years." ***Procedia engineering*** **164 (2016): 206- 213,** conducted a thorough systematic review of the academic literature that has been published over the last decade primarily identified via online databases, main research themes such as optimization, maintenance/downtime, productivity, robotics and automation, operator's competence, innovation, environment are determined and discussed and future research directions are proffered. The outcome of this paper will facilitate future researchers to develop a body of knowledge of progress on construction equipment and its potential functions and provide future research directions on this issue.

Waris, M., et al. "Criteria for the selection of sustainable onsite construction equipment." International Journal of Sustainable Built Environment 3.1 (2014): 96-110, aims to determine a selection criterion based on the fundamental concept of sustainability and provides an assessment framework. A questionnaire survey was conducted among a classified group of Malaysian contractors to elicit information pertaining to the sustainable selection of onsite machineries. The findings of this study will guide the decision makers to appraise the selection process of construction equipment on the triple bottom line of sustainability. Based on the qualitative and quantitative findings, the study has established criteria for the selection of sustainable construction equipment for onsite mechanization. The sustainable criteria presented as a result of this endeavor are different from the conventional way of procurement which emphasizes on cost, time and quality.

III. METHODOLOGY

The research used the methodology of a questionnaire survey and examined construction professionals who are directly involved in construction projects. It also aimed to develop a construction object detection model using deep learning to detect construction equipment, construction workers and the collisions between them.

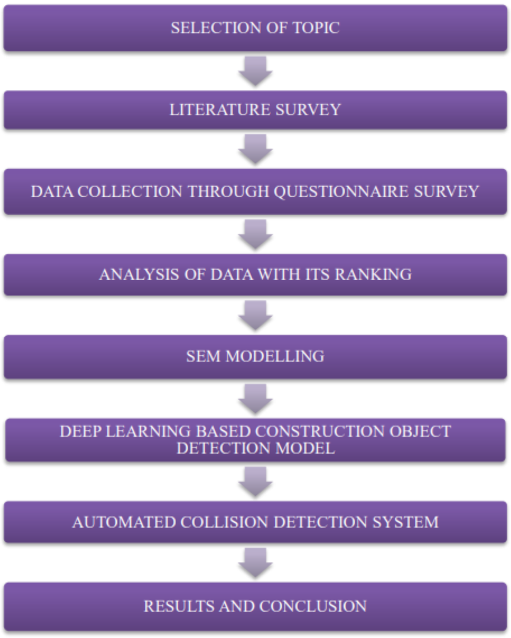


Fig.3.1 Schematic representation of research methodology

IV FACTORS AFFECTING CONSTRUCTION EQUIPMENT SELECTION

The selection of construction equipment for a particular construction task is a significant factor because the right selection leads to profit for contractors and at the same time wrong selection results in suffering from overhead costs. The various criteria for equipment selection include considerable experience in operation and maintenance, data from previous projects on O & M and actual output obtained, knowledge and technology and capacity of the current brand of equipment, the time required to complete the projects, and cost that will be accrued. The criteria for equipment selection are classified mainly into two namely technical performance and cost criteria. It can also be classified into cost and operational technical requirements. Selection of equipment is typically made by matching equipment in a fleet with tasks.

SELECTION: - Appropriate selection of equipment for any construction project is essential for its speedy and economical completion. The equipment selection process has become more complicated because there is a whole lot of equipment in large variety being manufactured these days. The selection of equipment for a project is one of the key decisions in planning and executing a construction project as it affects how efficiently the work will be done, the time required to complete the work and the total cost that will be accrued. It is the duty of an equipment manager to select the right equipment, whereas it is also the responsibility of the construction planning group to select equipment.

INFLUENCING FACTORS: - Most construction projects involve arduous work which is to be handled by the construction workers and the equipment designed for doing the work undersigned. The versatility of equipment available commercially involves the decision of people. There are a few basic factors to be considered in the selection of suitable equipment further discussed in this chapter. Through a detailed literature survey, 48 influencing factors were identified and classified under sub-scales. There are ten subscales; 'economic criteria' with 5 items, 'human and social criteria' with 5 items, 'equipment specific factors' with 6 items, 'engineering criteria' with 5 items, and 'environmental criteria' with 5 items, 'safety' with 4 items, 'advertisement' with 3 items, 'project and site-specific factors' with 5 items, 'technology and innovation' with 5 items, and 'service and maintenance with 5 items.

Economic criteria: - The economics of equipment is an important consideration in the selection of equipment. When calculating owning cost, all items of expenses, like freight, packing, forwarding, insurance, erection, commissioning, and the price paid to the supplier, etc., should be considered. This also includes operating fuel cost, operating labor cost, maintenance cost, and resale value. The operating cost of construction equipment comes into play only when the machine starts to operate. It depends on the period of operation (hours), location of the construction site, the site conditions under which the machine is operated, and the type and category of the equipment. This cost increases with the age of the equipment. Proper and timely maintenance of the construction equipment decreases the repair and maintenance cost with time. Most of the minor repair is performed at the site without any delay. Whereas, major repairs can be performed at a specific facility set up for the equipment by skilled and authorized dealers of the equipment. Resale value is the replacement cost of existing equipment. Some parts of the equipment have a shorter life as compared to the service life of the equipment. These are hence categorized as high-wear items. These include cutting edges, drill bits, bucket teeth, blades, etc. The normal expected life of these items can be estimated either from the records or from the manufacturer guidelines.

Human and Social criteria:- If there is a shortage of manpower at the job site, then the companies may opt for highly automated machines. Further, the selection of CE may also be highly governed by the availability or non-availability of trained manpower as then the company may or may not opt for highly sophisticated equipment. Available operators and technicians should be able to handle selected equipment. Sophisticated equipment may give excellent performance but it may be difficult to handle and maintain. Efficient and reliable lifting equipment will do you no good if you do not have the skill or dexterity to use it. Working with heavy machinery is quite challenging and poses a workplace safety hazard if not handled carefully. Only trained and specialized machine operators should be incharge of running such machines to keep the workplace safe and eliminate accidents. If the available operator does not specialize in heavy equipment management, hire an experienced operator for the same. It would be a wise decision to invest in training the operating staff.

Equipment specific factors :-The Equipment which is easily available in the market should be purchased. It should also be ensured that the equipment is of repute and is likely to be continued to be manufactured in the future also. This is necessary for future standardization and ensuring spare parts supply. It is easy to dispose off such equipment after completion of the project. Equipment age is a factor when already used equipment is being taken on a lease. Larger equipment gives higher output on full load, but its cost of production on part load is usually greater than that of smaller units working on full load. Larger equipment needs the correspondingly larger size of matching units, and shutting down of one primary unit may render several other large units idle. Transportation to work is generally difficult and costly. The economy should be worked out. The equipment selected should also satisfy the operating requirements i.e., it should be easy to operate and maintain, acceptable to the operator, and should have lesser fuel consumption.

Engineering criteria :- During the selection of construction equipment, there is a need for the most rational criteria that will have a positive impact on operational efficiency, productivity, cost minimization, etc. Therefore, equipment efficiency, equipment productivity, and equipment capacity should be considered prior to selection. To improve equipment efficiency, the equipment should consume as little energy as possible. Equipment productivity generally refers to the time during which the machine is in operation performing productive work. The more efficiently the workers can complete their tasks, the higher the production level is. The capacity of power equipment is determined by its power output, that is, by the quantity of work produced per unit time; this capacity is measured in kilowatts. One way to bring down your costs is by opting for fuel-efficient machines. Since fuel is one of the major costs in the construction business, machines that consume less fuel will save you a lot of money in the long term. It is desirable to have minimum number of types so that there is uniformity in the type of equipment on a project. It is desirable to select common type of engine for different machine such as excavators, dump trucks, tractor and scrapers purchased on the projects.

Environmental criteria:- This criterion includes energy-saving, greenhouse gas/ pollutants emissions, oil/lubricant 16 leakage control, noise control, and vibration during operations. Among the environmental impacts from construction processes (such as waste generation, energy consumption, resource depletion, etc.), emissions from onsite construction equipment account for the largest share (more than 50%) of the total impacts. All non-road construction equipment, machinery, and vehicles that are power-driven by diesel engines have a high impact on the environment. The emissions from these types of equipment are considered a source of air pollution. Oil spills on a construction site are even more concerning as they prove to be fatal for everyone working on the site apart from the dangers they pose to the environment. When everyone on the construction site knows that there are provisions in place to prevent an oil spill, they can work stress-free and concentrate better on their work. When it comes to noise control, construction workers are exposed to noise levels that pose a potential risk to their auditory health and well-being. In addition to affecting the working conditions for these workers, the sound produced at construction worksites affects the living quality of the surrounding communities and environments. One of the most significant contributors to these elevated noise levels is the construction equipment employed, such as excavators and bulldozers. Unchecked machine vibration can accelerate rates of wear (i.e. reduce bearing life) and damage equipment. Vibrating machinery can create noise, cause safety problems and lead to degradation in plant working conditions. This criterion makes it possible for the contractors to consider the sustainability agenda in the equipment selection procedures.

