DECISION MAKING FOR SELECTION OF OPTIMUM MACHINERY IN MEGA CONSTRUCTION PROJECT USING ARTIFICIAL INTELLIGENCE TECHNIQUES

Submitted in partial fulfilment of the requirements

for the degree of

MASTER OF ENGINEERING (CIVIL)

(With Construction Engineering and Management Subjects)

By

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University of Mumbai

(2015-2016)

Dissertation Report

On

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This is to certify dissertation report entitled **"Decision Making for Selection of Optimum Machinery in Mega Construction Project Using Artificial Intelligence Technique"** is a bonafide work of **Mr. Khan Sakib Mohd Dastagir (Roll No. Anjuman 04)** submitted to the University of Mumbai in partial fulfilment of the requirements for the award of the degree of **Master of Engineering** in **Civil Engineering** with specialization in **Construction Engineering and Management** course conducted by University of Mumbai in Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel.

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This is to certify that dissertation report entitled **"Decision Making for Selection of Optimum Machinery in Mega Construction Project Using Artificial Intelligence Technique"** is the own work of **Mr. Khan Sakib Mohd Dastagir (Roll No. Anjuman 04)** in partial fulfilment of the requirements for the award of the degree of **Master of Engineering** in **Civil Engineering** with specialization in **Construction Engineering and Management,** in the Department of Civil Engineering of Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel under my supervision during the period of 2014-2016.

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Declaration

I declare that this written submission entitled **"Decision Making for Selection of Optimum Machinery in Mega Construction Project Using Artificial Intelligence Technique"** represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any data/fact in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Dissertation Approval for M. E

This dissertation entitled ***Decision Making for Selection of Optimum Machinery in Mega Construction Project Using Artificial Intelligence Technique*** by ***Khan Sakib Mohd Dastagir*** is approved for the degree of ***Master of Engineering in Civil Engineering*** with specialization in ***Construction Engineering and Management Subjects***.

Examiners

1.______________________________

2.______________________________

Date:

Place: New Panvel

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ABSTRACT

Selection of machineries in construction projects is a central element in the planning phase of the life cycle of the project. Appropriately selected machineries are the lifeblood of any multistoried construction project and contribute largely to the efficient, timeliness, and profitability of the project. An error in selection can lead to large and unnecessary expenses arising from operational inadequacy or failure, and can produce an unsafe working environment which leads to undesirable expenses. It is assured that optimum selection of machineries lower the risk and costs associated with it.

Selection of machineries depends greatly on skilled judgment that accounts for all likely involved variables. Much information is available to assist in this process in the form of work study data, manufacturer's machines performance, specifications and guidelines on methods of calculating production output and resources requirements. Parameters mentioned above are qualitative and subjective judgment implicit in these terms cannot be directly incorporated into the classical decision making process. Some of these factors are partially quantified and often entangled with personal opinions and seldom based on scientific analysis. These considerations are handled using fuzzy logic techniques.

This study presents a systematic approach to aid the contractor in the proper selection of machineries. After determining the criteria that affect the selection of machineries, fuzzy MADM, fuzzy TOPSIS and SDI Computer tool are applied to the problem and results are presented. The similarities and differences of two methods are also discussed to indicate the applicability and efficiency of the proposed model and the results shows that for the selection process which involve linguistic criterion can be easily deal with fuzzy logic.

