A Review on Design and Analysis of Sand Transfer Machine

Shreyash Taware[1], V. B. Rajmane[2]
[1]*M.E Student, Department of Mechanical Engineering, SVPM COE Malegaon Bk*
[2]*Associate Professor, Department of Mechanical Engineering, SVPM COE Malegaon Bk.*

***Abstract*—Material handling is a critical component of manufacturing and construction, involving the short-distance movement of materials through manual or automated means. While large-scale construction sites benefit from advanced automation, small-scale sites often rely on manual labour for tasks like unloading sand, collecting soil, and displacing concrete. Manual material handling poses significant risks, including musculoskeletal disorders and injuries due to the physical strain of lifting and carrying heavy loads.**

This project introduces a Conceptual Sand Transfer Machine designed to address the lack of affordable automation for small-scale construction and agricultural sites. The machine is an electrically automated system intended to displace and collect materials from piles of sand, soil, or grains, thereby reducing human effort and project time. A field survey conducted in Pune highlighted the inefficiency of manual sand displacement, where eight workers were required to move 2m³ of sand over 35 minutes—a process this machine aims to optimize.

The technical development of the machine involves the design and analysis of key mechanical components, including a compound helical gear train, shafts, keys, and specialized blades. The design methodology utilizes analytical calculations for torque and gear strength, which are then validated through Finite Element Analysis (FEA) using ANSYS software. By providing a low-cost, portable solution for material handling, the Sand Transfer Machine offers a safer and more efficient alternative to manual labour on smaller worksites.

***Index Terms*—Material handling, bulk material handling, sand transfer machine, automation, ANSYS analysis (FEA), Manual material handling (MMH), Occupational safety.**

I. INTRODUCTION

1.1. Material handling:

The Material handling involves short distance movement within the confines of a building or between a building and a transportation vehicle. It uses a wide range of manual, semi-automated, and automated equipment and includes consideration of the protection, storage, and control of materials throughout their manufacturing, warehousing, distribution, consumption, and disposal. Material handling can be used to create time and place utility through the handling, storage, and control of material, as distinct from manufacturing, which creates form utility by changing the shape, form, and makeup of material.

Material handling is integral to the design of most production systems since the efficient flow of material between the activities of a production systems is heavily dependent on the arrangement of the activities. If two activities are adjacent to each other, then material might easily be handed from one activity to another. If activities are in sequence, a conveyor can move the material at low cost. If activities are separated, more expensive industrial trucks or overhead conveyors are required for transport. The high cost of using an industrial truck for material transport is due to both the labor costs of the operator and the negative impact on the performance of a production system (e.g., increased work in progress) when multiple units of material are combined into a single transfer batch in order to reduce the number of trips required for transport.

1.2. Role of material handling:

Material handling plays an important role in manufacturing and logistics, which together represent over 20% of the U.S. economy. Almost every item of physical commerce was transported on a conveyor or lift truck or other type of material handling equipment in manufacturing plants, warehouses, and retail stores.

While material handling is usually required as part of every production worker's job, over 650,000 people in the U.S. work as dedicated "material moving machine operators" and have a median annual wage of $31,530 (May 2012). These operators use material handling equipment to transport various goods in a variety of industrial setting including moving construction materials around building sites or moving goods onto ships.

1.3. Types of material handling:

Two types of material handling are as follows:

1) Manual material handling.
2) Automated material handling.

1.3.1.Manual Material handling:

Manual handling refers to the use of a worker’s hands to move individual containers by lifting, lowering, filling, emptying, or carrying them. It can expose workers to physical conditions that can lead to injuries that represent a large percentage of the over half a million cases of musculoskeletal disorders reported in the U.S. each year, and often involve strains and sprains to the lower back, shoulders, and upper limbs. Ergonomic improvements can be used to modify manual handling tasks to reduce injury.

These improvements can include reconfiguring the task and using positioning equipment like lift/tilt/turn tables, hoists, balancers, and manipulators to reduce reaching and bending. The National Institute for Occupational Safety and Health (NIOSH) 1991 revised lifting equation can be used to evaluate manual lifting tasks. Under ideal circumstances, the maximum recommended weight for manual lifting to avoid back injuries is 51 lb (23.13 kg). Using the exact conditions of the lift (height, distance lifted, weight, position of weight relative to body, asymmetrical lifts, and objects that are difficult to grasp), six multipliers are used to reduce the maximum recommended weight for less-than-ideal lifting tasks. The Fig 1 shows the workers who are collecting the sand and ‘khadi’ using the spade

Fig 1: Manual Material Handling

1.3.2.Automated Material handling:

Whenever technically and economically feasible, equipment can be used to reduce and sometimes replace the need to manually handle material. Most existing material handling equipment is only semi-automated because a human operator is needed for tasks like loading/unloading and driving that are difficult and/or too costly to fully automate. However, ongoing advances in sensing, machine intelligence, and robotics have made it possible to fully automate an increasing number of handling tasks. In many cases, automated equipment is not as flexible as a human operator, both with respect to not being able to do a particular task as well as a human and not being able to be as easily redeployed to do other tasks as needs change. The Fig 2 shows advanced big crane which is displacing the materials from ground floor to the top floor.

Fig 2: Automated Material Handling

1.3.3.Bulk Material Handling:

Bulk material handling is an engineering field that is centered on the design of equipment used for the handling of dry materials. Bulk materials are those dry materials which are powdery, granular or lumpy in nature and are stored in heaps. Examples of bulk materials are sand, minerals, ores, coals, cereals, woodchips, gravel, clay, cement, ash, salt, chemicals, grain, sugar, flour and stone in loose bulk form. It can also relate to the handling of mixed wastes. Bulk material handling is an essential part of all industries that process bulk ingredients, including food beverage, confectionary, pet food, animal feed tobacco, chemical, agricultural, polymer, plastic, rubber, ceramic, electronics, metals, minerals, paint, paper, textiles and more. More characteristics of bulk materials so far as their handling is concerned are lump size, bulk weight (density), moisture content, flowability, angle of repose, abrasiveness, material form, and corrosivity.

Bulk material handling systems are typically composed of stationary machinery such as conveyor belts, screw conveyors, moving floors, top loaders, stackers, reclaimers, bucket elevators, truck dumpers, railcar dumpers or wagon tipplers, ship loaders, hoppers and diverters and various mobile equipment such as loaders, mobile hopper loaders / unloaders, various shuttles combined with storage facilities such as stockyards, storage silos or stockpiles. Advanced bulk material handling systems feature integrated bulk storage, conveying and discharge.