Safety:- Any construction site is the locus of multiple high-risk activities. So, safety controls are to be incorporated to safeguard the occupational health and safety of employees. Mechanization of equipment shall not create any new hazards. Many research studies attempt to identify the root causes of construction accidents. Major causes of construction accidents are unsafe working conditions and behaviors. On the other hand, root causes of construction accidents in a non-human error aspect include ergonomic design, equipment selection, supporting policy, and environment issues, such as ventilation, light, equipment design, and site layout as critical factors in improving accident records. Therefore, some of the factors to be considered while selecting a piece of equipment include stability and safety, hazard protection and alarm systems, healthy working conditions in the control room, and safety systems for nighttime operations.

Advertisement:- This criterion includes factors like the company name(logo), the prestige of the company, and 17 its image to the public. Select the brand and model that is most demanded in the market because in the future if you need to rent it out so you get a good rental income from your heavy equipment. Out of the many models and brands take care of the resale value also of equipment. Is there any policy of buyback from the manufacturer if not then ask to have it before finalizing the equipment.

Project and site-specific factors: - The equipment selected should suit the demands of the job conditions. Both grounds, as well as climatic conditions at the site, also affect the selection decision. For example, the soil and overall terrain at the job site and nearby surroundings define which construction equipment (CE) should be used. At the same time, climatic conditions such as the presence of strong winds, visibility level, etc., also affect the decision process. Topography and geology of the site, geotechnical characteristics of the ground or rocks, temperature, rain, snow, and how near the site is from urban centers or industrial sites for provisioning. Investment should be suitable to the project for which you are making an investment. The wrong decision puts you in a problem. As you require the EOT crane but made the decision to buy a tower crane.

Technology and Innovation :-Technology should be embraced as it is an ally you want on your side. Heavy equipment that has the latest technology will surely impact and enhance the overall performance of a business. These machines will get more work done in less time and with less manpower as compared to their 'nontech' counterparts. It also helps in attracting and retaining more business to the contractors. The work would be smoother, helping them complete the projects faster and on time. The versatility of equipment indicates the multi-purposes that it can perform. There are certain types of equipment that are not utilized fully. Therefore, if possible, they must be capable of performing more than one function, for example, excavator with wheel loader bucket arrangement or with rock breaker attachments. If the construction site is in a remote location, weather conditions could be unpredictable, unfamiliar, or harsh.

Service and Maintenance :- Easy availability of spare parts is also a criterion of selection for constriction equipment. If spare parts are not easily available in the market, it will result in extra costs in the future and it can stop work at the project site and impact income. The single seal of a cylinder can stop your whole project site work. The Standard and interchangeability of spares are vital. Keeping the equipment idle due to the non-availability of spares is a cost to the project. The cost of maintenance is approximately 40% of the total project cost.

V VISION BASED CONSTRUCTION SITE MONITORING

Construction projects are facing challenges like low productivity, time & cost overrun, safety issues, etc. The applications of computer vision (CV) based techniques are found as a cost-effective solution for remote project monitoring. Further, the deep learning models have automated the monitoring process by learning from the images and videos captured at construction sites and thus eliminated the time consuming and labor-intensive part of monitoring. Faster Region-based CNN (Fast R-CNN) for object detection, SORT for object tracking, and stacked hourglass network (HG) for pose estimation have been used mostly for effective monitoring of construction safety, resource productivity, structural health, and, construction waste.

CONSTRUCTION OBJECT DETECTION

Object detection is the most fundamental technique in computer vision applications. It involves locating objects in an image and classifying them. It helps in identifying a specific object in a set of images using its semantic or location features. Also, it helps in initiating other CV techniques such as object tracking, pose estimation, etc. Recently CNN based object detection is found in many construction management applications. Faster Region-based Convolutional Neural Network (Faster R-CNN) got the highest popularity among the researchers because of its high accuracy level. FasterR-CNN can be used for detecting construction workers and equipment to prevent struck-by accidents, detecting construction waste & recycling, and sewer pipe defects detection for structural health monitoring. Single Shot MultiBox Detector (SSD) is another popular method for object detection. Multiple equipment detection, construction workers' hard hat detection, and other Personal Protective Equipment (PPE) detection are some of the applications of SSD. The You Only Look Once – version 3 (YOLOv3) method for object detection is generally known for its lesser computational cost and real-time applications. Detection of construction workers and equipment in UAV videos can be done using YOLOv3 for preventing struck-by accidents. The same can be applied to site management. Mask Region-based Convolutional Neural Network (Mask R-CNN) can be used in construction workers, structural support, and vehicle detection for construction safety and structural health monitoring applications. Region-based Fully Convolutional Networks (R-FCN) and FuseNet models are found in the applications of earthmoving equipment productivity assessment and progress monitoring through 4D BIM respectively. Customized CNN models based on Visual Geometry Group (VGG16) are in use for safety guardrail detection at construction sites. General applications of construction object detection include- tracking work progress, measure productivity, litigate claims, safety monitoring, proper site management, waste management, structural health monitoring and revision plans. Fig 5.1 shows a synthetic image generated by plotting 3D models of workers at various positions of a real-world scene of a construction site

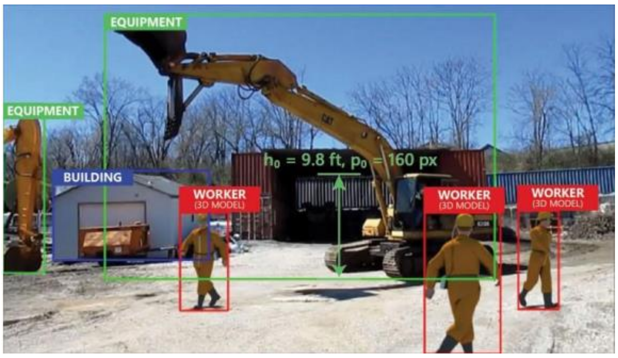


Fig 5.1: A synthetic image

DEEP LEARNING BASED DETECTION MODEL

Although construction project monitoring through video data or image data is gaining popularity among researchers, the manual analysis of those data is very time-consuming and demands high domain expertise. To overcome this challenge, recent Convolution Neural Network (CNN) based deep-learning models are found to be very effective. YOLO (You Only Look Once) is a method / way to do object detection. It is the algorithm /strategy behind how the code is going to detect objects in the image. Earlier detection frameworks, looked at different parts of the image multiple times at different scales and repurposed image classification technique to detect objects. This approach is slow and inefficient. YOLO takes entirely different approach. It looks at the entire image only once and goes through the network once and detects objects. It is very fast. That's the reason it has got so popular.

HARDWARE AND SOFTWARE REQUIREMENTS

The selection of hardware is very important in the existence and proper working of any software. Then selection hardware, the size and capacity requirements are also important.

• Processor : Intel Pentium Core i3 and above, 64 bits
• RAM : Min3GB RAM
• HARD DISK: 10 GB

One of the most difficult tasks is selecting software for the system. Once the system requirements are found out then we have to determine whether a particular software package fits to it. The application requirement:

• OPERATING SYSTEM: WINDOWS 10
• FRONT END: HTML, CSS, JAVASCRIPT
• BACK END: MySQL
• IDE USED: JetBrains PyCharm, Android studio
• TECHNOLOGY USED: PYTHON JAVA
• FRAME WORK USED: Flask

VI COLLISION HAZARDS AT CONSTRUCTION SITES

In general, construction sites have a complex and dangerous working environment by requiring a large number of workers and by moving construction equipment during work processes. In particular, construction workers located near the equipment are vulnerable to struck-by accidents due to several risk factors (i.e., a decrease in the worker's risk perception ability due to noise generated during the operation, the blind spot of construction equipment, and a decrease in driver awareness). Construction site monitoring techniques that can reduce the risk of struck-by accident are essential to solving such problems. In the past, a safety monitoring task involved assigning an experienced supervisor at construction sites to monitor workers, which was time-consuming and ineffective. Studies on automated construction site monitoring have been conducted to overcome the limitations of the previous approach. Computer Vision (CV)-based construction site monitoring has been studied for various purposes, from object detection to object tracking and activity recognition. However, this technique has difficulties in collecting visionary data from the construction site due to frequent visual obstructions. Also, to implement computer vision techniques, it is necessary to secure a certain level of illumination. Considering that continuous monitoring is important for the prevention of struck-by accidents, the development of a different technique for struck-by accident prevention would be essential for addressing such limitations.