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Abbreviation Notation and Nomenclature

TOPSIS	Technique for order preference by similarity to ideal solution
MCDM	Multi-criteria decision making
MADM	Multi-attribute decision making
GA-ANN	Genetic algorithms and artificial neural network
BIM	Building information modelling
GIS	Geographical information system
2D	Two Dimensional
3D	Three Dimensional
MODM	Multi-objective decision making
AHP	Analytical hierarchy process
WSM	Weighted sum method
WPM	Weighted product method
RAHP	Revised analytical hierarchy process
VIKOR	Vlse Kriterijumska Optimizacija Kompromisno Resenje (Serbian name meaning multi-criteria optimization and compromise solution)
DM	Decision Maker
DGC	Vector maximization (or minimization) problem
DS	Goal Programming
MOLP	Multi-objective liner programming
SIMOLP	Simplified interactive multi-objective liner programming
STEM	Step Method
SWT	Surrogate worth trade-off
SEMOPS	Sequential multiple objective problem solving
SDI	Statistical design institute
VOC	Voice of the customer
QFD	Quality function deployment method
TRIZ	Teorija rezbenija izobretatelskib zadach (Russian phrase meaning theory of inventive problem solving)
FMEA	Failure mode and effects analysis
TC	Tower Crane
CP	Concrete Pump
MH	Material Hoist
SAW	Simple additive weighting method
MAUT	Multi-attribute utility theory

Chapter 1

Introduction

1.1 General

In India, construction is the second largest economic activity next to agriculture. Construction accounts for nearly 65 per cent of the total investment in infrastructure and is expected to be the biggest beneficiary of the surge in infrastructure investment over the next five years. According to the Indian construction equipment industry's revenues are estimated to reach US$ 22.7 billion by 2020, so by this there will be a huge development in machineries, new technologies will be introduced over the existing ones, ultimately there will be large number of alternatives available to choose from.

Decision making is the study of identifying and choosing alternatives based on the values and preferences of decision maker (Harris, 2009). As magnitude and scope of problem increases, decision making process gets more and more complicated, because with increase in size and scope, number of alternatives and related factors also increase (Von, 2003).

Construction machinery is considered as cost effective equipment that can be used to perform repetitious, difficult and unsafe manufacturing tasks with high degree of accuracy. Selection of proper machine is one of the important issues for achieving high competitiveness in the global market. The main advantage of selecting a proper machine lays not only in increased production and delivery, but also in improved product quality, increased product flexibility and enhanced overall productivity. Improper selection of a machine tool may cause problems affecting productivity, flexibility and process capability. Evaluation and selection of a machine tool is a complex decision-making problem involving multiple conflicting criteria, such as capital cost, speed, capacity, flexibility, safety and compatibility. As a result, the problem of machine selection should be carefully studied before a large capital investment is made.(Zeleny,1974)

This study presents a logical and systematic procedure to evaluate the construction machineries in terms of system specifications and cost by using the technique for order preference by similarity to ideal solution (TOPSIS) method, which is observed to be quite capable of solving such type of multi-criteria decision-making (MCDM) problems. The priority weights for different criteria are collected from different experts from construction site and machine manufacturer, these weights are used for arriving at the best decision regarding selection of the optimum machineries using Fuzzy TOPSIS method and Fuzzy MADM method.

Several specific characteristics of the decision-making problem should be taken into account in order to obtain good results in the application of any decision-making model.

These critical characteristics are:

1. Decision making is a multi-criteria problem. The proposed model should do analysis of the criteria on a simultaneous basis.
2. Decision making contains risks inherited from different decision maker's opinion.
3. Decision making includes uncertain data given by different contractors.
4. Decision making contain subjective judgement made by decision makers.
5. Decision making include nonlinear relationships between contractor's attributes and their corresponding Experience.
6. The model should be able to adapt the results to suite changes associated between different contractors.
7. It should be able to deal with qualitative as well as quantitative.

1.2 Objectives of the Work

The objective of the work is to select an appropriate construction machineries using fuzzy MADM approach and Fuzzy TOPSIS method by considering the viewpoints of the experts in the relevant fields Pursuant to this, following objectives are proposed in the present investigation.

1. To identify any three important construction machineries out of various machineries available for the proposed thesis.
2. To identify the set of alternatives for selected machineries, set of criteria and numerous decision makers, each with their own set of viewpoints.
3. To select an optimum machinery using Fuzzy TOPSIS through Microsoft excel and statistical design institute (Software).
4. Validating the result obtain from Fuzzy TOPSIS with fuzzy dominance matrix.
5. Discussion, Comparison and Conclusion obtain from Fuzzy TOPSIS and Fuzzy MADM.

