Indian Journal of Science and Technology, *Vol 9(23), DOI: 10.17485/ijst/2016/v9i23/95974, June 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Robotics in Construction Industry

V. R. Prasath Kumar, M. Balasubramanian and S. Jagadish Raj*

Department of Civil Engineering, SRM University, Kattankulathur, Chennai – 603203, Tamil Nadu, India; jagadishrajs23@gmail.com

Abstract

The robotization of on-site reinforcement mat preparation robot, interior/ floor finishing robot, quality inspection robot, drones for carrying loads and proximity detection sensors are considered. Costs and benefits of applying the proposed robot system for construction works are outlined and estimated. Conclusions regarding the profit obtained and time reduced of work performed by robot and its economic feasibility are drawn. **Objectives:** To analyse the efficiency usefulness of automation and robotics in construction, to measure cost effectiveness of automation in comparison to manual work practices and to improve safety and quality standards in construction using automation. **Methods:** By adopting the methods such as value estimation, payback period, return on investment and straight line method for each and every robot the cost parameter is analysed. **Findings:** Automated instruments are found to be efficient by reducing average time consumed for major activities by 57.85% of time taken, automated equipment's are found to reduce cost incurred in net working cost by an average of 51.67% in comparison to cost incurred for performance by manual labor and Quality of output is greatly increased and cost incurred for rework and scrap is reduced by 66.76% by employing automation. **Application Improvement:** By utilizing these robots in real time constructions the various parameters such as time, cost and quality can be improved.

Keywords: Automation, Cost, Robotics, Safety

1. Introduction

India is the seventh largest country in the world and still its record of implementing major projects is far from satisfactory. The success or failure of any project mainly depends on two factors time and cost, apart from its quality which are the lifelines of each and every project. From the observations made one can infer that many of the construction projects in India is involved with extra time, money and resources.

The construction project's requires people of different skills, equipment, materials and machinery for each and every activity as result of which the construction process becomes complicated. Apart from the difficulties faced by the construction industry the two factors safety and quality have been the major determining factors for the outcome of the construction projects. Due to faulty construction works and unsafe working conditions, the works have to be demolished and rebuilt leading to loss in labour time and escalation of cost the project[1].

In the situation as such the advancement of technology in recent years that have been found to be playing a major role across sectors such as manufacturing are finding their way into construction industry[2]. Robotics and automation which has been the crux of scientific developments for the last century has been playing a major role in all other sectors except construction. A process to apply the same technologies in this field also will greatly benefit the outcome of construction activities[3].

This paper deals with studies on various types of robotics, automation and feasibility of their application in construction industry, also comparison of cost benefit between implementation of automation and other manual practices and to improve safety and quality standards in construction using automation.

2. Methodology of Study

2.1 General

The methodology process of carrying out this project was performed in the following manner (i) Study on poor

* *Author for correspondence*

quality and safety standards (ii) Study on robotics and automation in manufacturing sector (iii) Implementation of automation in construction sector (iv) Comparison of conventional methods and automation (v) Further suggestions for use of automation in construction.

2.1.1 Study on Poor Quality and Safety Standards

In today's construction process, due to involvement of huge amount of materials, manpower and machinery and at the same time high pressure and effect of deadlines, a compromise is made on safety and quality standards to achieve the required goals of the project. In this project, an effort is made to study the major safety and quality lacunae that are widely present such as follows

Placement of reinforcement bars of appropriate dimensions with required spacing and direction with proper binding.

Proper finishing of surface of floors and walls to ensure complete finish and lack of damage and rough surface.

Quality inspections carried out in finished structures to ensure that the final outcome confirms with the required standard of quality and finish as required.

Spray of paints and other finishes on surface of falls with proper uniformity in application.

Carry of loads manually by labor from one place to another which may contribute to trip and fall and also has a serious effect on ergonomics.

Possibility of working personnel to trip and fall into excavated area which may lead to injury and at times even act fatal.

Accidents and injuries that may occur due to fall of debris on personnel during process of demolition of structures.

Possibility of working personnel to fall from height due to absence of safety belt or other protective provisions which may result in heavy injury or death.

2.1.2 Study on Robotics and Automation in Manufacturing Sector

The use of robotics and automated equipment's are used to a large extent in order to increase the productivity and work efficiency of manufacturing sector. Also the dependency on labor for many major work practices is reduced to a maximum thus leading to a mechanized work culture in industries. Some of the major types of robots used in manufacturing sector are

Preprogrammed and regulated equipment's are used to package consumables and other food products in factories.

Automated spray painting hose equipment's are used to a large extent in car manufacturing industries to spray paints at lesser time.