The purpose of a bulk material handling facility may be to transport material from one of several locations to an ultimate destination or to process material such as ore in concentrating and smelting or handling materials for manufacturing such as logs, woodchips and sawdust at sawmills and paper mills. Other industries using bulk materials handling include flour mills and coal-fired utility boilers. Provide storage and inventory control and possibly material blending is usually part of a bulk material handling system.

II. LITERATURE SURVEY

Below Literature survey speaks about:

- Automation in material handling equipment of construction sites.
- Onsite safety of material handling.
- Risky manual material handling related to human safety.

I. Temiz et. al. [1] described Selection of Construction Equipment by Using Multi- criteria Decision-Making Methods. Minimizing cost of a project is one of the most desired goals for a construction company which in nature is profit oriented to maintain their existence and position in such a competitive sector. However, making only cost- focused selections can result in making incorrect decisions and neglecting many factors that can be as important as cost. Selection of proper construction equipment is essential for cost, quality and duration of a construction project. The rapid development in the manufactory and construction sectors has increased the number of potential construction equipment, which serves the same purpose with different features. Along with the developments in the construction and manufacturing sector, a broad array of construction equipment is produced for different purposes. However, numerous construction equipment is available in the market with different qualities and costs make the construction equipment selection process a difficult task. For that reason, the MCDM methods, which take into account multiple criteria and rank the alternatives analytically, are widely used to solve the construction equipment selection problem. The aim of this paper is to compare the MCDM methods via a case study. Within this scope, an excavation machine selection problem was carried out for a construction company located in Izmir. Assessment criteria, which are taken from the literature, were defined as purchasing cost, engine power, and hydraulic pump flow rate, operating weight, fuel consumption, service conditions, secondary market, spare part conditions and comfort of the operator.

James L. Sullivan et. al. [2] did Development and application of an iterative heuristic for roadway snow and ice control. Weather and climate are important considerations in managing transportation infrastructure systems throughout the world. Increasingly, strategic transportation planning has become more focused on how transportation infrastructure systems may be impacted by weather and how to plan for, and adapt to, changing weather patterns. Nearly 70 percent of the population and 74 percent of the roadways in the United States (U.S.) are located in regions of the country that typically receive snowfall throughout the winter. In recent years, many states in the Northeast, Great Lakes, and northern Midwest regions of the U.S. have experienced an increased demand for roadway snow and ice control (RSIC) due to extreme winter weather events such as heavy snowfall, sleet, and freezing rain; and the frequency of these events is expected to increase in the future. As the frequency and severity of extreme winter storms increases, the state and local agencies responsible for RSIC operations are faced with increasing costs such as maintenance materials (salt, sand, chemicals, etc.), plow operator time, equipment maintenance and replacement, and fuel. In this paper, we present a novel heuristic that provides a theoretical extension to the cluster-first, route- second approach used to solve the combined clustering, allocation, routing problem in RSIC applications. We introduce a novel measure of priority for each link in the network, which quantifies the relative importance of each link to everyday travel. We then use the priority measure in our RSIC routing heuristic to determine initial vehicle allocations for each depot. The heuristic then employs an innovative iterative approach for (1) increasing time windows for the CVRP to maximize the number of available vehicles routed at each depot, and (2) re-allocating idle RSIC vehicles to clusters or depots with the greatest need. The iterations continue until there are no idle vehicles in the entire fleet across all depots. Each initial allocation scenario included up to 105 runs of the CVRP with time windows tow iteration loops. The heuristic balances the competing objectives of minimizing total vehicle hours traveled (VHT) and time required to service the cluster for each depot, while ensuring that the entire vehicle fleet is deployed and the most critical links are serviced as quickly as possible.

Weili Fang et. al. [3] did automated detection of workers and heavy equipment on construction sites: A convolutional neural network approach. The use of computer vision to automatically detect the presence of people, plant, materials and equipment (i.e., objects) from images or videos on construction sites to improve safety and productivity has received widespread attention in the extant literature. Specific applications of computer-vision include: monitoring of progress; tracking of workers; occupational health assessments; quality management, and tracking the use of personal protection equipment (PPE). Several studies have utilized video cameras in conjunction with methods such as the Histograms of Oriented Gradients and Colors (HoG+C) features descriptor, Histogram of Optical Flow (HOF), and Scale Invariant Feature Transform (SIFT), to detect the presence of objects on construction on-sites. Methods of this nature have been overly reliant upon manually extracting hand-crafted features from inputs that are derived from conventional machine-learning and pattern recognition. Constructing a pattern-recognition or machine learning system requires careful engineering and considerable domain expertise to design a feature extractor that is able to transform raw images data into a feature vector that can be used by a classifier (e.g., Support Vector Machine (SVM) and k-Nearest Neighbors (k-NN)) to detect or determine patterns in the input. The research presented in this paper utilized an I Faster R-CNN to detect workers and excavators in real-time on construction sites, which can therefore provide managers with information to improve their decision- making around safety and planning. This was enabled by creating a database of objects from construction sites that was used to train a CNN model to accurately detect their occurrence. The proposed method provides an easy-to-use and low-cost solution to detect objects on-site in real time at a speed of 0.101 s per image. The average detection accuracy of a worker and excavator were 91% and 95% respectively, which exceeds performance levels of state-of-the-art methods (e.g., HOG, SIFT, SURF, ORB, BRISK) by an average of 50%. This is due to the automatic learning of the spatial features contained within the images of the deep CNN model. The proposed method can potentially be used to automatically detect unsafe actions (e.g., hardhat-wearing detection) and unsafe conditions (dangerous areas) during construction. The corollary being intervention by management and resulting in immediate behavior modification.

Jimmie W. Hinze et. al. [4] studied Visibility-related fatalities related to construction equipment. The construction industry continues to rank among the most dangerous industries in the United States and worldwide. Construction workers perform tasks daily in often-crowded and sometimes hazardous settings to accomplish their job objectives. These dangers include, but are not limited to falls, electrocutions, contact with faulty or improperly-operated power tools, and working in close proximity to large equipment such as trucks and cranes. Construction workers consistently sustain a disproportionately high number of fatalities and injuries when compared to workers in other industries. Because of the constantly changing work environment, construction workers are often faced with new hazards that may go unnoticed. In some cases, the hazards are not seen by the workers. The objective of this research was to evaluate the circumstances surrounding vision-related fatalities. This paper presents information on the extent to which vision (or the lack of good visibility) played a role in construction worker fatalities and the nature of those circumstances. The focus on worker safety continues to grow in importance throughout the construction industry. Safety is a major priority that has been and will likely continue to be emphasized by public opinion, policy makers, and construction managers. Fatalities on construction jobsites are no longer considered a part of doing business. As construction research continues to identify areas for safety improvement, there are reasons to suggest that fatality numbers will continue to decline. This research targeted visibility-related fatalities in the construction industry with the aim of discovering relevant patterns of unsafe practices, such as the frequency of incidents related to vehicles backing up, that need to be addressed in future research. The roles of specific factors that contributed to worker fatalities were identified. By increasing the knowledge base and the known facts surrounding these incidents, the application of an effective safety model would contribute to improve the methods of how construction operations are planned and performed. For example, concepts such as Design for Safety and Prevention through Design (PtD) can address the causes for injuries and fatalities identified in this research. In particular such work can help focus safety education, training, and technology development to reduce injuries and fatalities before work is started in the field.