COLLISION DETECTION SYSTEM

Currently, construction safety monitoring mainly relies on observing the real-time site conditions manually through on-site surveillance cameras. Early alerts of potential hazards are judged based on previous experiences and provided based on observations from the cameras. Such manual approaches are labor-intensive and error-prone considering the difficulty of monitoring through multiple cameras simultaneously. Human fatigue could lead to the ignorance of potential hazards, such as workers unconsciously approaching heavy equipment. Furthermore, the alerts based on personal experiences can be subjective or belated, leading to severe consequences. Therefore, a method capable of automatically monitoring and predicting safety issues on construction sites is desired to reduce the resources and to improve the efficiency for safety monitoring. The proximity-based technique has been widely studied in the construction domain to prevent possible collisions at construction sites. This technique utilizes a radio signal which is less vulnerable in data collection compared to the visionbased approach. Radiofrequency identification (RFID), Bluetooth, and magnetic sensing were applied to measure the distance between the equipment and the worker. Recently, studies on construction site monitoring based on sound data have been attempted. Compared to CV, the sound is less constrained by the environment (i.e., weather, illumination, obstacles) and the data processing weight is relatively light. Also, the sound-based approach doesn't require the installation of additional sensors considering that the speaker and microphone are generally installed inside the equipment and a mobile device, respectively.

VII RESULTS AND DISCUSSIONS

The outcomes of the analysis of the data collected are presented in this section and the findings are discussed, including the respondent profiles, reliability test results, and ranking of obstacle factors using RII method. The 48 influencing factors identified from the literature survey are listed down under 10 subscales. Each scale is based on a 5-point Likert scale. Descriptive analysis and comparison tables for Relative Importance Index (RII) were used to rate the results. SEM models were developed to examine the causal relationships between the key factors affecting construction equipment selection. A construction object detection model was developed using deep learning to detect construction equipment, construction workers and collisions between them.

RESPONDENT'S FEATURES AND DEMOGRAPHIC PROFILE

A total of 230 questionnaires were sent online, out of which 207 respondents responded. In the questionnaire adopted for this research, the respondents have been classified based on their professionality, education, and their years of experience. The results for "Professional field" indicated that the highest frequency was observed for "Civil Engineer / Structural Engineer" (19.8%) followed by "Project Engineer" (13.5%), "Quantity Surveyor" (13%), "Contractor" (12.6%), "Supervisor" (11.1%), "Construction manager" (10.1%), "Site equipment manager" and "Architect" (9.7%) and the lowest frequency 0.5% belonged to "Others". Based on the results of education most respondents had a "Bachelor's degree" (39.1%) followed by a "Diploma" (22.7%), "Master's degree" (18.4%) and "ITI" (10.1%), "MBA" (5.8%), "PhD" (2.4%), and "Others" (1.4%). Results for "Work Experience" showed the highest frequency (34.3%) for professionals with "11 to 20 years" experience followed by professionals with "6 to 11 years" experience (23.7%), "Greater than 20 years" (22.2%), and "less than 5 years" (19.8%).

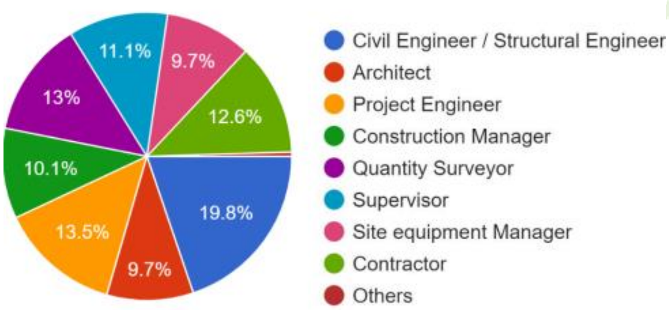


Fig 7.1: Professional Field

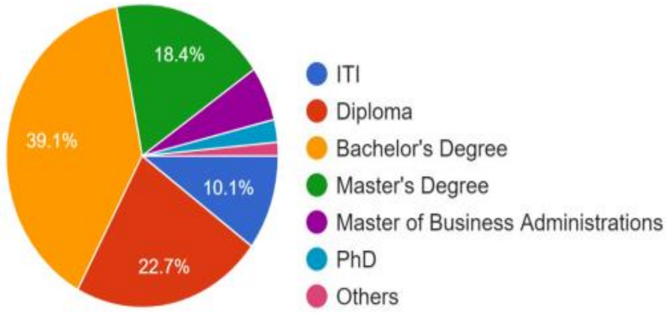


Fig 7.2: Education

Concerning the knowledge of the respondents in terms equipment selection, two yes or no questions were asked. 92.3% of people responded "yes" for the statement - "Selection of the right equipment is an important factor in the success of any construction project" and 90.8% people responded "yes" to "Right selection leads to profit for contractors and wrong selection results in losses".

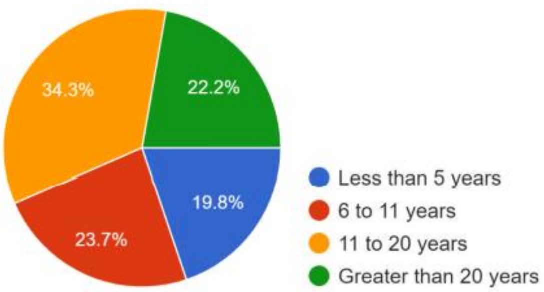
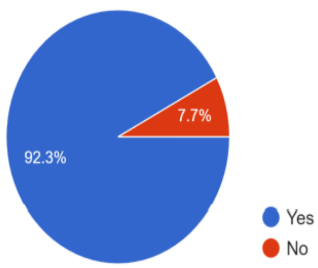
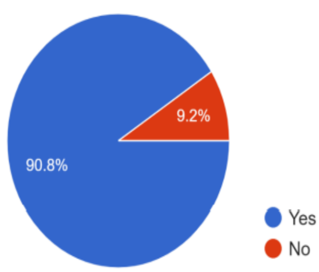


Fig 7.3: Work Experience



(a)



(b)

Fig 7.4: (a) Right selection of equipment an important factor in the success of a construction project (b) Right selection leads to profit for contractors and wrong selection results in loses

The 48 influencing factors identified from the literature survey are listed down under 10 subscales in Table 7.1. Table 7.2 represents the respondent's distribution for all demographic variables along with the 2 yes or no questions concerning the knowledge of the respondents in terms construction equipment selection.

Table 7.1: Factors influencing construction equipment selection

INFLUENCING FACTORS	ITEMS	STATEMENTS
1) ECONOMIC CRITERIA	EC 1 EC 2 EC 3 EC 4 EC 5	Ownership cost Operating labor cost Operating fuel cost Maintenance cost Resale value
2) HUMAN AND SOCIAL CRITERIA	HSC 1 HSC 2 HSC 3 HSC 4 HSC 5	Availability of skilled operator Operator health Operator view and comfort Relationship with dealer (supplier) Buying equipment from same manufacturer
3) EQUIPMENT SPECIFIC FACTORS	ESF 1 ESF 2 ESF 3 ESF 4 ESF 5 ESF 6	Availability of equipment Equipment age Size of equipment Past performance Use in future projects Operating requirements
4) ENGINEERING CRITERIA	EnggC 1 EnggC 2 EnggC 3 EnggC 4 EnggC 5	Equipment productivity Equipment capacity Use of standard equipment Equipment efficiency Fuel efficiency
5)ENVIRONMENTAL CRITERIA	EnvC 1 EnvC 2 EnvC 3 EnvC 4 EnvC 5	Energy saving Greenhouse gas / pollutant emissions Oil / lubricant leakage control Noise control Vibration during operations
6) SAFETY	SFTY 1 SFTY 2 SFTY 3 SFTY 4	Stability and safety Hazard protection and alarm systems Healthy working conditions in control room Safety systems for night time operations
7) ADVERTISEMENTS	ADV 1 ADV 2 ADV 3	Company name (logo) Prestige of company Image to public
8) PROJECT AND SITESPECIFIC FACTORS	PSS 1 PSS 2 PSS 3 PSS 4 PSS 5	Project site weather Soil conditions at the site Surface geography Matching of equipment to the type of construction activity Project deadlines
9) TECHNOLOGY AND INNOVATION	TI 1 TI 2 TI 3 TI 4 TI 5	Versatility of equipment Quality of equipment material and parts Tolerance and equipment operating life Research on equipment development Technological obsolescence
10) SERVICE AND MAINTENANCE	SM 1 SM 2 SM 3 SM 4 SM 5	Availability of spare parts Availability of a maintenance staff Suitable with maintenance staff's ability Manufacturer's maintenance services Ease of obtaining maintenance tools