Detection of faulty and damaged equipment's using x-ray analyzer equipment's are used to separate quality products from defective ones.

2.1.3 Implementation of Automation in Construction Sector

Once the major quality and safety lacunae are identified, with knowledge of robotics and automation obtained from literature review, efforts are made to innovate and design robots to prevent such occurrences. These are

Use of SCARA robotic technology arm to automatically measure and place rebar with digital feed.

Mobile assembly consisting of joint arm manipulator, distance sensor assembly and controller to provide uniform layer of finishing.

Mobile assembly consisting of detachable track mounted/wall climbing robot with tactile sensor and spray gun.

Suspended/vacuum gripper robots that detect discrepancies by ultrasonic sensor and store data electronically.

Use of light weight fiber drones that are capable to carrying loads to heights.

Placing of laser diode sensors at a proximity of approximately 1m away from edge of excavation to alert workers from tripping and falling.

Use of diamond tipped SCARA arm controllers to ascend and demolish even at heights with ex-situ remote control.

Use of detachable and mobile wall mounted, remote controllable base on which workers can stand and work.

Once the process of approximate design of such robots is complete, a study is made on the various costs involved in production and usage of such robots. These costs include

Acquisition cost

Sophistication of movement and control.

Type and movement of end effectors.

Development of equipment – labor, material, research, testing.

Investment cost
Interest on capital cost.
Depreciation of equipment.

Set up cost
Installation of equipment.
Testing of installed equipment.
Training of personnel for operation of equipment.

Maintenance cost
Regular inspection and maintenance of equipment.
Repair and replacement of spares.
Service after breakdown.

Operating cost
Cost of power for equipment -electric/hydraulic/pneumatic.
Cost of operator.

Apart from this the benefits obtained through this process of automation in the form of labour wages saved, materials reduced, reduction in rework and scrap etc. are also calculated to know about the total monetary advantage that is obtained.

2.1.4 Comparison of Conventional Methods and Automation

Once the costs involved in manufacture and operation of each robot is ascertained, then a detailed economic analysis is made on the performance of each robot by using the following techniques

Value Estimation Method
Compares purchase price of robot with the value of robot to user i.e. present worth of net annual benefits desired over economic life as in equation (1)[4].

Net annual benefits = savings in cost – cost incurred in usage.

$$V = (KL - M - O - T - tP) \times \frac{(1+I)^n - 1}{I(1+I)^n} \tag{1}$$

Where,
V = discounted net worth of service over the economic life of the robot
K = the number of replaced workers
L = =labor savings per year per one worker
M = annual robot maintenance cost
O = annual robot operating cost
T = annual robot transfer cost
t = tax reduction rate
P = initial purchase price of robot
I = interest rate
N = economic life of robot.

Payback period analysis
It is the length of time required for the owner to recover his initial investment in the robot as in equation (2)[4]. Short payback periods are a positive incentive and are preferred.

$$P = \frac{I}{L - E} \tag{2}$$

Where,
P = payback period in years
I = total capital investment in robot. This includes the initial purchase cost and any setup and installation costs incurred.
L = annual labour savings generated by the robot, dependent upon the number of workers replaced by the robot.
E = total annual expenses for the robot

Return on investment evaluation
It gives the investor a simple method of determining whether the potential investment will meet his investment criteria before the investment is made as in equation (3)[4]. Based on it a decision can be obtained if implementing the process will give the desired results or not.

$$ROI = \frac{(S - E) \times 100}{I} \tag{3}$$

Where,
ROI – Return on investment
S = annual savings generated by use of the robot, dependent upon the number of workers replaced.
E = total annual expenses for the robot including depreciation.
I = total capital investment in the robot including initial purchase price and setup or installation costs involved.

2.1.5 Further Suggestions for Use of Automation in Construction

Once the economic analysis and cost comparison between automated process and manual procedure of performing activities in construction is performed, final conclusion based on the summary of analysis is provided as to such automated techniques are feasible to be used in construction and are practically and economically viable or not. Based on it, suggestions for betterment of the study to enable complete automation in construction to enhance safety and quality standards is provided, which can be used in future studies as well.

3. Data Analysis and Results

3.1 Innovation of Robots for Construction

Based on the inputs and data obtained from the types of robots used in manufacturing sector, innovation was made to utilize similar technology to suit the needs of the construction industry in order to enhance the safety and quality output obtained from each project. The different schemes of robots developed for the same are:

SCARA robotic technology arm to automatically measure and place rebar with digital feed.