1.3 Scope of Work

Selecting of an optimum machinery in the construction industry depends greatly on skilled judgment that accounts for all likely involved variables. Much information is available in terms of qualitative factors and unfortunately this information is incomplete and requires judgment of experts to take decisions. Engineers are increasing their risk by relying on this limited information for the optimum selection of machineries in the construction industry. Decision making problems are governed by inadequate data, insufficient knowledge, and improper input parameters. Selection of machines for large construction projects requires sufficient data for analysis. As the project size increases, machineries selection problems become larger and larger and needs some new techniques which can accommodate these factors. However, in reality construction managers are forced with multiple criteria that need to be included before a final decision is reached. The inability to incorporate these factors into the analysis needs a new methodology which can accommodate these qualitative and quantitative factors. There is a need to develop a systematic and quantitative method for assisting decision maker's to select appropriate machineries for construction by considering multiple attributes and integrating decision group member opinions. The scope of the work is limited to selection of optimum tower crane, material hoist and concrete pump by developing the membership values for various criteria in construction industry.

1.4 Organization of Dissertation

The dissertation report is organized in following six chapters and structured in uniform, well-paced and streamlined flow of the narration. The outline of each chapter is as follows:

Chapter 1 (**Introduction**) contains the background to the study, Objective of the Work, Scope of the Work & Organization of the Dissertation.

Chapter 2 (**Literature Review**) provides a survey of literature available and the detailed study of application of fuzzy logic to selection of machineries in construction industry. The review compiled various general articles and text references.

Chapter 3 (Methods and Methodology) introduces the significance of Multi-criteria decision making. Discusses the classical decision making methods and fuzzy multi objective decision making scenario in the construction industry, research methodology & Steps to achieve the Objective.

Chapter 4 (**Case Study- Construction projects, Mumbai and Navi Mumbai)** includes Case Study- Construction projects, Mumbai and Navi Mumbai and also focuses on various surveys like reconnaissance survey, pilot survey, secondary survey and primary survey along with the identification of machineries for construction, their alternatives and specification.

Chapter 5 (Statistical Analysis) deals with the Statistical Analysis which includes descriptive statistics of the survey along with the various findings based on survey using artificial intelligence techniques.

Chapter 6 (**Results and Discussions**) summarizes the findings of the research study. Comparison of the result obtain from all the different method adopted for study for all the machineries and validating it.

Chapter 7 (**Conclusions**) summarizes the findings of the research study and provides conclusions, future scope, and summary.

Chapter 2

Review of Literature

2.1 General

Lifting, hoisting and placing concrete are important construction process tasks that require meticulous planning. Due to the diverse lifting and hoisting needs of the construction industry, many types of cranes have been designed and produced by crane manufacturers. Each type is designed to handle different types of lifting and hoisting requirements. On a typical construction project, the selection of an appropriate machine can have a significant influence on the time, cost, and safety of the construction operations.

Before exact machine model is selected from crane manufacturer's or operator's database, it is important to select an appropriate machine for the specific lifting or hoisting requirements of a construction site. The available types of machines and input parameters pertaining to the construction project for which the machine is to be chosen provide the starting point in the construction process. Heuristics and past experience is used to select an appropriate type of machine.

Due to the central role of machinery in construction operations, specialists of the machine in construction industries have cooperated in the development and use of structured methods and software tools for machine selection. For years, machines of numerous types have been dominating the construction site as a major task equipment.