Table 7.2: Frequency distribution of demographic characteristics

VARIABLE	LEVEL	FREQUENCY	PERCENTAGE
Professional Field	Civil Engineer / Structural Engineer	41	19.8
	Architect	20	9.7
	Project Engineers	28	13.5
	Construction manager	21	10.1
	Quantity Surveyor	27	13
	Supervisor	23	11.1
	Site equipment manager	20	9.7
	Contractor	26	12.6
	Others	1	0.5
Education	ITI	21	10.1
	Diploma	47	22.7
	Bachelor's degree	81	39.1
	Master's degree	38	18.4
	MBA	12	5.8
	PhD	5	2.4
	Others	3	1.4
Work Experience	Less than 5 years	41	19.8
	6 to 11 years	49	23.7
	11 to 20 years	71	34.3
	Greater than 20 years	46	22.2
Right selection of equipment an important factor in the success of a construction project	Yes	191	92.3
	No	16	7.7
Right selection leads to profit for contractors and wrong selection results in loses	Yes	188	90.8
	No	19	9.2

RELIABILITY TEST

Statistical analysis of data was done using IBM SPSS Statistics 22. Before ranking was done using RII analysis, a reliability test was conducted to measure the internal consistency reliability using the Cronbach's Alpha reliability coefficient in SPSS. According to the researches, this is the most commonly reported reliability coefficient used. It tells us the extent to which a test is internally consistent and to what extent there is a good amount of balance or correlation between various parts of the score. Parts of scores mean indicators and dimensions of the score. In this research, it indicates how well the set of 48 influencing factors are correlated to one another. According to a general thumb rule, Cronbach's Alpha (α) of 0.7 and above is good, 0.8 and above is better, and 0.9 and above is best. Table 7.3 demonstrates that all the Cronbach's Alpha coefficient values were above 0.8, ranging from 0.803 to 0.880 which is well within the acceptable range. This indicates that the items are related to the construct they were designed to measure. So, reliability analysis needs to be conducted on each subscale individually. After the data has been imported from excel to SPSS, the reliability test is carried out. In the "analyse" tab click on "scale", then select "reliability analysis". Select the variables for which we need to find the reliability, model is set to "alpha" mode and then click "ok" as shown in fig 7.5. Similarly, the reliability analysis for all the 10 factors is carried out.

Table 7.3: Reliability analysis of factors influencing construction equipment selection

INFLUENCING FACTORS	CRONBACH'S ALPHA
Economic criteria	0.846
Human and social criteria	0.855
Equipment specific factors	0.866
Engineering criteria	0.853
Environmental criteria	0.847
Safety	0.853
Advertisements	0.803
Project and site-specific factors	0.834
Technology and innovation	0.835
Service and maintenance	0.880

RII ANALYSIS OF INFLUENCING FACTORS

The collected responses were analyzed using SPSS software. Frequency analysis was conducted. Frequency table (showing the frequency of respondents) and bar charts were obtained as output which is provided in Appendix C and Appendix D respectively. The RII method (Relative Importance Index) was used to analyze the collected data. The relative importance of the factors influencing construction equipment selection was determined using RII and were ranked from 1 to 10. Table 7.4 shows the mean RII values and ranking results of the influencing factors. Tables 7.5 to table 7.14 shows the RII values and ranks of individual items under each subscale. The event of frequency and intensity of the responses are evaluated on a 5-point Likert scale, where, 1= Not at all important, 2= Less important, 3= Neutral, 4= Very important, 5= extremely important. RII is calculated using Eq. (7.1). The RII value ranges from 0 to 1 with 0 not inclusive.

$$RII = \sum W\ A\ X\ N$$

$$RII = \frac{5n5+4n4+3n3+2n2+1n1}{A\ X\ N}$$

Where, RII = Relative Importance Index

W = Weighting given to each factor by the respondent, ranging from 1 to 5

$n5$ = no. of respondents for strongly disagree $n4$ = no. of respondents for disagree

$n3$ = no. of respondents for neutral $n1$ = no. of respondents for strongly agree

A = Highest weight N = Total number of respondents

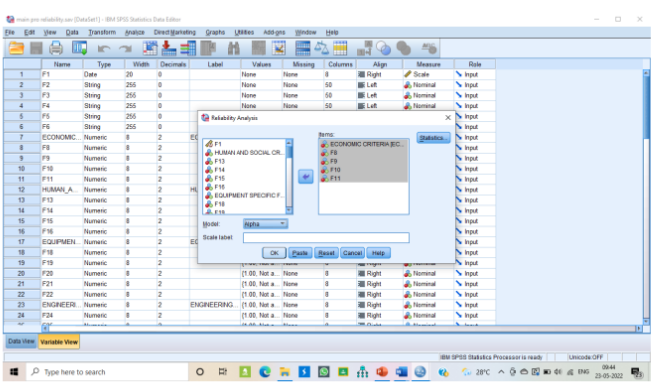


Fig 7.5: Reliability analysis using SPSS software

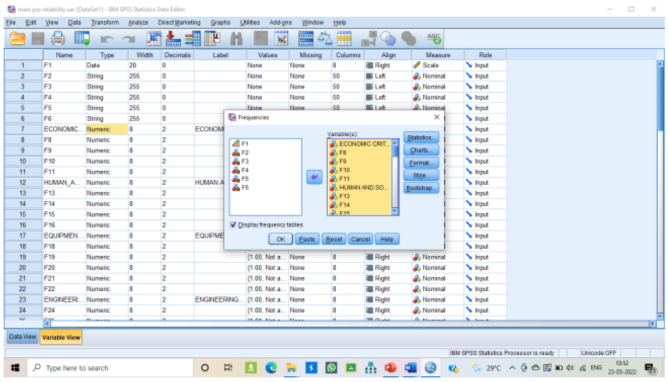


Fig 7.6: Descriptive analysis using SPSS software

Table 7.4: Ranking of the factors influencing construction equipment selection

INFLUENCING FACTORS	RII MEAN	RANK
Economic criteria	0.710	7
Human and social criteria	0.661	9
Equipment specific factors	0.726	3
Engineering criteria	0.731	2
Environmental criteria	0.705	8
Safety	0.719	4
Advertisements	0.638	10
Project and site-specific factors	0.741	1
Technology and innovation	0.717	5
Service and maintenance	0.717	6

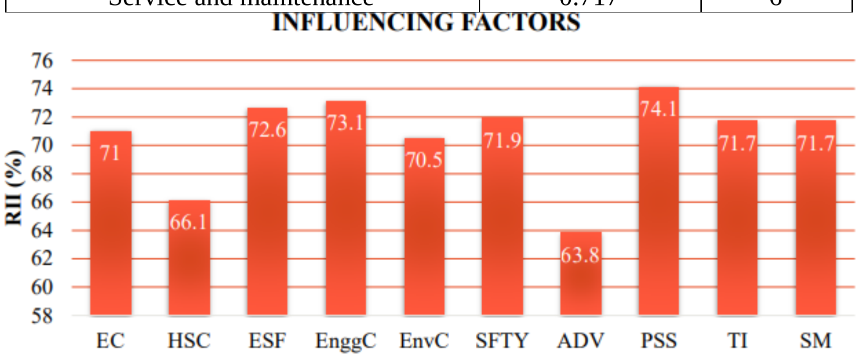


Fig 7.7: RII of factors affecting construction equipment selection

The factor "Project and site-specific factors" holds the first rank making it the most contributing factor influencing construction equipment selection. This is followed by "Engineering criteria" and "Equipment criteria" holding the second and third rank respectively. The factor "Advertisement" gets the tenth rank and becomes the least contributing factor.