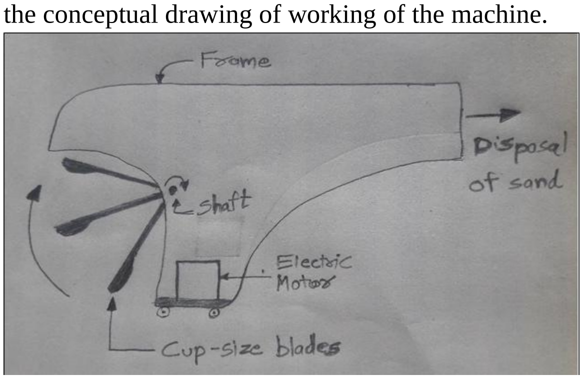
Kanika Prasad et. al. [5] described a software prototype for material handling equipment selection for construction sites. Material handling at a construction site, where the building materials in bulk need to be transported from one place to the other, has a direct influence on transit time, resources usage and service levels. It is intrinsically associated with the flow of construction and can be time consuming, expensive, troublesome and often dangerous. Moreover, improper, inadequate or unsafe handling of materials may cause injuries and even death to the workers in many cases. Therefore, the importance of recent concepts and ongoing efforts in the development of advanced construction technologies based on automation and information sciences, material science and system engineering should be duly acknowledged. Handling materials safely, smoothly and directly with proper material handling equipment (MHE) must be the primary goal of a construction company to keep the process under control at all times. It also accounts for a major percentage of the total construction cost, and thus, efficient handling of construction materials is of paramount importance in significantly reducing this cost. Having an efficient and cost- effective material handling system necessitates designing the entire system at once even though it may comprise several subsystems. Selection and configuration of MHE types are the key sub-systems in the design of a material handling system. The ability to handle construction materials safely is vital for proper functioning of any construction company that can only be attained while employing appropriate MHEs. Availability of a large number of MHEs with varying technical specifications and application areas makes the selection process more complicated and time consuming. Therefore, in this paper, a software prototype based on QFD technique is developed to automate the entire decision-making process for selection of two bulk-type MHEs, i.e., excavator and wheel loader for specific handling tasks at a construction site. A software prototype in Visual BASIC 6.0 with an exhaustive database is designed to remove the huge mathematical calculations involved, while reducing the time taken in the entire MHE selection process. It can evaluate any number of MHE alternatives with respect to any number of selection criteria. The construction engineers now need not to have any in-depth technical knowledge regarding the details of the available MHEs.

Pradip Kumar Ray et. al. [6] studied on Status survey of occupational risk factors of manual material handling tasks at a construction site in India. Any construction-related Manual Material Handling (MMH) task is considered to be an extremely risky work system as it may be associated with frequent occurring work-related injuries to the concerned workers. The injuries are mainly caused by occupational risk factors, such as musculoskeletal disorders (MSDs) as they are typically associated with any MMH tasks or job. However, very limited research has been carried out on occupational risk factors pertaining to MSDs in the construction industry mainly because of varying physical characteristics of such a job and their varying work contents, and a high probability that a worker may work under multiple supervisors over time.
India is the second most populated country in the world and about 0.55 billion workers are involved in construction work. It has been reported that about 165 per 1,000 workers get injured while engaged themselves in the construction activities because of the associated occupational risk factors that are significantly higher in India as compared to developed and some of the developing countries. In a typical construction site in India, a number of workers (both skilled and unskilled) with different occupations carry out various phases of the construction work. Skilled workers include carpenters, rod binders, masons, welders, grinders, gas cutters, fitters, riggers, and 'sarang' (crane operator). The unskilled workers mainly help the skilled workers to work at ground level and at heights. It is justified to assume that the research issues considered in this survey are relevant for the evaluation of MMH tasks at similar kinds of work systems with comparable types of technology and persons employed. The approach with which the survey has been conducted enables key areas, such as need for design of body postures, work methods and activities, to be identified irrespective of the occupations so that it may be applied consistently in similar such work systems from human-machine interaction perspective. The potential benefit of carrying out such a survey lies in developing appropriate guidelines for construction workers to secure a sustainable change in the construction work systems which may reduce the occupational hazards (particularly MSDs) to a large extent and improve health, safety and performance of workers under prevailing construction work environment in India.

Zhenhua Zhu et. al. [7] predicting movements of onsite workers and mobile equipment for enhancing construction site safety. The construction site is typically dirty, disordered, and cluttered with different kinds of resources. Also, it is characterized by a constantly changing environment with the movement and interactions between workers and equipment. In such a chaotic and dynamic place, an incredibly high number of construction activities take place, which easily lead to construction accidents and work-related injuries and deaths. For example, in Canada, around 27,000 accepted time-loss injuries and 200 fatalities were reported in the construction sector every year from2010 to 2012, according to the Association of Workers' Compensation Boards of Canada. Similarly, the U.S. Bureau of Labour Statistics noted that 183,000 construction workers were injured, and 775 workers died on the job with a fatal work injury rate of 9.5 deaths per 100,000 fulltime equivalent workers. The large number of injuries and deaths makes the construction sector one of the most dangerous job sectors over the world. This paper designed Kalman filters to predict the future positions of onsite workers and mobile equipment. The predictions were made based on the current positions of the workers and equipment on the sites and also their previous movement records. The prediction results could indicate the movements of the workers and equipment in a short period of time from the current moment. This information is useful to create a proactive warning system to prevent immediate potential collisions on the construction site and therefore enhance construction site safety. The Kalman filters designed in the paper have been tested with real site videos. The test results showed that the position predictions made by the filters could reflect the real movement of the worker and equipment. Specifically, the average errors in predicting the worker's and vehicle's movements could reach 0.38m and 0. 18m.More accurate predictions could be achieved, when the Kalman filter got sufficient knowledge from its previous prediction errors. For example, the average prediction errors for the worker's and vehicle's movements could be reduced to 0.10 m and 0.11 m, when the first 90 predictions within approximately 3 s were ignored. The high prediction accuracy indicated the effectiveness of the Kalman filters designed in this paper. Future work will focus on creating a pro-active collision warning system based on the work presented in this paper.