Mobile assembly consisting of joint arm manipulator, distance sensor assembly and controller to provide uniform layer of finishing.

Mobile assembly consisting of detachable track mounted /wall climbing robot with tactile sensor and spray gun.

Suspended/vacuum gripper robots that detect discrepancies by ultrasonic sensor and store data electronically

Use of light weight fibre drones that are capable to carrying loads to height

Placing of laser diode sensors at a proximity of approx. 1m away from edge of excavation to alert workers from tripping and falling

Use of diamond tipped SCARA arm controllers to ascend and demolish even at heights with ex-situ remote control

Use of detachable and mobile wall mounted, remote controllable base on which workers can stand and work.

3.2 Economic Analysis of each Robot

Once the different types 1of robots were finalized, economic analysis using various tools and procedures are carried out to ascertain if it is practically feasible for application of the technology in the field of construction to obtain maximum benefits in its performance in various aspects like time taken, material consumed, cost incurred etc.

3.2.1 Reinforcement Mat Preparation Robot

This type of robot is used in manufacturing process for the purpose of pick and carry in line assembly works as shown in Figure 1. for the following activities

Packaging of finished products like soap, consumer durables etc.

Shifting of raw materials from one location to another within the factory.

Line assembly in manufacturing of large components.

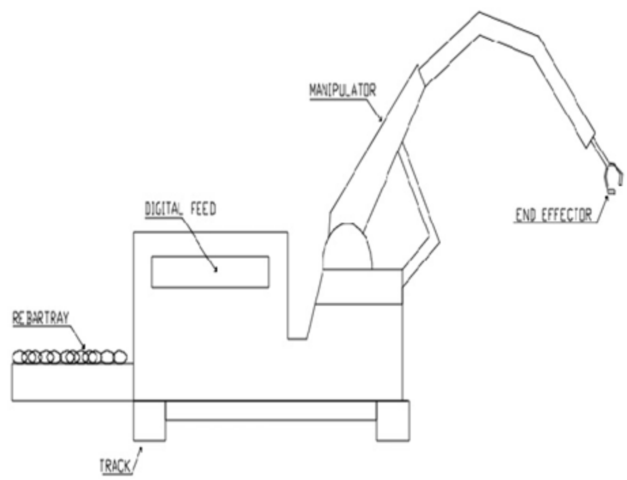

Figure 1. Reinforcement Mat Robot.

This robot is to be used for measurement, placement and binding of steel reinforcement bars for rebar mat preparation for slabs etc.

Features of robot

Anthropomorphic jointed arm capable of performing repetitive tasks.

Degrees of freedom-3(arm) +3(wrist) = 6, flexible wrist for payload orientation.

Reach – 65 – 100 ft.

Payload – 0.2 – 0.5 T

End effectors used are Magnetic finger gripper for lifting and placing of rebar

Movement is made possible by Mobile vehicle mounted on track or crawler.

Material supply is possible by provision of deck on rear for preposition of appropriate rebar.

Control of robots is done by pre-programmed digital feed by offline programming using closed loop control system.

Power for robots is given through electric supply to maintain light weight of equipment.

Tactile sensors – to measure co-ordinates of placement of rebar and compare with digital feed.

Based on the components involved in manufacturing this particular equipment, costs incurred in manufacturing, operation and maintenance are calculated.

Cost involved

Acquisition cost = 45,00,000 (assembly) + 8, 0

Investment

Depreciation – calculated by straight line method[5].

Lifetime of equipment – 10 years

Salvage value=Rs.6, 00,000

$$Depreciation = \frac{62{,}00{,}000 - 6{,}00{,}000}{10}$$ =Rs 5, 60,000 per year

Set up cost

Installation	= Rs 85,000
Training and testing	= Rs 50,000
Maintenance	= Rs 3, 00,000 /year
Operating cost	= Rs 7, 20,000 / year
Transfer cost	= Rs 10,500/year

Benefits obtained

Labour – performs work of 6 labours

Salary + insurance + overheads= Rs 420/day/labour (Or)

35/hr/labour x 12 hrs x 26 days x 12 monthsx6 no's = Rs 7, 86,240

Quality

Material saving = Rs 60,000

Rework – Rs.35/hr/labour x 60hrs/month x 12 months =Rs 25,200

Productivity

6 labours-40dia rebar x 15 no's/hr x 10 hrs/day x 26 days/month x 12 months = 5546 T

Automated machinery

40dia rebar x 25 no's/hr x 12 hrs/day x 26 days/month x 12 months = 7679T

Extra work done =2133 T/year

Additional profit obtained at Rs 1000/ton=Rs 21, 33,000

Other benefits that are attained for labourers on use of this equipment are:

The need for labourers to work with steel reinforcement in hot climates in reduced.