Among the overall housing market, public housing has apportioned more than 50% in the last few decades. Owing to the shortage of land supply, high-rise residential buildings becomes a norm. In order to speed up the construction process, the government encourages mechanization and standardization in construction. Consequently, cranes and concrete pump have been used extensively in public housing construction. On large construction projects several cranes generally undertake transportation tasks, particularly when a single crane cannot provide overall coverage of complete demand and supply points, and when its capacity is exceeded by the needs of a tight construction schedule. Many factors influence crane location and in the interests of safety and efficient operation, cranes should be located as far as possible in distance places to avoid interference and collisions, on the condition that all planned tasks can be performed. Similarly, the selection and position of material hoist and concrete pump is also significant.

2.2 Overview of Literature Review

Concept of fuzzy logic was introduced in 1965 by Prof. Lofti A. Zadeh, professor of computer science at the University of California in Berkelay. Basically, fuzzy logic is a multivalued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no etc. and notions like rather tall or very fast can be formulated mathematically in order to apply a more human like way of thinking.

Mac (1973) firstly recognized the importance of MCDM method for selection and proposed a taxonomy of MCDM methods, and created a method specification chart in the form of a tree diagram and provided an illustrative application example**.**

Rodriguez and Francis (1983) developed a mathematical model to establish the optimal location of a single tower crane within a construction site. The model aimed at locating the best position of the crane hook when waiting between movements. The objective of the model was to minimize the total crane transportation cost between crane and the construction supportive facilities that were serviced by the crane.

Furusaka and Gray (1984) developed a mathematical model of locating a crane on a construction site and selecting cranes to give the most economical solution. The model examined the suitability of a crane in terms of lifting capacity, working range, and services-height limitations. With respect to the building layout and the site conditions, the costs of a set of suitable cranes meeting the selection criteria were calculated. In optimizing the suitable combination of crane types yielding the least cost, computer program was written for analyzing the complex combinations. This model revealed that it might not be necessary to use a single type of crane working from the first floor through to the top floor, and that the least cost solution is likely to be obtained from a combination of cranes.

Gray and little (1985) developed a systematic approach to the selection of an appropriate crane for a construction site. They described the process and criteria for the selection of two categories of crane, namely, tower cranes and mobile cranes. The selection process was in the form of decision flow charts. A computer based expert system was developed and used to simplify the selection process and is named CRANES.

Warszawski (1990) developed a knowledge-based system LOCRANE to assist the construction planner in selecting and locating a crane for a construction site. This system was developed using a commercially available shell (SAVOIR). The system asks the user to input all information related to building geometry and possible for application for the proposed crane. The system outputs, most appropriate alternative from a set of cranes available.

Shapiro *et al.* (1991) stated that lifting and positioning of heavy objects is one of the basic tasks in construction. The broad array of specific needs and conditions created a wide variety of types of cranes and hoisting equipment in general. As per Mobile cranes, which are the category of hoisting equipment used in construction industry, can generally move freely around a jobsite with their own wheels or tracks and without being restricted to a predetermined travel path that requires extensive preparation. Mobile cranes are made for open spaces**.** They require great skill and training for proper and safe operation. Crawler, truck mounted, all-terrain, and rough terrain cranes fall under the category of mobile cranes. All mobile cranes are capable of traveling within a jobsite; however, wheeled mobile cranes are also able to travel on the street or highway.

Choi and Harris (1991) introduced a model to optimize single tower crane location by calculating total transportation times incurred.

Hanna (1994) developed a knowledge-based expert system SELECT CRANE within the EXSYS professional shell, which can assist the contractor in selecting the type and configuration of cranes. The user provides the system with the expected weights, dimensions and lift radii of heaviest loads, wind speed, the rental charges and other project information. SELECTCRANE will then provide the user, the recommended type of crane. The system will facilitate the decision-making process and serve as an advisor for field engineers. However, as any other expert system developments, the system is limited to the size and source of data base. Another limitation is that the user has to respond to some subjective questions and has to manually calculate the number of crane days.

Zhang *et al.* (1996) stated that most crane location-related studies relied on the use of mathematical programming formulations and some of these methods are designed to minimize the total crane transportation cost. Researchers have also developed mathematical models in an attempt to decrease total crane transportation time.