III. CONCEPTUAL SAND TRANSFER MACHINE

The innovation in the construction industry can be evidenced through availability of a diverse range of new Material Handling Equipment's (MHEs) in the market having varying advanced features, even then we have problems on small construction site for loading and unloading of material. As we note that on large construction sites, there are advance automation systems for material handling but on small construction sites, manual work is usually carried out for sand loading, unloading, collection, concrete and soil displacement. To overcome these problems, we are going to develop a new machine or product, which is called as Sand Transfer Machine. It is electrically automated machine which will displace or collect the material from pile of sand, concrete, soil, etc. The main aim of this project is to make a machine which will be useful on small construction sites for material handling and on sand sites also in low cost as it will be affordable and will reduce human efforts. Fig 4 shows the conceptual drawing of working of the machine.



IV. DESIGN OF SAND TRANSFER MACHINE

The parts of machine which are designed are as follows:

- Gear pairs.
- Shafts.
- Keys.
- Blades of machine.

A gear train is formed by mounting gears on a frame, the teeth of the gear are engaged. Gear teeth are designed by the pitch circles of engaging gear roll on each other without slipping and the module of both the gears are same, this provides a smooth transmission of rotation from one gear to another gear.

Parameters of machine:

- Input power: 0.5 hp = 0.3728 kW
- Input speed: N1= 1440 rpm.
- Output speed: N2= 288 rpm.

Calculation of Torque:

- Input torque:

$$P = \frac{2\pi N_1 T_a}{60 \times 1000}$$

$$T_a = \frac{0.3728 \times 60000}{2\pi \times 1440}$$

$$T_a = 2.47\ Nm$$

- Output torque:

$$P = \frac{2\pi \times N_2 T_b}{60 \times 1000}$$

$$T_a = \frac{0.3728 \times 60000}{2\pi \times 288}$$

$$T_a = 11.86\ Nm$$

Steps for design of gearbox train:

1. Speed reduction ratio and its stages.
2. Gear design.
3. Gear strength and wear strength.
4. Gear pattern.
5. Shaft design.
6. Keyway design.

Step 1: Stage and type of gearbox train:
As speed reduction is from 1440 rpm to 288 rpm which is higher reduction of speed. So, the choice of the train is compound gear train. As it is compound gear train so for it two stages are decided for further calculations.

Step 2: Speed reduction ratio:
Speed ratio: 5:1

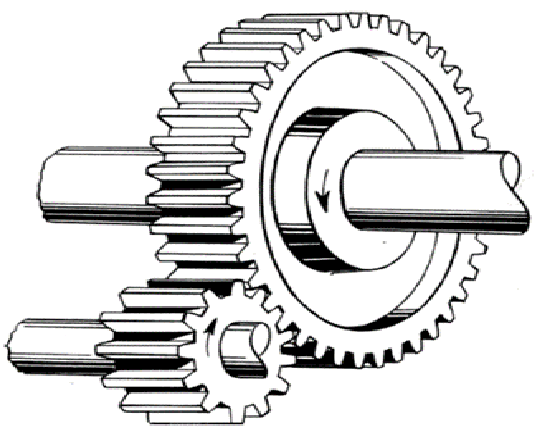
Two stage speed ratios:
- 1st stage: 2.5:1
- 2nd stage: 2:1

Therefore, the speeds of the gears are as follows:
- Input gear speed = 1440rpm
- Intermediate gear speed =576rpm
- Output gear speed = 288 rpm

Selection of gear:
From the above theory of gears, the suitable gears are spur gears & helical gears.
As spur gears teeth are parallel to axis of shaft while helical gears teeth's are inclined to some angles which are much beneficial compare to spur gear.
Also spur gear have disadvantage of wear & tear fast compare to helical gears. So, finally choice of gear is helical gears.

Gear material:
C45 steel heat treatable, tempered with hardness 380 BHN
Tensile strength σ_{ut} = 1240 MPa

4.1. Calculations:
Stage 1: (1440 rpm to 576 rpm) since there are no constraints for the drive design, the number of teeth of pinion is assumed as Z1=18. Helix angle = 20° and normal pressure angle φ_n = 20° are taken for the gears & b= 1.2*pa is assumed.



$$\omega_1 = \frac{2\pi N_1}{60} = \frac{2\pi \times 1440}{60} = 150.79 \text{ rad/s}$$

$$i = \frac{N_1}{N_2} = \frac{1440}{576} = 2.5$$

$$Z_2 = i \times Z_1 = 2.5 \times 18 = 45$$

Torque:

$$T_1 = \frac{1000 \times p}{\omega_1} = \frac{1000 \times 0.3728}{150.79} = 2.47 \text{ Nm}$$

The American Gear of Mechanical Association (AGMA) bending stress equation:

$$P = \pi m = \frac{\pi \times m_n}{\cos \psi} = \frac{\pi \times m_n}{\cos 20^\circ} = 3.343\, m_n$$

$$P_a = \frac{P}{\tan \psi}$$

Assuming,

$$b = 1.2 P_a = \frac{1.2 \times P}{\tan \psi} = \frac{1.2 \times 3.343 m_n}{\tan 20^\circ} = 11.021\, m_n$$

$$F_1 = \frac{2T_1}{d_1} = \frac{2T_1}{mZ_1} = \frac{2 \times T_1 \times \cos \psi}{m_n Z_1} = \frac{2 \times 2472.206 \times \cos 20^\circ}{m_n \times 18} = \frac{258.12}{m_n} \text{ N}$$

J for pinion with teeth Z

$$z_{v1} = \frac{z_1}{\cos 3\psi} = \frac{18}{\cos 3 \times 20} = 51.91 \text{ is } J = 0.47$$

J multiplier for mating with Z

$$z_{v2} = \frac{z_2}{\cos 3\psi} = \frac{45}{\cos 3 \times 20} = 127.27 \text{ is } J = 1.012$$

From fig 8, the multiplier factor J, is noted as 0.47 For pinion J = 0.47 * 1.012 = 0.4756
J factor for gear with teeth Z_{v2} = 127.27 and Ψ = 20^0 is J = 1.012 J multiplier for mating with Zv1 = 50.91 is 0.98.