Project and Site-specific factors

The eight subscale ‘‘Project and Site specific factors” has the first rank from RII analysis. The item "Matching of equipment to the type of construction activity" has the highest RII value 0.764. This is followed by the item "Surface geography" having RII 0.754, “Soil conditions at the site” (0.753), “Project site weather” with RII value of 0.719 and finally “Project deadlines” with the least RII value of 0.716. This infers that most of the professionals agree that the equipment selected should primarily meet the work requirements and also should be suitable to the surface geography.

Engineering Criteria

The forth subscale "Engineering Criteria" is ranked second. The item “Equipment capacity” has the highest RII value of 0.742, followed by the item “Use of standard equipment” having RII 0.732, “Equipment efficiency” and “Fuel efficiency” having RII 0.728 and the item “Equipment productivity” has the least RII 0.727. The respondents view equipment capacity and standardization as a deciding factor in the selection of a construction equipment. Equipment and fuel efficiency are given moderate importance.

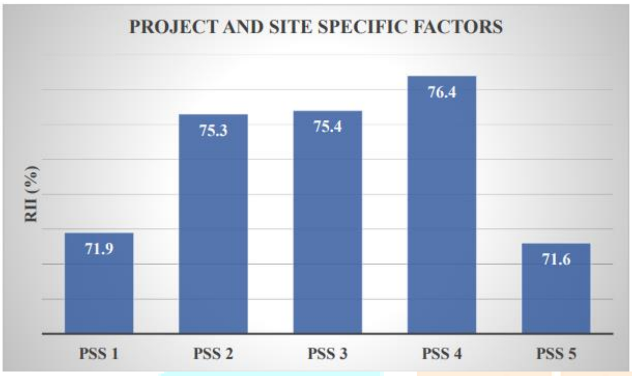


Fig 7.8: RII of Project and Site-specific factors

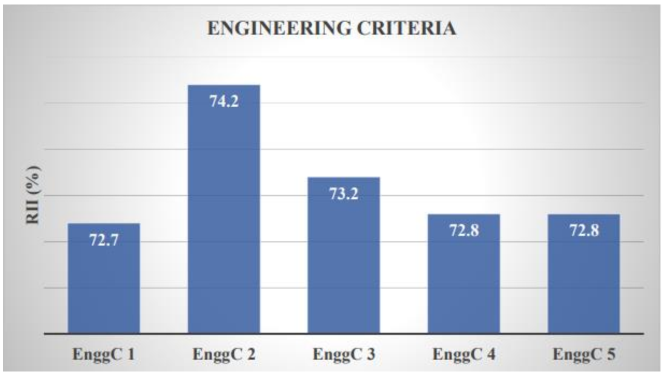


Fig 7.9: RII of Engineering Criteria

Equipment Specific factors

The third subscale ‘‘Equipment Specific factors” has the third rank from RII analysis. The item "Use in future projects" has the highest RII value 0.755. So, when equipment completes a part of its useful life in a project, it should be kept in view that the equipment can be used in future projects and may not become obsolete. This is followed by the item "Operating requirements" having RII 0.744, “Past performance” (0.73), “Availability of equipment” with RII value of 0.722, “Equipment age” (0.72) and finally “Size of equipment” with the least RII value of 0.686. Operating requirements is also considered to be a deciding factor i.e., the equipment should be easy to operate and maintain, acceptable to operator and fuel consumption should be less.

Safety

The sixth subscale ‘‘Safety” has the forth rank from RII analysis. The item "Hazard protection and alarm systems" has the highest RII value 0.728. This is followed by the item "Stability and safety" having RII 0.721, “Safety systems for night time operations” (0.72), and finally “Healthy working conditions in control room” with the least RII value of 0.709. So, it can be inferred that respondents believe that equipment should have an alarm systems and other hazard protection features for workers safety. Although respondents do feel the need for safety at work place, they are not well concerned about workplace conditions being healthy.

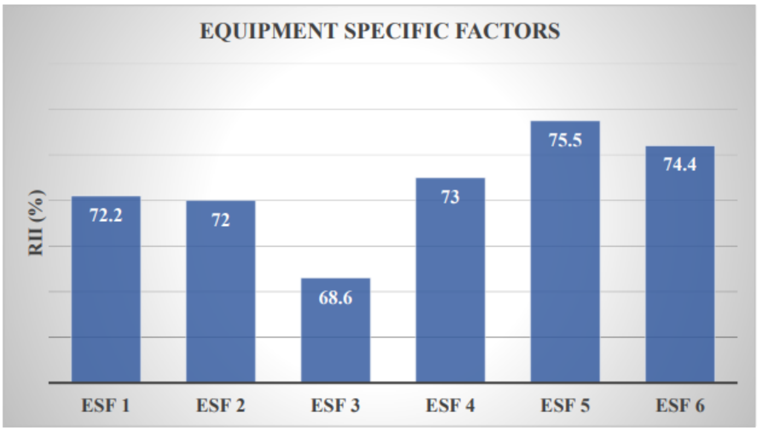


Fig 7.10 RII of Equipment Specific factors

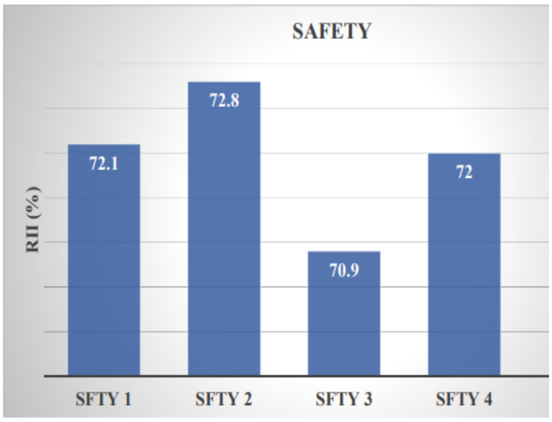


Fig 7.11: RII of Safety

Technology and Innovation

The ninth subscale "Technology and Innovation" gets the fifth rank making it a factor of moderate importance. The item “Quality of equipment material and parts” has the highest RII value of 0.739, followed by the item “Versatility of equipment” (0.735), “Tolerance and equipment operating life” (0.719), “Technological obsolescence” (0.702) and the item having the least RII is “Research on equipment development” (0.692). This indicates that professionals do realize the importance of equipment quality and the versatility (multi-purpose use) of equipment during selection. Professionals rely less on research results to make equipment selection. Instead they may take help from a consultancy or make decisions based on their own experiences.

Service and Maintenance

The tenth subscale "Service and Maintenance" gets the sixth rank. The item “Availability of spare parts” has the highest RII value of 0.729, followed by the item “Availability of maintenance staff” (0.727), “Suitable with maintenance staff’s ability” (0.72), “Ease of obtaining maintenance tools” (0.706) and the item having the least RII is “Manufacturer’s maintenance services” (0.705). This indicates that professionals agree that while purchasing an equipment it is to be made sure that it’s spare parts and its maintenance tools are easily available in the market in case of emergency times. Also, a skilled maintenance staff should be available.

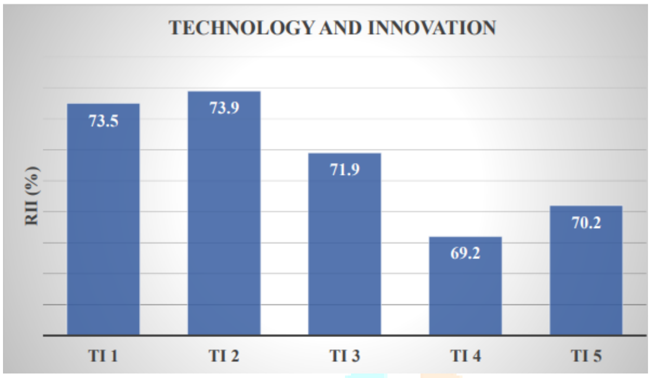


Fig 7.12: RII of Technology and Innovation

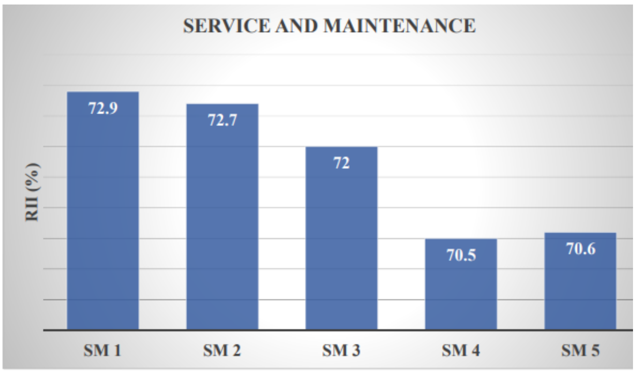


Fig 7.13: RII of Service and Maintenance

Economic Criteria

The first subscale ‘‘Economic Criteria” has the seventh rank from RII analysis. The item "Owning cost" has the highest RII value 0.764. Owning cost includes all items of expenses, like freight, forwarding, insurance, erection, commissioning, the price paid to the supplier, etc. This is followed by the item "Maintenance cost" having RII 0.716, “Operating labour cost” (0.710), “Operating fuel cost” with RII value of 0.694 and finally “Resale value” with the least RII value of 0.667. This infers that more importance is given to owning cost and maintenance cost while purchasing an equipment and least importance to “resale value”.