Al-Tabtabai *et al.* (1997) mentioned that accurate construction planning is a major determinant in ensuring the completion of a project on time. Scheduling tools currently available in the construction industry, in particular the critical path method, do not provide much assistance to the project manager in updating the project schedule in terms of alleviating the latest expected deviations. Rather, they leave the project manager to reach passively only after the deviations become apparent on site. Hence, accurate estimation of activity duration is a prerequisite to planning. In planning crane-dependent activities such as concreting, fixing precast units, transporting reinforcement bars, and formwork, the correct estimation of the hoisting times can improve the utilization of tower cranes and avoid imbalance hoisting schedule. However, the number of cranes installed for similar public housing sites by different contractors may vary from 4, 5, 6, and up to 8. The utilization levels of the tower cranes, thus, vary among different projects. Due to the constraint of a tower crane, the duration of floor construction cycles varies between 4 and 6 days per floor. Hence, the efficient use of the tower crane is critical to achieving the planned floor cycle time.

Zhang *et al.* (1999) proposed a model to locate a crane group based on the concept that the workload for each crane should be balanced. In this approach the lowest possibility of conflict concept was applied to identify optimal location for cranes. Although these studies can handle issues related to tower crane problems such as locations and operation, there are limitations that need further research. One main limitation to be further investigated is the type and number of cranes that should be predetermined at the early stages. Also, for each supply point, only one demand point can be applied in the model. In addition, many of the previous studies failed to consider the supply locations as an alternative in determining optimal crane locations.

Leung and Tam (1999) used multiple linear regression techniques to determine the optimal location of cranes in terms of minimizing the hoisting times. Others have used mathematical algorithms for different artificial intelligence techniques in order to optimize crane location.

Shapira and Schexnayder (1999) have described the culture of using mobile and tower cranes for building construction. They demonstrated project characteristics and compared tower cranes and mobiles cranes to select the favored alternative. They further found that the selection of cranes fora project is affected not only by project-specific considerations but also by prevailing external conditions that often are the cumulative effect of the characteristics of a whole project population.

Andre and Sawhney (2001) said that the selection of the appropriate crane can have a significant influence on the cost, time and safety of construction operations on typical construction projects. Due to this role, many models have been developed over the past 20 years for solving tower crane problems, generally related to financial and operational efficiency.

Tam and Tong (2003) developed genetic algorithms and an artificial neural network model (GA-ANN) for predicting tower crane operations and site layout. However, only limited attempts have been made to determine the optimal number and location of tower cranes based on a graphical programming environment.

Al-Hussein *et al.* (2005) mentioned that the tower cranes are considered as the centerpiece of construction equipment in building projects. They play a key role in transporting a variety of materials vertically and horizontally. The efficiency of tower cranes largely depends on their type, number and location. As the number of work tasks and the demand for tower cranes increase, planners may experience difficulties in making an appropriate decision about the optimum layout of tower cranes. A poor decision, however, is likely to have significant negative effects, which will lead to additional costs and delays.

Al-Hussein *et al.* (2005) after research they had proven that computer simulation is an efficient and cost-effective validation tool to experiment with potential plans. However, simulation is an abstraction of the real-world which may be confusing for a number of users.

Shapira *et al.* (2006) the presence of tower cranes the most conspicuous symbol of construction has gradually increased in construction industry in recent years. Whereas until recently they were seen almost only on sites on which no other lifting solution could be used in high-rise construction or tight sites. Today they are increasingly also favored by contractors for projects that traditionally would employ cranes.

Shapira *et al.* (2007) said that, cranes play crucial roles in construction industry, especially mobile cranes due to their high capacity in respect to construction assembly operations on-site. Crane operation is critical to implementing projects in the construction industry because it strongly influences successful project completion for modules' installation without potential site errors such as spatial collision which could lead to reduce productivity by increasing cost and time. Crane application has improved the construction industry's efficiency dramatically in recent decades, making prefabrication and on-site installation possible. Efficient crane use also improves work productivity and quality with cost and time savings. After modules are manufactured in a factory, they are delivered to construction sites for assembly.