From fig 7, the geometry factor J, is noted as 1.012 For gear J = 1.012 * 0.98 = 0.9917

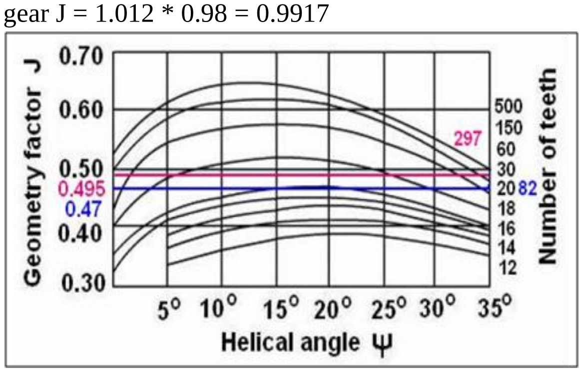


Fig 7: Geometry factor J [10]

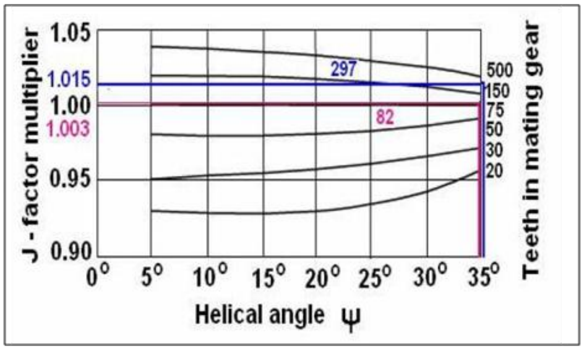


Fig 8: Multiplier factor J [10]

$K_v = \frac{78 + (200V)^{0.5}}{78} = 1.25$ assumed since V is not known.

K_o (overload factor) = 1.25 assuming uniform form of source of power and moderate shock from the driven machinery. From table 2, the overload factor K_o is noted 1.25

Table 2: Overload factor K_o [10]

Source of power	Driven Machinery		
	Uniform	Moderate shock	Heavy shock
Uniform	1.00	1.25	1.75
Light shock	1.25	1.50	2.00
Medium shock	1.50	1.75	2.25

Table 3: Load distribution factor K_m [10]

	Face width(mm)			
Characteristics of support	0 -50	150	225	400 up
Accurate mountings, small bearing clearance, minimum deflection, precision gears	1.2	1.3	1.4	1.7
Less rigid mountings, less accurate gears, contact across the full face	1.5	1.6	1.7	2.0
Accuracy & mounting such that less than full – face contact exists	Over 2.0	Over 2.0	Over 2.0	Over 2.0

K_m =1.3 expecting b= 150 mm accurate mountings, small bearing clearances, minimum deflection, precision gears, from table 3, the load distribution factor K_m is noted 1.3

For the pinion:

$$\sigma_{b1} = \frac{F_1}{bm_n J} K_v K_o (0.93 K_m) = \frac{258.12 \times 1.25 \times 1.25 \times 0.93 \times 1.3}{11.021 \times 0.4756 \times m^2} = \frac{9302.83}{m^3}$$

For the gear

$$\sigma_{b2} = \frac{F_1}{bm_n J} K_v K_o (0.93 K_m) = \frac{258.12 \times 1.25 \times 1.25 \times 0.93 \times 1.3}{11.021 \times 0.9917 \times m^2} = \frac{4461.32}{m^3}$$

Corrected bending fatigue strength of the pinion& gear:

$$\sigma_e = \sigma_e' \times K_l \times K_v \times K_s \times K_r \times K_t \times K_f \times K_m$$

$$\sigma_e' = 0.5\sigma_e = 0.5 \times 1240 = 620 \text{ MPa}$$

K_l = 1.0 for bending

K_v = 1.0 for bending for m≤ 5 module K_s = 0.645 for σ_{ut} = 1240MPa

K_r =0.897 for 90% reliability

K_t = 1.0 with temperature < 120° C K_f = 1.0

K_m = 1.33 for σ_{ut} = 1240 MPa

σ_e = 620 × 1 × 1 × 0.645 × 0.897 × 1 × 1.33 = 477 MPa

Permissible stress for the pinion & gear is bending fatigue with factor of safety 1.6 for finite life gearing.

$$\sigma_b = \frac{\sigma_e}{s_b} = \frac{477}{1.6} = 298\, MPa$$

For the pinion:

$$\sigma_{b1} = \frac{9302.82}{m_n{}^3} = 298$$

m_n = 2.856

For the gear

$$\sigma_{b2} = \frac{4461.32}{m_n{}^3} = 298$$

m_n = 2.23

From table 4, the standard modules are given, value of 3mm is selected.

Table 4: Standard modules in mm [10]

0.3	0.4	0.5	0.6	0.7	0.8	1.0
1.25	1.5	1.75	2.0	2.25	2.5	3
3.5	4	4.5	5	5.5	6	6.5
7	8	9	10	11	12	13
14	15	16	18	20	22	24
26	28	30	33	36	39	42

$$m = \frac{m_n}{\cos\varphi} = \frac{3}{\cos 20^0} = 3.192\ mm$$

$$d_1 = mZ_1 = 3.192 \times 18 = 57.456\ mm$$

$$d_2 = mZ_2 = 3.192 \times 45 = 143.64\ mm$$

$$P = 3.343 m_n = 10.029\ mm$$

$$P_a = \frac{P}{\tan\varphi} = \frac{10.029}{\tan 20} = 27.554\ mm$$

$b = 1.2P_a = 33.064\ mm$

$d_{a1} = d_1 + 2m_n = 63.456\ mm$

$d_{a2} = d_2 + 2m_n = 149.64\ mm$

Transverse pressure angle: $\tan \varphi_n = \tan \varphi \cos \varphi$

$$\varphi_n = \tan^{-1} \frac{\tan 20}{\cos 20} = 21.17^0$$

$d_{b1} = d_1 \cos \varphi = 54\ mm$
$d_{b2} = d_2 \cos \varphi = 134.97\ mm$
$C = 0.5(d_1 + d_2) = 100.54\ mm$
$V = 0.5\omega d_1 = 4.33\ m/s$

$$F_t = \frac{2\,T_1}{d_1} = 85.978\ N$$

Contact stress on gears is given by:

$$\sigma_H = C_p \sqrt{\frac{F_t}{bd}\left(\frac{\cos\phi}{0.95CR}\right) K_v K_o (0.93K_m)}$$

Where Cp = 191(MPa)$^{0.5}$ for steel CR = 1.7082

$$K_v = \left(\frac{78 + (200V)^{0.5}}{78}\right)^{0.5} = 1.1735$$

$K_o = 1.25, K_m = 1$

$$\sigma_b = C_p \sqrt{\frac{F_t}{bd}\left(\frac{\cos\varphi}{0.95CR}\right) K_v K_o (0.93K_m)}$$

$\sigma_b = 605.69$ MPa.