Chances of dropping heavy reinforcement and getting injured is reduced.

Ergonomic issues on continuous binding of reinforcement for preparation of reinforcement mat is decreased.

Based on the costs calculated, value analysis is performed for the equipment to ascertain the usefulness of usage of robot

Value estimation

$$V = (KL - M - O - T + tP) \times \frac{(1+I)^n - 1}{I(1+I)^n}$$

V = (30,04,440 - 3,00,000 - 7,20,000 - 10,500 + 0.07 × 62,00,000) × $\frac{(1+0.1)^{10} - 1}{0.1(1+0.1)^{10}}$ =Rs 14, 79,558/year

Payback period

$$P = \frac{I}{L-E} = \frac{6{,}20{,}000 + 1{,}35{,}000}{30{,}04{,}440 - 10{,}20{,}000} = 3.19 \ years$$

Return on investment

$$ROI = \frac{(S-E) \times 100}{I} = \frac{(30{,}04{,}000 - 10{,}20{,}000) \times 100}{62{,}00{,}000 + 1{,}35{,}000} = 31.32\%$$

Based on the value estimation and costs involved in manual labour for the same activity, a cost comparison is made as shown in Table-1.

Table 1. Cost Comparison for Reinforcement Mat Preparation

	Automated machinery	Manual labour
Initial capital cost (Rs)	62,00,000	7,86,240(wages)
Operating cost (Rs)	7,20,,000	18,000(insurance)
Breakdown/service cost (Rs)	3,00,000	20,000(turnover)
Quality/rework cost (Rs)	Nil	85,200
Productivity (Rs)	76,79,000	55,46,000

3.2.2 Interior / Floor Finishing Robot

This type of equipment is utilized for creating a flat surface to enable lack of aberrations in preparation of glass plates. It can be modified appropriately to finish surfaces both in horizontal and vertical direction and also for spraying of paints etc. The difference between such a robot and those that are used in certain locations in construction projects is that while regular machinery can be used to finish floors in either a horizontal or vertical surface, this particular robot has the capability to perform finishing activities in both directions in the same instant. Also apart from finishing, it can be used to spray paints on walls and other surfaces at a rapid speed in comparison to manual spraying. Also the provision of tracks/wheels for this robot ensures easy and quick mobility thus reducing time duration of transition from one place to another too.

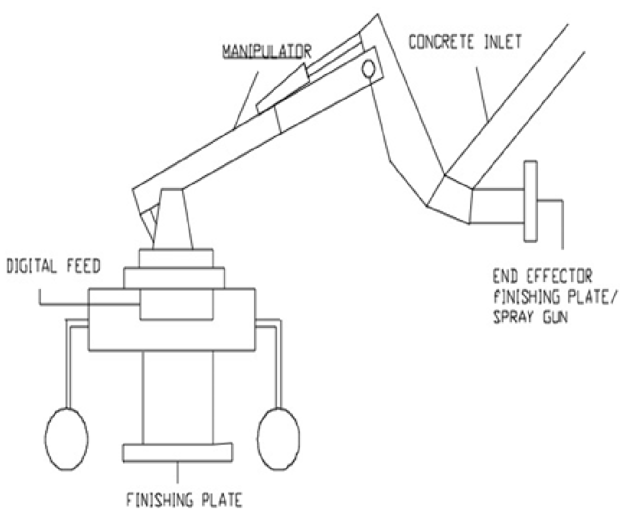

Figure 2. Floor Finishing Robot.

Use

This robot is to be used for application of concrete and finishing of surface of floors and walls. Can also be used for spray painting with spray gun

Features of robot

Anthropomorphic jointed arm capable of spraying

Degrees of freedom-3(arm) +3(wrist) = 6, flexible wrist for payload orientation.

Reach – 8 - 14 ft.

Payload – 50 – 100 kg

End effectors used are Concrete placement gun and finishing plate. Spray gun for panting

Movement is possible by Mobile vehicle mounted on wheels.

Material supply is done by means of pumping through tube to end effector.

Control of robots is possible by offline programming with manual interface as and when required.

Power through electric supply to maintain light weight of equipment.

Tactile sensors is used for tactile sensors for navigation and anti-collision ability for autonomous movement.