Kang and Miranda (2008) stated that cranes must not only avoid collisions with these elements that have previously been installed but also need a collision-free path for each subsequent element to be installed. The snapshots generated by BIM are capable of appropriately representing the changing construction environment. However, due to the limitations of GIS tools in automated drafting and lack of semantic information about building elements, one can utilize different visualization tools. Regarding the distance between the crane's cab and load location, finding an optimal place for the tower crane plays an important role in improving operator's view. To respond to this need, it is appropriate to model the operator's viewpoint through the use of Building Information Modeling (BIM). Furthermore, visual representation can be extended to monitor the crane's movements and to prevent the collision of tower cranes operating in a shared work zone. In reality, the number of structural elements (obstacles) increases with construction progress.

Tantisevi and Akinci (2008) recommended 3D visualization to be combined with simulation to provide practitioners with detailed project information to ease understanding of the construction process**.** Since communication is a key to succeed projects, 3D visualization streamlines information exchange between users from diverse fields to identify space conflicts, site layout, construction sequences, workspace requirements and schedule errors in order to save time, and reduce costs and risks before actual implementation**.** However, 3D visualization has only been applied as a supporting tool for validating and verifying new methodologies and algorithms; it does not actively develop new methodologies and algorithms.

Chi and Kang (2010) mentioned various methods have developed automated crane path planning for mobile crane lifts, including collision detection, in both 2Dand 3D. Although private companies and researchers develop computer applications to select and locate cranes, and plan crane paths, validation and verification is required to reduce risks, costs, and time before implementing on the actual site.

Wu Di *et al.* (2011) discussed about automated computer applications and developed programming languages, which have implemented for crane selection and on-site location using algorithms. A number of factors such as delivery material information and site constraints influence crane operation including crane type, number, selection, and location. Due to the complexity of crane operation, computer applications have been developed to assist engineers in selecting, locating, and using cranes. These applications use various algorithms which are based on crane types, namely mobile or tower cranes. Mobile crane commonly installs modules on-site in the construction industry.

Yang *et.al.* (2012) developed AHP model based upon the views of various experts. A well-researched methodology has been adopted for the synthesis of priorities and the measurement of consistencies. A consistency ratio has also been calculated. Industries have been classified into small scale, medium scale and large scale. Various criteria for vendor selection process as received from the expert have been identified. These criteria have been compared using average matrix, priority matrix and overall priority matrix. After analysis of the results it has been found that for large scale industries, vendor reliability, product quality and vendor experience are the top three vendor selection problems that needs to be taken up on priority for effective vendor selection.

Lee et al (2012) aimed to suggest a methodology leading to effective supplier management processes utilizing information obtained from the supplier selection processes. For this methodology, they proposed the supplier selection and management system (SSMS) that includes purchasing strategy system, supplier selection system, and supplier management system, and they explain how the SSMS is applied to a real supply chain. The methodology identifies the managerial criteria using information derived from 10 supplier selection process and makes use of them in the supplier management process.

Boer et al (2013) presented a review of decision methods reported in the literature for supporting the supplier selection process. The review is based on an extensive search in the academic literature. We position the contributions in a framework that takes the diversity of procurement situations in terms of complexity and importance into account and covers all phases in the supplier selection process from initial problem definition, over the 11 formulation of criteria, the qualification of potential suppliers, to the final choice among the qualified suppliers.

Zarand and Saghir (2013) developed a comprehensive multiple products and multiple suppliers model for this process. Moreover, various targets are discussed and analyzed in the form of objectives, in addition to the related constraints. Such model development is fulfilled in a real-world situation with wide ranges of uncertainties. In this work, a fuzzy decision making model is presented. In the proposed Fuzzy Multiple Objectives Decision Making (FMODM) model, all goals, constraints, variables and coefficients are fuzzy. It is shown that with the application of the fuzzy methodology, the complex multi-objective problem is converted to a single one that can be solved and interpreted easily.