Contact fatigue strength of pinion is:
$\sigma_{sf} = \sigma' \times K_l \times K_h \times K_r \times K_t$
$\sigma'_{sf} = 2.8(BHN) - 69 = 2.8 \times 380 - 69 = 995\ MPa$
KL= 0.9
KH= 1.005 for K=380/331=1.14 & i=4
KR= 1.0 for 99% reliability
KT= 1.0 assuming temp < 120^o C
$\sigma_{sf} = 995 \times 0.9 \times 1.005 \times 1 \times 1 = 900\ MPa$

Factor of safety for pinion & gear against pitting:

$$s_h = \frac{\sigma_{sf}}{\sigma_h} = \frac{900}{605.69} = 1.48$$

Specification of gears is as follows for stage 1:
Speed: 1440 rpm to 576 rpm Helix angle: 20^o
Gear ratio: 2.5:1
Number of tooth: pinion: 18 & gear: 45
The Table 5 shows all the above calculated specifications of the gear pair.

Table 5: Specification of stage 1 gear pair

	Z number of teeth (mm)	dn (mm) pitch circle diameter	da Addendum (mm)	db dedendum (mm)	dr (mm) Root Circle diameter	mn Normal Module (mm)	mt Transverse module (mm)
Pinion	18	57.456	63.456	54	49.476	3	3.192
Gear	45	143.64	149.64	134.97	135.66	3	3.192

	Transverse Pressure Angle Ψt	Pressure Angle Ψn	b width of tooth (mm)	P Transverse Pitch (mm)	Pa Normal Pitch (mm)	ontact ratio	Factor Of safety
Pinion	21.17^0	20^0	33.06	10.029	27.554	1.7082	1.48
Gear	21.17^0	20^0	33.06	10.029	27.554	1.7082	1.48

Stage 2: (576 rpm to 288 rpm) since there are no constraints for the drive design, the number of teeth of pinion is assumed as Z1=18. Helix angle = 20^o and normal pressure angle $\varphi_n = 20^o$ are taken for the gears & b= 1.2*pa is assumed.

$$\omega_1 = \frac{2\pi N_1}{60} = \frac{2\pi \times 576}{60} = 60.318\ rad/s$$

$$i = \frac{N_1}{N_2} = \frac{576}{288} = 2$$

$$Z_2 = i \times Z_1 = 2 \times 18 = 36$$

Torque:

$$T_1 = \frac{1000 \times p}{\omega_1} = \frac{1000 \times 0.3728}{60.318} = 6.18\ Nm$$

The American Gear of Mechanical Association (AGMA) bending stress equation:

$$P = \pi m = \frac{\pi \times m_n}{\cos\varphi} = \frac{\pi \times m_n}{\cos 20^0} = 3.343\, m_n$$

$$P_a = \frac{P}{\tan\varphi}$$

Assuming,

$$b = 1.2P_a = \frac{1.2 \times P_a}{\tan\varphi} = \frac{1.2 \times 3.343 m_n}{\tan 20^0} = 11.021\, m_n$$

$$F_1 = \frac{2T_1}{d_1} = \frac{2T_1}{m_{t1}} = \frac{2 \times T_1 \times \cos\varphi}{m_n Z_1} = \frac{2 \times 6180.57 \times \cos 20}{m_n \times 18} = \frac{645.31}{m_n}\ N$$

From fig 7, we get the multiplier factor J, as follows J factor for gear with teeth Zv2 = 108.57 and Ψ = 200 is J = 1 J multiplier for mating with Zv1 = 50.91 is 0.98.

For gear J = 1 * 0.98 = 0.98

$$K_v = \frac{78 + (200V)^{0.5}}{78} = 1.25$$

assumed since V is not known.

From table 3.5.1, we get K_o (overload factor) = 1.25 assuming uniform form of source of power and moderate shock from the driven machinery.
From table 3.5.2, we get K_m =1.3 for accurate mountings, small bearing clearances, minimum deflection, precision gears.

For the pinion:

$$\sigma_{b1} = \frac{F_1}{b m_n J} K_v K_o (0.93 K_m) = \frac{645.31 \times 1.25 \times 1.25 \times 0.93 \times 1.3}{11.021 \times 0.47 \times m^3} = \frac{5691.32}{m^3}$$

For the gear:

$$\sigma_{b2} = \frac{F_1}{b m_n J} K_v K_o (0.93 K_m) = \frac{645.31 \times 1.25 \times 1.25 \times 0.93 \times 1.3}{11.021 \times 0.98 \times m_n^3} = \frac{3897.10}{m_n^3}$$

Corrected bending fatigue strength of the pinion& gear:

$$\sigma_e = \sigma_e' \times K_l \times K_v \times K_s \times K_r \times K_t \times K_f \times K_m$$

$$\sigma_e' = 0.5\,\sigma_u = 0.5 \times 1240 = 620 \text{ MPa}$$

K_l = 1.0 for bending
K_v = 1.0 for bending for m≤ 5 module K_s = 0.645 for σ_{ut} = 1240MPa
K_r =0.897 for 90% reliability
K_t = 1.0 with temperature < 120° C K_f = 1.0
K_m = 1.33 for σ_{ut} = 1240 MPa
$\sigma_e = 620 \times 1 \times 1 \times 0.645 \times 0.897 \times 1 \times 1 \times 1.33 = 477\ MPa$

Permissible stress for the pinion & gear is bending fatigue with factor of safety 1.6 for finite life gearing

$$\sigma_b = \frac{\sigma_e}{s_b} = \frac{477}{1.6} = 298\ MPa$$

For the pinion:

$$\sigma_{b1} = \frac{5691.32}{m_n^{\,3}} = 298$$

$$m_n = 2.673$$

For the gear:

$$\sigma_{b2} = \frac{3897.10}{m_n^{\,3}} = 298$$

$$m_n = 2.355$$

From the above table of standard modules value of 3mm is selected.

$$m = \frac{m_n}{\cos\varphi} = \frac{3}{\cos 20^0} = 3.192 \text{ mm}$$

$d_1 = mZ_1 = 3.192 \times 18 = 57.456\ mm$
$d_2 = mZ_2 = 3.192 \times 36 = 114.912\ mm$
$P = 3.343 m_n = 10.029\ mm$

$$P_a = \frac{P}{\tan\varphi} = \frac{10.029}{\tan 20} = 27.554\ mm$$

$b = 1.2P_a = 33.064\ mm$
$d_{a1} = d_1 + 2m_n = 63.456\ mm$
$d_{a2} = d_2 + 2m_n = 120.912\ mm$