Based on the individual components used in preparation of robot, costs incurred is calculated

Cost involved

Acquisition cost = 36,00,000(assembly)+5,00,000(closed loop system) + 8,00,000(sensor)+2,00,00

Investment

Depreciation – calculated by straight line method [5]

Lifetime of equipment – 8 years

Salvage value = Rs.10, 00,000

$$Depreciation = \frac{51{,}00{,}000 - 1{,}00{,}000}{8} = \text{Rs } 5,12{,}500$$

Set up cost

Installation	= Rs.60000
Training and testing	= Rs 40000
Maintenance per year	= Rs 3, 00,000
Operating cost per year	= Rs 8, 00,000
Transfer cost per year	= Rs 10,920
Capital cost	= Rs 51, 00,000
Set up cost	= Rs 1, 00,000
Annual expenses	= Rs.11, 10,920

Benefits obtained

Labour – performs work of 3 labours

Salary + insurance + overheads (per day per labour) = Rs 400

(Or)

33/hr/labour x 12 hrs x 26 days x 12 months x 6no's= Rs 3, 84,400

Quality

Material saving = Rs 20,000

Rework Rs.33/hr/labour x 60hrs/month x 12 months = Rs 23,720

Productivity

3 labours complete 100sq.ft/hour

Automated machinery complete 160 sqft/hour

Extra work done is 60sq.ft x 12hrs x 26 days x 12 months @ Rs 5/sqft.

Additional profit obtained = Rs 11, 23,200

Total benefits= Rs 15, 51,360

Apart from monetary benefits, in terms of safety for construction labourers the following benefits are obtained:

Extended exposure to concrete surfaces is reduced thus preventing chances of skin infections and other diseases for labourers

The need to work in high scaffoldings which may result in trip and fall is prevented thus minimising chances of accidents.

Spraying paints by manual tubes is reduced has reducing exposure to toxins and chemicals in paint.

Value estimation using equation (1)

$$V = (KL - M - O - T + tP) \times \frac{(1+I)^n - 1}{I(1+I)^n}$$

$$V = (15{,}51{,}360 - 3{,}00{,}000 - 8{,}00{,}000 - 10{,}92 + 0.07 \times 51{,}00{,}000) \times \frac{(1+0.1)^8 - 1}{0.1(1+0.1)^8}$$

=Rs.7, 21,531/year

Payback period using equation (2)

$$P = \frac{I}{L-E} = \frac{51{,}20{,}000 + 1{,}00{,}000}{15{,}51{,}360 - 11{,}10{,}920} = 11.8 \text{ years}$$

Return on investment

using equation (3)

$$ROI = \frac{(S-E)\times 100}{I} = \frac{(15{,}51{,}360 - 11{,}10{,}920)\times 100}{51{,}00{,}000 + 1{,}00{,}000} = 8.47\%$$

Based on the results obtained a cost comparison in made between automated method and manual work done by using labourer is shown in Table .2

Table 2. Cost Comparison for Interior/Floor Finishing

	Automated machinery	Manual labour
Initial capital cost(Rs)	51,00,000	3,74,000(wages)
Operating cost(Rs)	8,00,000	9,000(insurance)
Breakdown/service cost(Rs)	3,00,000	10,000(turnover)
Quality/rework cost(Rs)	Nil	43,760
Productivity(Rs)	29,95,200	18,72,000

3.2.3 Quality Inspection Robot

This equipment is used in manufacturing industries for detecting flaws or aberrations in manufacturing of food and consumable goods as shown in Figure 3. It can be used in construction for quality inspection of high rise buildings and lattice towers. The major advantage of utilising this robot is that the need for manual inspection by ascending to heights is reduced which not only increases the safety aspect involved, but also increases the quality of inspection process. Also the time duration involved in completing the entire process is minimised to the maximum extent possible, as a result of which the saved time and manpower can be utilised for increasing the productivity in other processes and activities.

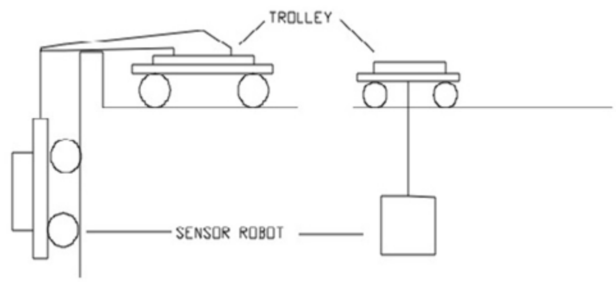

Figure 3. Features of robot

Features of robot

Separate trolley and sensor robot with work envelope up to width of robot used.

Degrees of freedom-2 for trolley and 4 for sensor robot.

Reach – up to 250 ft. vertical and horizontal access based on track placement.