Environmental Criteria

The fifth subscale ‘‘Environmental Criteria” has the eight rank from RII analysis. The item "Energy saving" has the highest RII value 0.736. This is followed by the item "Vibration during operation" having RII 0.721, “Noise control” (0.710), “Oil / lubricant leakage control” with RII value of 0.680 and lastly “greenhouse gas / pollutant emissions” with the least RII value of 0.675. This infers that more importance is given to purchasing energy saving equipment as this also brings profits. Vibration during operation is also considered to be important because vibrating machinery can create noise, cause safety problems and lead to degradation in plant working conditions.

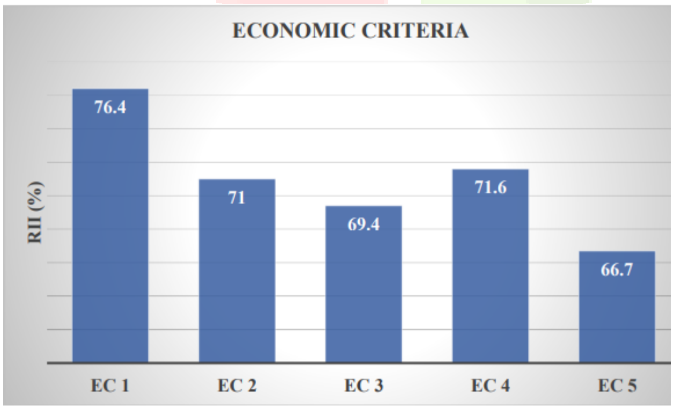


Fig 7.14: RII of Economic Criteria

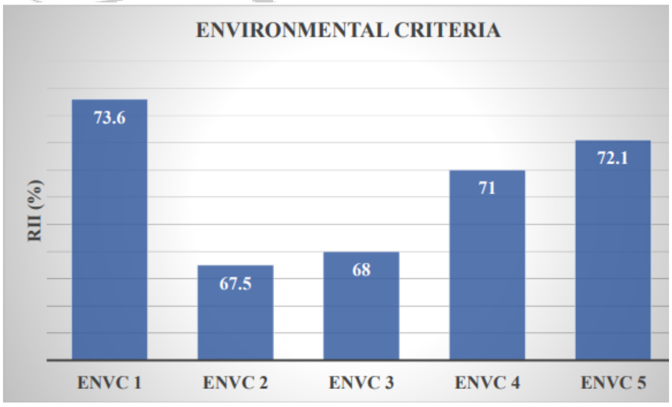


Fig 7.15: RII of Environmental Criteria

Human and Social criteria

The second subscale "Human and Social criteria" gets the ninth rank making it the second last important factor. The item “Availability of skilled operator” has the highest RII value of 0.693, followed by the item “Operator health” (0.679), “Operator view and comfort” (0.672), “Relationship with dealer” (0.656) and the item having the least RII is “Buying equipment from same manufacturer” (0.603). This indicates that professionals think that there is no requirement to have a special relationship with the dealer or to buy the equipment from the same manufacturer. Although they find it important to have a well skilled and trained operator to carry out the tasks. Operator health and comfort are given moderate importance.

Advertisements

The last and tenth rank goes to the seventh subscale "Advertisements" making it the least important factor. The items "Company name (logo)" has the highest RII of 0.643, followed by "Prestige of company" (0.639). The item having the least RII is "Image to public" (0.632). This shows that professionals rely less on company name, prestige and public image to make decision regarding purchasing of an equipment.

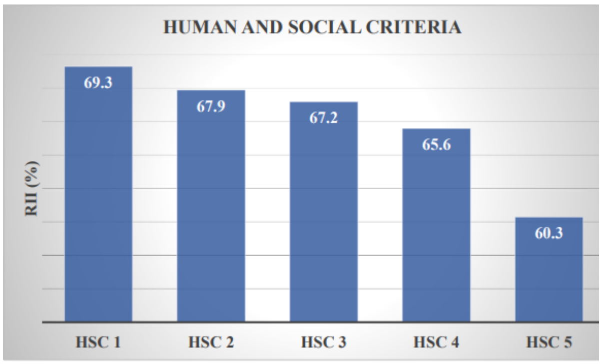


Fig 7.16: RII of Human and Social criteria

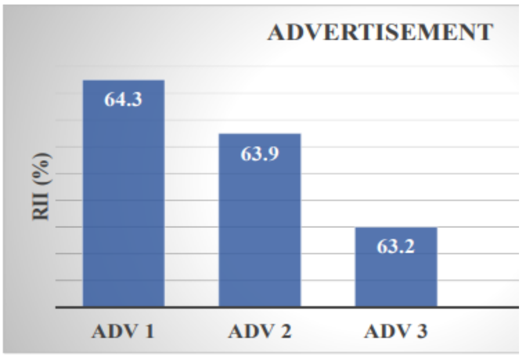


Fig 7.17: RII of Advertisements

STRUCTURAL EQUATION MODELLING

It is a set of statistical techniques used to measure and analyze the relationships of observed and latent variables. It can also be called a Multivariate statistical analysis technique that is used to analyze structural relationships. This analysis technique is adopted to examine causal relationships among key factors affecting construction equipment selection. The SEM method is widely used in construction-related studies, such as construction performance, construction safety, and construction delay. The two types of variables used are endogenous variables and exogenous variables. Endogenous variables are equivalent to dependent variables and exogeneous variables are equal to the independent variable. SEM has the ability to test hypothesised patterns of directional and non-directional relationships among a set of observed and unobserved variables. To assess a model fit, four fit indices are used here, including the normal chi-square (CMIN/DF), comparative fit index (CFI), p-value, and root mean square error of approximation (RMSEA). The CMIN/DF and CFI are affected by the sample size, while the TLI is less affected by the sample size. Model adjustment can also be performed to increase the model fit using the modification indices (MI) provided in the model output. Correlation and path coefficients with high MI values should be added to the model to improve model fit, while those with low MI values should be removed from the model. Here, two SEM models were developed: the first model relating most contributing and least contributing factor and the second model relating all the factors affecting construction equipment selection. The measurement model is performed to confirm correlations among key factors affecting construction equipment selection decision. Modelling was done using SPSS-AMOS software.

SEM Model 1

This is the model relating the most contributing and the least contributing factor

Computation of degree of freedom (Default model):

Number of distinct sample moments = 44 ,Number of distinct parameters to be estimated = 25, Degrees of freedom (44 – 25) = 19 where, ✓ DOF = 0 just identified ✓ DOF > 0 over identified ✓ DOF < 0 unidentified

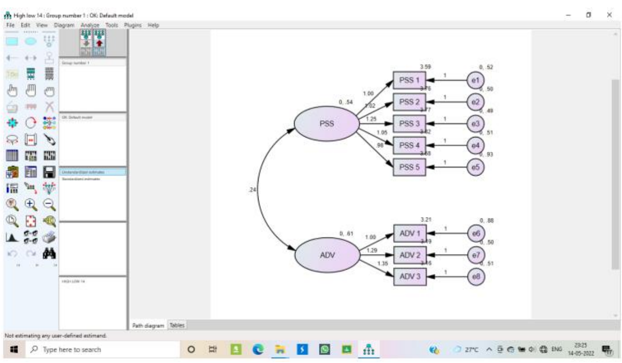


Fig 7.18: SEM model 1 using AMOS

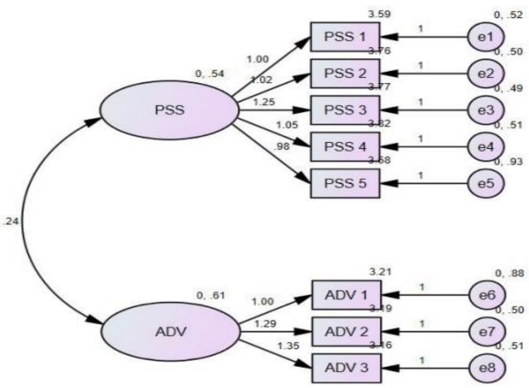


Fig 7.19: Measurement model relating most contributing and least contributing factor