Transverse pressure angle: $\tan\varphi_n = \tan\varphi \cos\varphi$

$$\varphi_n = \tan^{-1}\frac{\tan 20}{\cos 20} = 21.17^0$$

$d_{b1} = d_1 \cos\varphi = 54\ mm$
$d_{b2} = d_2 \cos\varphi = 107.98\ mm$
$C = 0.5(d_1 + d_2) = 86.18\ mm$
$V = 0.5\omega d_1 = 1.732\ m/s\ 2\ T_1$

$$F_t = \frac{2\,T_1}{d_1} = 215.12\ N$$

Contact stress on gears is given by:

$$\sigma_H = C_p \sqrt{\frac{F_t}{bd}\left(\frac{\cos\varphi}{0.95CR}\right) K_v K_o (0.93 K_m)}$$

Where Cp = 191(MPa)$^{0.5}$ for steel CR = 1.6308

$$K_v = \left(\frac{78 + (200V)^{0.5}}{78}\right)^{0.5} = 1.1129$$

$$K_o = 1.25, K_m = 1$$

$$\sigma_b = C_p \sqrt{\frac{F_t}{bd}\left(\frac{\cos\varphi}{0.95CR}\right) K_v K_o (0.93K_m)}$$

$$\sigma_b = 982.55 \text{ MPa.}$$

Contact fatigue strength of pinion is:

$\sigma_{sf} = \sigma' \times K_l \times K_h \times K_r \times K_t$

$\sigma'_{sf} = 2.8(BHN) - 69 = 2.8 \times 380 - 69 = 995\ MPa$

KL= 0.9

KH= 1.005 for K=380/331=1.14 & i=4

KR= 1.0 for 99% reliability

KT= 1.0 assuming temp < 120° C

$\sigma_{sf} = 995 \times 0.9 \times 1.005 \times 1 \times 1 = 900\ MPa$

Factor of safety for pinion & gear against pitting:

$$s_h = \frac{\sigma_{sf}}{\sigma_h} = \frac{982.55}{900} = 1.09$$

Specification of gears is as follows for stage 2:

Speed: 576 rpm to 288 rpm

Helix angle: 20°

Gear ratio: 2.5:1 Number of tooth: pinion: 18 & gear: 36

The Table 6 shows all the above calculated specifications of the gear pair.

Table 6: Specification of stage 2 gear pair

	Z number of teeth (mm)	dn (mm) pitch circle diameter	da Addendum (mm)	db dedendum (mm)	dr (mm) Root Circle diameter	mn Normal Module (mm)	mt Transverse module (mm)
Pinion	18	57.456	63.456	54	49.476	3	3.192
Gear	36	114.91	120.91	107.98	105.334	3	3.192

	Transverse Pressure Angle Ψt	Pressure Angle Ψn	b width of tooth (mm)	P Transverse Pitch (mm)	Pa Normal Pitch (mm)	Contact ratio	Factor Of safety
Pinion	21.17^0	20^0	33.06	10.029	27.554	1.6308	1.09
Gear	21.17^0	20^0	33.06	10.029	27.554	1.6308	1.09

4.2. Design of Shaft:

Input Shaft: P = 0.0932 kW N = 1440 rpm

L = 60 mm

Fig 9 shows the loading diagram of the input shaft.

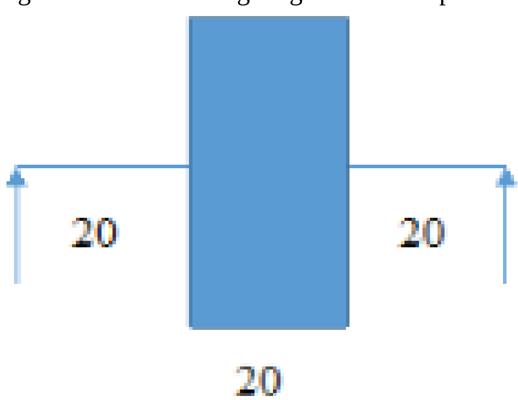


Fig 9: Loading on input shaft

Shaft material: C50

Sut = 700 N/mm^2

Syt = 460 N/mm^2

$\sigma_1 = 0.30\ S_{yt} = 0.30 \times 460 = 138\ N/mm^2$

$\sigma_2 = 0.18\ S_{ut} = 0.18 \times 700 = 126\ N/mm^2$

Taking minimum value from both these stress value

$\tau_{max} = 0.75 \times 126 = 94.5\ N/mm^2$

Torque transmitted by shaft:

$$T = \frac{P \times 60}{2\pi \times N} = \frac{60 \times 0.0932 \times 10^3}{2\pi \times 1440} = 0.618\ N/mm$$

Tangential force on gear:

$$F_t = \frac{T}{R} = 9.657\ N$$

Normal load acting on gear:

$$w = \frac{F_t}{\cos \alpha} = 10.273\ N$$

Bending moment from B:
$M = 10.273 \times 20 = 205.46\ N.mm$

Twisting equivalent moment:

$$T_e = \sqrt{M^2 + T^2} = 205.46\ N.mm$$

Diameter of input shaft:

$$T_e = \frac{\pi}{16} \times \tau \times d^3$$

d = 22.28 mm ≈ 25 mm

Intermediate Shaft:
Fig 10 shows the loading diagram of the intermediate shaft

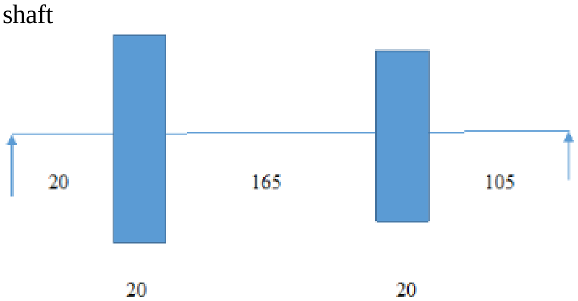


Fig 10: Loading on intermediate shaft

Same material as input shaft
P = 0.3728 kW
N = 576 rpm L = 300 mm

$$T = \frac{P \times 60}{2\pi \times N} = \frac{60 \times 0.3728 \times 10^3}{2\pi \times 576} = 6.1805\ N.mm$$

Tangential force on C:

$$F_{tc} = \frac{T}{R_c} = 53.743\ N$$

Tangential force on D:

$$F_{td} = \frac{T}{R_d} = 20.6\ N$$

Bending moment for vertical and horizontal loading:
Considering vertical loading at C
$R_{av} + R_{bv} = 53.743\ N$

Taking moment at A
$R_{bv} \times 330 = 53.743 \times 115$
$R_{bv} = 18.728\ N$
$R_{av} = 35.015\ N$