Payload is possible by self-load of equipment

End effectors used are Piezometric pressure transducers with electromagnetic sensors to take readings by inspection.

Movement is possible by Track mounted trolley robot and suspended sensor robot.

Control is manual by means of remote or completely automated by digital feed.

Power is given through hydraulic in order to provide sufficient power for pull of sensor robot.

Cost involved

Acquisition cost = 36,00,000 (assembly) +3,00, 00(sensor)

= Rs.39, 00,000

Investment

Depreciation – calculated by straight line method

Lifetime of equipment – 15 years

Salvage value = Rs.12, 00,000

$$Depreciation = \frac{39,00,000 - 1,20,000}{15} = \text{Rs } 1,80,000$$

Set up cost

Installation = Rs 80,000

Training and testing = Rs 50,000

Maintenance per year = Rs 2, 00,000

Operating cost per year = Rs 3, 00,000

Capital cost= Rs 39, 00,000

Set up cost= Rs 1, 30,000

Annual expenses = Rs 5, 00,000

Benefits obtained

Labour – performs work of 1 engineer + 2 labour

Salary + insurance + overheads =1000+400+400 = Rs 1800/day

(Or)

1800x 26 days x 12 months = Rs 5, 61,600

Safety benefits obtained on use of this equipment are:

Need to ascend heights in man baskets for inspection of lattice towers is substantially reduced.

Exposure to extreme climates at such heights is decreased

Quality

Equipment per year = Rs 72,000

Material saving = Rs 60,000

Productivity

Manual time taken = 120 mins

Automated machinery time taken= 30 mins

Time saved = 90 mins/day x 26 days x 12 months (man days) = 468

Additional profit obtained = 468 man days x Rs.1800/day = Rs 8, 42,400

Total benefits = Rs 15, 36,000

Value estimation per year

$$\mathrm{V} = (\mathrm{KL} - \mathrm{M} - \mathrm{O} - \mathrm{T} + \mathrm{tP}) \times \frac{(1+\mathrm{I})^{\mathrm{n}} - 1}{\mathrm{I}(1+\mathrm{I})^{\mathrm{n}}}$$

$$V = (15,36,000 - 5,00,000 - 3,00,000 + 0.07 \times 39,00,000) \times \frac{(1+0.1)^{15} - 1}{0.1(1+0.1)^{15}}$$

= Rs 2, 27,250

Payback period

$$P = \frac{I}{L - E} = \frac{39,00,000 + 1,30,000}{15,36,000 - 5,00,920} = 3.8 \textit{ years}$$

Return on investment

$$ROI = \frac{(S - E) \times 100}{I} = \frac{(15,36,000 - 5,00,000) \times 100}{39,00,000 + 1,30,000} = 25.70\%$$

Based on the cost incurred, a cost comparison between automated and manual work methodology is made as shown in Table .3.

Table 3. Cost Comparison for Quality Inspection

	Automated machinery	Manual labour
Initial capital cost(Rs)	39,00,000	5,61,600(wages)
Operating cost(Rs)	3,00,000	12,000(insurance)
Breakdown/service cost(Rs)	2,00,000	15,000(turnover)
Quality/rework cost(Rs)	Nil	Nil
Productivity(man hours used)	156=Rs 2,80,800	624=Rs 11,23,200

3.2.4 Drones for Carrying Loads

The use of drones are maximised to the maximum possible extent in many of the other sectors from surveillance to shifting loads as shown in Figure.4. It can be used for similar purposes to carry and shift loads from one location to another in construction sites.

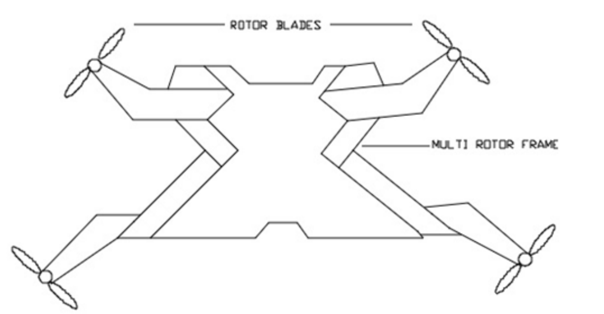

Figure 4. Drone for Load Carrying.

Use

This robot can be used to carry loads from ground level to higher surfaces and also horizontally from one place to another which reduces time duration and occurrence of accidents.

Features of robot

Multi rotator frame motor with RC transmitter and receiver to control propellers and speed of drone.

Degrees of freedom-multiple, in all directions.