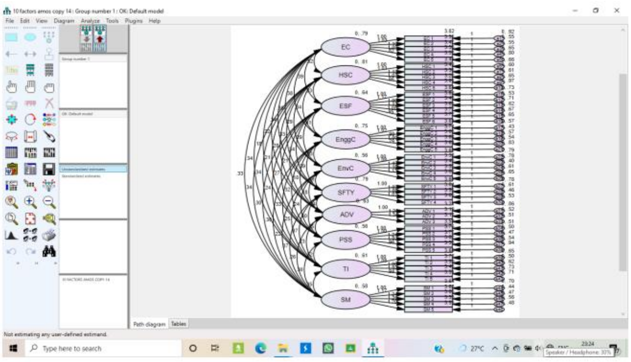
Result (Default Model)

✓ Minimum was achieved ✓ Chi-square = 52.569 ✓ Degrees of freedom = 19 ✓ Probability level = .000 Here, the minimum criterion was achieved for the default model. Also, goodness-of-fit criterion was checked as shown in Table 7.15. p-value is the probability of obtaining as large of a discrepancy that was obtained with the present sample. $\chi 2$ /df (relative chi-square) is the minimum discrepancy divided by its degrees of freedom. CFI (comparative fit index) is one of the fit indices less affected by sample size and avoids the underestimation of fit often noted in small samples. It is an index that compares the existing model fit with a null model. RMSEA (root mean square error of approximation) is a measure of approximate fit in the population and is therefore concerned with the discrepancy due to approximation. Here, p-value, χ2 /df value and CFI value have satisfied the acceptance range. RMSEA value is slightly greater than the maximum limit, but since the value 0.092 is closer to 0.08, it is also acceptable.

SEM Model 2

This is the model relating all the 10 factors affecting construction equipment selection.

Computation of degree of freedom (Default model): Number of distinct sample moments = 1224 Number of distinct parameters to be estimated = 189 Degrees of freedom (1224 – 189) = 1035 where, ✓ DOF = 0 just identified ✓ DOF > 0 over identified ✓ DOF < 0 unidentified



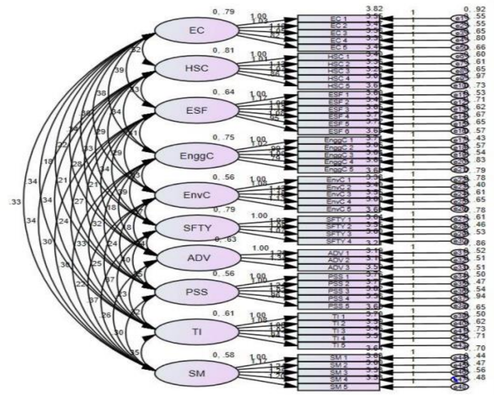


Fig 7.20: SEM model 2 using AMOS Fig 7.21: Measurement model relating factors affecting construction equipment selection

Result (Default Model)

✓ Minimum was achieved ✓ Chi-square = 1617.215 ✓ Degrees of freedom = 1035 ✓ Probability level = .000. Here, the minimum criterion was achieved for the default model. Also, goodness-of-fit criterion was checked as shown in Table 7.16. Here, p-value, χ2 /df value, RMSEA value and CFI value have satisfied the acceptance range.

CONSTRUCTION OBJECT DETECTION MODEL FOR COLLISION PREVENTION

Construction site monitoring is a process of understanding the dynamic and complex natures of construction worksites. Continuous monitoring allows project managers to evaluate the operational efficiency of input resources (e.g., direct work rate, hourly production rate), discover potential risk factors that can cause safety accidents (e.g., access to dangerous areas), and understand the current construction progress (e.g., schedule delays). By being aware of the performance and project health of a jobsite, project managers can pay special attention and take proper corrective actions to handle unexpected events, which could adversely affect the project's completion. For example, managers can allocate more dump trucks on site if there are too many loaders waiting for trucks to arrive. Hazardous objects, e.g., holes on worksites, can be identified and removed in advance, and potential accidents can be prevented. This jobsite monitoring and decision-making process can bring an opportunity to enhance on-site performance and enable successful completion of construction projects. In the past, project managers have directly visited and monitored construction sites manually. However, they have faced difficulties in monitoring dynamic and large-scale jobsites owing to time and cost limitations, and thus many researchers have investigated various automated monitoring systems. One of the most popular systems is an Internet-of-Things-based (IoT-based) approach, which involves attaching electronic sensors to target construction objects, analysing their physical movements (e.g., locations, speeds, accelerations), and evaluating the operational performance, such as hourly productivity and ergonomic risks. Despite the promising results, there are several practical issues that limit the applications of IoT systems. For example, IoT sensors should be tagged onto every single construction object. This requirement can hinder IoT applications in complex and dynamic construction sites where a significant number of objects exist, which means that it would not be possible to attach IoT sensors to all types of construction equipment and tools (e.g., jack hammers, concrete cutting saws). As an alternative, vision-based construction site monitoring has drawn considerable attention from many practitioners and researchers. It does not require every object to be tagged with camera sensors, and multiple objects can be even tracked at the same time if they appear in a camera's field-of-view. In addition to such technical benefits, the Korean Government has allowed construction companies to include camera installation costs in their safety management budgets since 2016. This has increased the willingness of construction companies to pay for camera installation at construction sites, and therefore vision-based approaches have become more practical and affordable The DL-based object detection model introduced here can be applied to construction images and videos obtained from the surveillance camera to retrieve specific visual contents. Results can be used in a variety of applications such as construction automation, work progress monitoring, and safety inspection.

Continuous monitoring gives the project management team insight into the health of the project, and identifies any areas that may require special attention. Moreover, the model's ability to perform in real time can be of significant interest in developing applications that require instantaneous situational awareness. Examples include the detection of an impending collision between a worker and a piece of equipment. Furthermore, since the trained models effectively learned the features of most commonly available construction objects, the transfer learning scheme can be adapted to improve or develop various other DL-based tools for the construction practice. As mentioned, the model can be deployed in different ways to monitor progress and safety in construction sites. An example of such applications is predicting the relative distance of detected objects (e.g., equipment and workers). This distance can be further analyzed to identify imminent collisions between objects. Measuring productivity, litigate claims, proper site management and revision plans are some additional applications. YOLO models may struggle at detecting small and poorly lit objects especially in crowded scenes. To improve the model's performance at detecting these objects, one potential solution is to collect high-resolution images, divide each image into smaller grids, and apply the YOLO model to each grid cell representing a part of the original image. However, in many cases, it may not be possible to collect high-resolution images. To remedy this situation, a generative adversarial network (GAN) can be applied to first improve the resolution of the image. Likewise, GAN can be applied to brighten a poorly lit image although a more straightforward method could be to collect long-exposure or large-aperture images that contain more light information and thus appear brighter even in a low-light environment Construction object here refers to construction equipment's and construction workers. Object detection involves locating objects in an image and classifying them. The model will ensure effective construction project management (CPM) by providing a productive and safe work site through close monitoring. The model is trained to detect four types of construction equipment's including "dump truck", "bulldozer", "excavator" and "crane". Fig 7.22, fig 7.23, fig 7.24, fig 7.25 and fig 7.26 indicates detection results of dump truck, bulldozer, excavator, crane and construction workers respectively. Object detection has many general applications as discussed above. One among them is site safety monitoring. The suggestive model developed here can be used as an on-site surveillance camera that is trained to detect any impending collision between a construction worker and a piece of construction equipment. If such on-site surveillance cameras are present and when a worker comes in the proximity of a moving construction equipment, the model generates a safety alarm. This safety alarm could be taken as a warning for the equipment operator for an imminent collision that is about to happen and thus to stop the construction equipment. Also, the person who is about to be hit also can be alerted with this alarm system. Fig 7.27 indicates a collision prediction scenario between a bulldozer and a worker obtained through this model. Fig 7.28 shows the detection of a back-over accident between a dump truck and a worker. Fig 7.29 indicates detection of a worker in close vicinity of a dump truck and a bulldozer.