Bending moment at A and B
$M_{av} = M_{bv} = 0$
$M_{cv} = R_{av} \times 115 = 4026.725\ N.mm$
$M_{dv} = R_{bv} \times 30 = 561.84\ N.mm$

Now considering horizontal loading at D
$R_{ah} + R_{bh} = 20.6\ N$

Taking moment at A
$R_{bh} \times 330 = 20.6 \times 300$
$R_{bh} = 18.727\ N$
$R_{ah} = 1.873\ N$

Bending moment at A and B
$M_{ah} = M_{bh} = 0$

Bending moment at C
$M_{ch} = R_{ah} \times 115 = 215.395\ N.mm$
$M_{dh} = R_{bh} \times 30 = 561.81\ N.mm$

Resultant bending moment at C

$$M_c = \sqrt{M_{cv}^2 + M_{ch}^2} = 4032.48\ N.mm$$

Resultant bending moment at D

$$M_d = \sqrt{M_{dv}^2 + M_{dh}^2} = 794.54\ N.mm$$

Taking bending moment M = Mc = 4032.48 N.mm
As shaft is stationary and gradually applied load. So, $K_m = 1$, $K_t = 1$

$$T_e = \sqrt{(M \times K_m)^2 + (T \times K_t)^2} = 4032.48\ N.mm$$

Diameter of shaft:

$$T_e = \frac{\pi}{16} \times \tau \times d^3$$

d = 49.89 mm ≈ 50 mm Output Shaft:
P = 0.0932 kW
N = 288 rpm L = 60 mm
Fig 11 shows the loading diagram of the output shaft

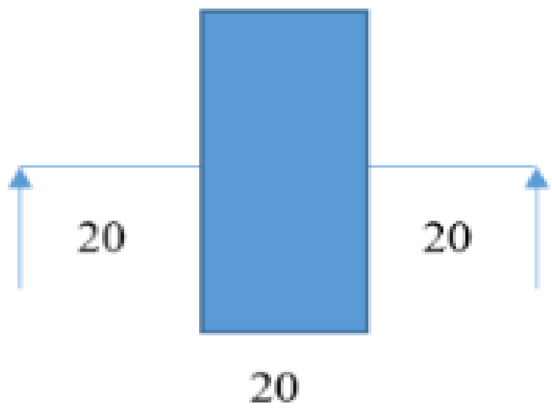


Fig 11: Loading on output shaft

Torque transmitted by shaft:

$$T = \frac{P \times 60}{2\pi \times N} = \frac{60 \times 0.0932 \times 10^3}{2\pi \times 288} = 3.0902\ N/mm$$

Tangential force on gear:

$$F_t = \frac{T}{R} = 154.54\ N$$

Normal load acting on gear:

$$w = \frac{F_t}{\cos \propto} = 164.42\ N$$

Bending moment from B:
$M = 164.42 \times 20 = 3288.4\ N.mm$

Twisting equivalent moment:

$$T_e = \sqrt{M^2 + T^2} = 4512\ N.mm$$

Diameter of input shaft:

$$T_e = \frac{\pi}{16} \times \tau \times d^3$$

d = 24.31 mm ≈ 25 mm

Design of Keyways:
Generally square key is the choice made. Material: C50
Generally, for square key:
Crushing stress, $\sigma_c = 2\tau = 2 \times 94.5 = 189\ N/mm^2$
B = t = d/4
Where d = diameter of shaft and b = width of key

Input Shaft Key:
Width of key, b = 25 / 4 = 6.25 mm

$$T = \frac{\pi}{16} \times \tau \times d^3 = 197.57\ N.mm$$

$T = l \times w \times \tau \times d/2$
$l = 22\ mm$ round to 25 mm = Length of key

Intermediate Shaft Key:
Width of key, b = 50 / 4 = 12.5 mm

$$T = \frac{\pi}{16} \times \tau \times d^3 = 2319.37\ N.mm$$

$T = l \times w \times \tau \times d/2$
$l = 31.34\ mm$ round to 35 mm = Length of key

Output Shaft Key:
Width of key, b = 25 / 4 = 6.25 mm

$$T = \frac{\pi}{16} \times \tau \times d^3 = 289.92\ N.mm$$

$T = l \times w \times \tau \times d/2$
$l = 23.56\ mm$ round to 25 mm = Length of key

V. CONCLUSION

As the methodology and project planning decided, the survey was done. From the survey we summarized that their time and workers both were not necessary for sand transfer. As we will use sand transfer machine for it, then time and manual work will be saved. The analytical calculations are done for the gear box for the machine to reduce the speed of the motor from 1440 rpm to 288 rpm by designing a 2-stage compound gear train. The design and analysis of the part of the sand transfer machine is done successfully now it is ready analysis by software

REFERENCES

[1] T. Temiz *et al.*, "Selection of construction equipment by using multi-criteria decision-making methods," *Procedia Engineering*, vol. 196, pp. 286–293, 2017.
[2] J. L. Sullivan *et al.*, "Development and application of an iterative heuristic for roadway snow and ice control," *Transportation Research Part A*, vol. 127, pp. 18–31, 2019.
[3] W. Fang *et al.*, "Automated detection of workers and heavy equipment on construction sites: A

convolutional neural network approach," *Advanced Engineering Informatics*, vol. 37, pp. 139–149, 2018.

[4] J. W. Hinze *et al*., "Visibility-related fatalities related to construction equipment," *Safety Science*, vol. 49, pp. 709–718, 2011.

[5] K. Prasad *et al*., "A software prototype for material handling equipment selection for construction sites," *Automation in Construction*, vol. 57, pp. 120–131, 2015.

[6] P. K. Ray *et al*., "Status survey of occupational risk factors of manual material handling tasks at a construction site in India," *Procedia Manufacturing*, vol. 3, pp. 6579–6586, 2015.

[7] Z. Zhu *et al*., "Predicting movements of onsite workers and mobile equipment for enhancing construction site safety," *Automation in Construction*, vol. 68, pp. 95–101, 2016.

[8] B. Ozdemir *et al*., "Simulation-based optimization of truck-shovel material handling systems in multi-pit surface mines," *Simulation Modelling Practice and Theory*, vol. 95, pp. 36–48, 2019.

[9] R. Azevedo *et al*., "Obstacle clearance while performing manual material handling tasks in construction sites," *Safety Science*, vol. 62, pp. 205–213, 2014.

[10] *Design Data Book*, Faculty of Mechanical Engineering, PSG College of Technology, Coimbatore, India, June 2006, sec. "Material Handling," p. 9.26.

[11] *NTN Ball and Roller Bearing Catalog*, pp. 20.

[12] Google – Material Handling References.