Reach – 150-250 ft vertically

Payload - 0.5 - 1 T

End effectors – Hook/basket arrangement to attach and carry load over vertical/horizontal distances

Movement – Airborne with a hang time of 50-55 mins

Control – Remote controlled manually or completed automated with GPS enabled device

Power – Battery operated.

Tactile sensors – tactile sensors for navigation and anti-collision ability for autonomous movement.

Cost involved

Acquisition cost = 1, 15, 000(assembly) +25,000(sensor) +60,000(controller)= Rs 2, 00,000

Investment

Depreciation – calculated by straight line method

Lifetime of equipment = 5 years

Salvage value =Rs.30, 000

$$Depreciation\ per\ year = \frac{2,00,000 - 30,000}{5} = \text{Rs } 34,000$$

Set up cost

Installation= Rs.15000

Training and testing = Rs 25000

Maintenance per year = Rs 36,000

Operating cost= Rs 3, 60,000

Capital cost= Rs 2, 00,000

Set up cost = Rs 40,000

Annual expenses = Rs 2, 76,000

Benefits obtained

Labour – performs work of 3 labour

Salary + insurance + overheads = Rs 750/day

(Or)

750x 26 days x 12 months = Rs 1, 80,000

Quality

Equipment cost per year = Rs 1, 20,000

Productivity

Manual time taken =10 mins

Automated machinery time taken = 2 mins

Time saved in man days = 8 mins x 10 times/day x 20 days x 12 months = 320

Additional profit obtained = 320 days x Rs.750/day = Rs.2, 40,000

Total benefits =Rs 5, 40,000

In addition to this other benefits obtained are

Reduces labourers from carrying heavy loads which may result in ergonomic issues.

Accidents due to moving machinery for load carrying is considerably reduced.

Value estimation per year

$$V = (KL - M - O - T + tP) \times \frac{(1+I)^n - 1}{I(1+I)^n}$$

$$V = (5,40,000 - 36,000 - 3,60,000 + 0.07 \times 2,00,000) \times \frac{(1+0.1)^5 - 1}{0.1(1+0.1)^5}$$

= Rs 1, 19,788

Payback period

$$P = \frac{I}{L-E} = \frac{2,00,000 + 40,000}{5,40,000 - 3,96,000} = 1.66\ years$$

Return on investment

$$ROI = \frac{(S-E) \times 100}{I} = \frac{(5,40,000 - 3,96,000) \times 100}{2,00,000 + 40,000} = 60.24\%$$

Based on the cost incurred, a cost comparison between automated and manual work methodology is made as shown in Table .4.

Table 4. Cost Comparison for Load Carrying

	Automated machinery	Manual labour
Initial capital cost(Rs)	2,00,000	5,61,600(wages)
Operating cost(Rs)	3,60,000	12,000(insurance)
Breakdown/service cost(Rs)	36,000	15,000(turnover)
Quality/rework cost(Rs)	Nil	Nil
Productivity(man hours used)	80=Rs 51,200	400= Rs 2,56,000

3.2.5 Proximity Detection Sensors

Sensors are used to a great extent in all fields for detection and ranging of obstacles. In construction, many a time's accidents occur due to trip and fall in excavated areas. To prevent such occurrences, proximity sensors can be placed on the excavated area to alert nearby coming machinery or personnel.

Use

Battery operated sensors placed at regular intervals around deep excavations to alert labours from trip and fall into excavated area.

Features of sensor

Active infrared motion activated sensors.

Range – 10-15mts

Power – battery operated

Movement –Easily detachable and mountable and hence can be shifted and carried from one location to another with minimal effort.

Cost involved

Acquisition cost = Sensor + proximity chip + transponder = Rs 8000*4= Rs 32,000

Investment

Depreciation – calculated by straight line method

Lifetime of equipment = 2 years

Salvage value = Rs.2000

$$Depreciation\ per\ year = \frac{32{,}000 - 2{,}000}{2} = \text{Rs } 15{,}000$$

Accidents due to excavation – occurs on an average 5 times a year

50 man hours lost/accident. Total per year =250

Cost incurred

Wages – 25/hour, Medical-10/hour, Alternate labour-25/hour

Delay in activities -5/hour

Total loss for 2 years = Rs 32,500

Profit obtained on using sensor with 0 accidents= Rs 500

3.3 Case Study on Application of Automation

Location - Albehudin, Portugal

Stretch of road project = 18 kms

Total cost estimated = $26mn.

Work progress - The entire project was split up into 3 segments of 6kms each and work was carried on simultaneously from both end in 2 different segments.