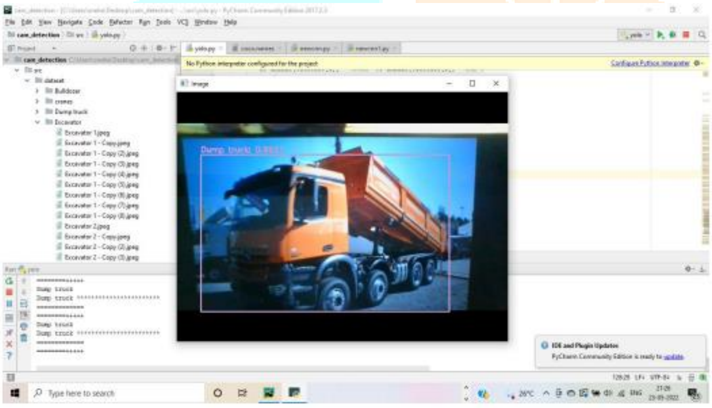


Fig 7.22: Detection result of Dump Truck

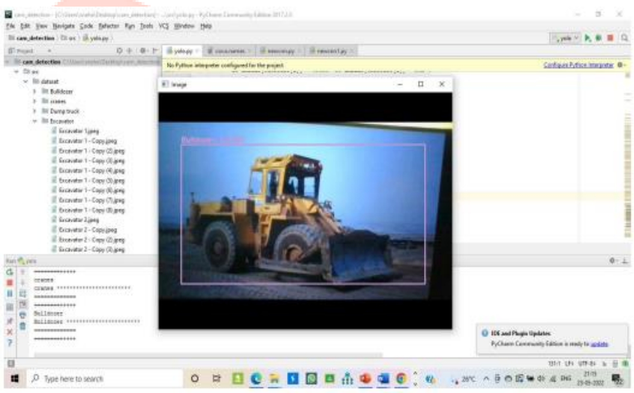


Fig 7.23: Detection result of Bulldozer

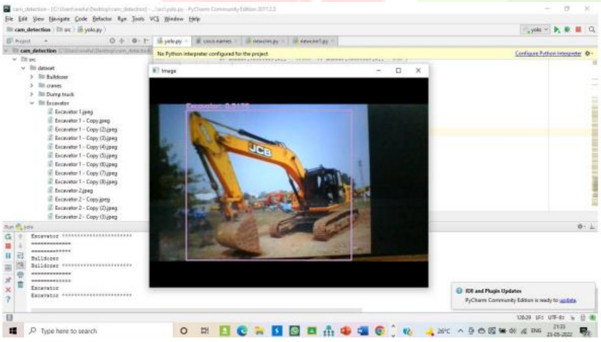


Fig 7.24: Detection result of Excavator

Fig 7.25: Detection result of Crane

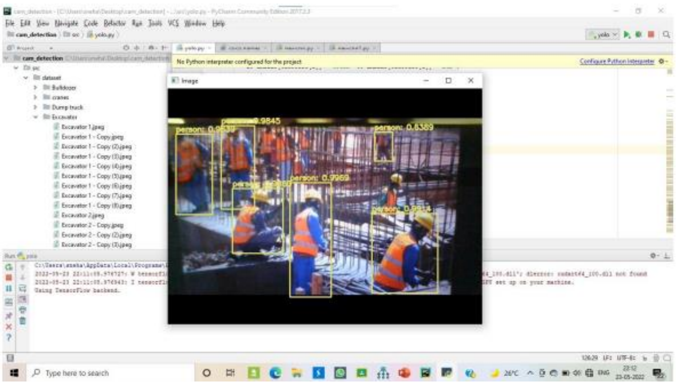


Fig 7.26: Detection result of Construction workers

Fig 7.27: Collision detection between a bulldozer and a worker

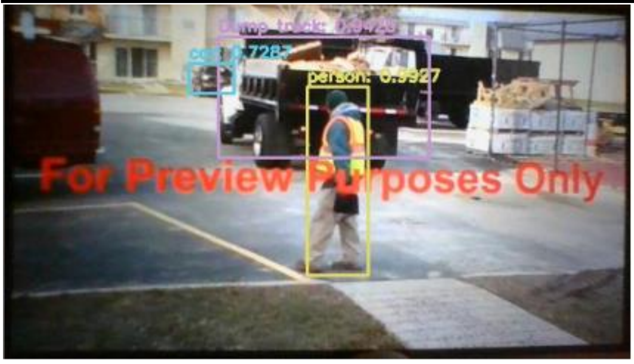


Fig 7.28: Detection of a back-over accident between a dump truck and a worker

Fig 7.29: Detection of a worker in the vicinity of a dump truck and a bulldozer

VII CONCLUSION

❖ The identified influencing factors were subjected to reliability test and they showed good internal consistency and RII analysis was done to rank the factors in order of high importance to low importance.

❖ The ranking of the factors determined that the project and site-specific factors was the most contributing factor which included project site weather, soil conditions at the site, surface geography, matching of equipment to the type of construction activity, and project deadlines. All these items are considered to be vital for making a decision.

❖ This was followed by engineering criteria and equipment specific factors having the second and third rank respectively.

❖ The least contributing factors include advertisements followed by human and social criteria and environmental criteria getting ninth and eight rank respectively.

❖ Human and social criteria is composed of 5 items such as availability of skilled labour, operator health, operator view and comfort, relationship with dealer and buying equipment from the same manufacturer. Past studies have established that construction equipment, plant and machineries are major causes of site accidents and injuries. The operation of mechanized equipment has a direct impact on worker's health. This is due to the fact that health and safety considerations for operators are kept at the lowest priorities in executing construction activities. Therefore, it is pertinent to consider items that are concerned with the occupational safety and health procedures of workers.

❖ The construction equipment has substantial impact on the environment. The emissions from these equipment's are considered as source of air pollution. Still, environmental criteria is among the lowest three rankings. This shows that environmental considerations are still at low priority for the selection criteria.

❖ SEM modelling results indicate that the factors are related. Also, to assess model fit, four fit indices were used: normal chi-square (CMIN/DF), comparative fit index (CFI), p-value, and root mean square error of approximation (RMSEA). The criterion indicating goodness-of-fit were met indicating that the models were fit.

❖ A deep learning-based construction object detection model was developed. The model successfully detected construction workers and construction equipment including- dump truck, bulldozer, excavator and crane.

❖ The developed model works as a collision detection system and detects any impending collision between a construction worker and a piece of construction equipment.

IX SUGGESTIONS

❖ Integration of telematics for tracking machine location, fuel consumption, availability and idle time to improve productivity. ❖ Data collection for the performance of the equipment, remote control of proactive maintenance, automation and "unmanned" machines could respond to the demands for lower construction costs.

❖ Respecting the operator's competence, emphasis is given on the use of simulators and game technologies to safely train them and consequently advance their skills and enhance their levels of proficiency in a cost-effective way. By joining simulated worksite applications with realistic controls, the machine operators gain familiarization and understanding of machine controls, learn proper operating procedures and discover how to maximize productivity.

❖ Usage of lightweight materials for construction and hence better performance with less fuel consumption.

❖ Less gas emissions by using hybrid engines. The machine's ability to collect, store and release energy during operation, enables lower fuel consumption and the potential for increased productivity, while decreasing the amount of harmful emissions released into the air.

❖ Equipment maintenance should be done on regular basis and after one month it should be checked from High specialized workshop in order to maintain and increase the life of equipment.

❖ When there is insufficient number of Equipment available with the Contractor, it is recommended that before award of Contract, qualification criteria should be setup strictly with the project requirements and sufficient number of equipment must be ensure then Project should be awarded to that Contractor which found satisfactory with project requirements.

❖ Equipment efficiency should be calculated before bringing the Equipment on site. Results of Equipment efficiency should be thoroughly checked up by Employer and those Equipment whose average frequency is less than 70% should not be recommended for the projects. All the old and outdated Equipment should be disposed off and modern equipment must be purchased by the Contractor in order to smoothly run the Projects.

❖ Usage of several software application for better CE management: increased productivity, effectiveness, safety and operational analysis.

❖ Ergonomic design that focuses mainly on the human being by offering better cabin conditions.

❖ Remote control of the CE through the applicability of neural networks applications until the autonomous machine control and use of robotics ("unmanned" equipment).

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