Segment A - manual work method

No. of

labours used = 250

Machinery – Road rollers, Concrete mixers, Pavers, Scrapper, backhoe, Front shovel

Time taken = 295 days

Cost actually incurred = $9.8mn

Delays in time – 21 (monsoon) + 6 (breakdown of machinery) + 4 (labour turnover) + 8 (accidents) = 39d x 12hrs = 468 hours

Segment B – Completely automated work method

No. of labours used = 40

Machinery – Road paver with tactile sensor and completely automated effector

Time taken = 210 days

Cost actually incurred = $10.1mn

Delays in time – 21(monsoon) +11(breakdown of machinery) = 32d x 12hrs = 384 hours

Conclusion

Even though cost incurred was bit higher, the work was completed in much shorter duration which would help in obtaining higher profits. Also 0 accidents and loss of man hours ensured that the image of the company is maintained and casualties and injuries to personnel is nil.

4. Conclusion

After studying on various robots and their use in construction works the profit and time reduction is discussed below

4.1 Comparison on Profit Obtained and Time Reduced

Taking into consideration only the working cost involved for each type of equipment and the amount of time saved by utilizing the functioning of the equipment, the following details can be concluded as shown in Table 5.

From these details, it can be concluded that utilization of automated equipment yields on an average Percentage increase of 51.67 for profit obtained per year, Percentage increase of 57.85 for time saved per year.

It provides an assessment on the efficiency of automation in construction that increases the networking profit and time duration saved by around 50% of that performed by manual labour.

In addition to the economic profit obtained on using these equipment's, the safety factor involved in these projects in increased resulting in lesser accidents, hence reducing loss of man hours and cost incurred due to it.

4.2 Final Cost Comparison and Suggestions

Based on the data obtained from analysis, a final comparison is made between the various innovative equipment's to recommend if it is feasible for practical usage in construction sites as shown in Table 6.

4.3 Conclusion and Recommendations

Based on the analysis performed to determine if the use of automated equipment in construction industries would benefit economically and be practically applicable or not, the objectives of the project have been attained in the following manner:

Automated instruments are found to be efficient by reducing average time consumed for major activities by 57.85% of time taken, if performed by manual labor alone.

Automated equipment's are found to reduce cost incurred in net working cost by an average of 51.67% in comparison to cost incurred for performance by manual labor.

Quality of output is greatly increased and cost incurred for rework and scrap is reduced by 66.76% by employing automation. Also accidents and man hours lost are reduced to a great extent as labor participation in works involving automated machinery is minimal.

Also, based on the output obtained from the performance of the project, the following recommendations can be made

Robotics and automation if not to a large extent, can be slowly introduced into the construction sector in the Indian context to keep abreast of foreign technologies.

Low cost indigenous robots usage can be promoted, resulting in lower cost and interest among public to carry on research in the field.

Replacement of labours completely by automated machinery in hazardous working conditions to

Preserve health of labour and also to reduce occurrence of accident

The ideas presented in the project are a prototype of the possibilities that can be further developed and utilized for practical applications in real life scenarios.

Table 5. Comparison on Profit Obtained and Time

Sl. no	Equipment	Profit obtained(per year in Rs)	% increase	Time saved(per year in hrs)	% decrease
1	Reinforcement mat preparation	22,18,200	39.99	874 hrs	38.91
2	Interior/floor finishing	11,46,920	61.26	1404 hrs	37.5
3	Quality inspection	6,21,600	45.44	468	75
4	Load carrying	1,80,000	60	320	80

Table 6. Summary of Analysis

Automated machinery	Value estimation (per year in Rs)	Payback period(years)	Return on investment (%)	Final suggestion
Reinforcement mat placing robot	14,79,558	3.19	31.32	Recommended
Interior/floor finishing robot	7,21,531	11.8	8.47	Not Recommended for small and medium scale projects.
Quality Inspection robot	2,27,250	3.88	25.70	Recommended
Drones to carry loads	1,19,788	1.66	60.24	Recommended
Sensors to prevent accidents	-	-	95	Recommended

5. References

1. Zavadskas EK. Automation in Construction Automation and robotics in construction: International research and achievements. Automation in Construction. 2010; 19(3):286–90.
2. Maas G, Van GF. The influence of automation and robotics on the performance construction. Automation in Construction. 2005; 14(4):435–41.
3. Slaughter ES. Characteristics of existing construction automation and robotics. Automation in Construction. 1997; 6(2):109–20.
4. Warszawski A. Robotics in Building Construction Technical Report R-84-147 Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, PA.1984; 1–8.
5. Deodhar SV. Construction equipment and job planning. IN: Planning and Selection of Construction Equipment, Khanna Publications, India. 2010; 214–45.