Metin Dagdeviren et al (2013), proposed a method including interdependencies of the personnel selection factors studied for the purpose of satisfying the defect noticed. A decision-making model demonstrating the dependency between these factors is developed. Weights of the factors in the model are estimated by means of Analytic Network Process (ANP).

Sun et al (2014) developed a supplier selection model based on support vector machine (SVM). The supplier selection criteria and quantitative methods using fuzzy and pairwise comparison is presented. Simulations show that the proposed supplier selection model is a more useful additional tool than fuzzy synthetically evaluation for supplier management

Shyur and Shih (2014) proposed a hybrid model for supporting the vendor selection process in new task situations. First, the vendor evaluation 13 problem is formulated by the combined use of the multi-criteria decision-making (MCDM) approach and a proposed five-step hybrid process, which incorporates the technique of an analytic network process (ANP). Then the modified TOPSIS (technique for order performance by similarity to idea solution) is adopted to rank competing products in terms of their overall performances.

Kumar et al (2014) proposed a model and various input parameters have been treated as vague with a linear membership function of fuzzy type. It is tested on a data set adopted from a case company. This approach provides a decision tool that facilitates the vendor selection and their quota allocation under different degrees of information vagueness in the decision parameters of a supply chain modelling.

Ahmad and Raja (2014) addressed the multi-objective criteria pertaining to supplier selection process by a combination of Quality Function Deployment (QFD), Analytical Hierarchy Process (AHP) and Pre-emptive Goal Programming (PGP) techniques. QFD facilitates in blending the requirement for suppliers and supplier evaluating criteria. AHP then helps in systematically prioritizing the relative importance of the requirements enumerated as part of the QFD. Finally, PGP aids in the formulation to maximize the value proposition and to minimize the cost involved by exploiting volume discounts.

Chen-Tung Chen et al (2014) presented a fuzzy decision – making approach to deal with the supplier selection problem in supply chain system. In general, many quantitative and qualitative factors such as quality, price and flexibility and delivery performance must be considered to determine the suitable suppliers. In this study, linguistic values are used to assess the ratings and weights for these factors.

Martinez (2014) proposed an alternative decision support system, termed Visual Interactive Goal Programming (VIG). An overview of the complexity and importance of supplier selection problem within the broader context of logistics and supply chain management is presented first. Second, problems are discussed that are related to the application of conventional solutions to supplier selection including goal programming. Third, VIG is introduced as an alternative approach to remedy these problems. Finally, the benefits and limitations of VIG are discussed.

Ke and Wei (2014) proposed a Linear Optimization Hierarchy Process (LOHP) by combining the multi-criteria decision model (MCDM) and the hierarchy thinking. The LOHP can not only reduce the subjectivity and complicacy efficiently, but also solve the special VSP easily which contains a large number of criteria. Thus, the LOHP has high practical value in dealing with the VSP. At the end of this article, a realistic example is applied to demonstrate how

Zhao and Sun (2014) developed based on the analysis of measuring criteria for supplier selection, a preference restraint DEA model. Comparing with exiting methods, the model is more robust without demanding too much information, reflects preference of the decision-maker. An empirical case demonstrates applicability and efficacy of the proposed model.

Yan et al (2014) proposed an integrated fuzzy multiple criteria decision making (MCDM) method that addresses issues in the context of the vendor selection problem. First, they used triangular fuzzy numbers to express the subjective preferences of evaluators. Second, they use interpretive structural modelling (ISM) to map out the relationships among the sub-criteria. Third, the fuzzy analytical hierarchy process (AHP) method is used to compute the relative weights for each criterion, and then they use nonadditive fuzzy integral to obtain the fuzzy synthetic performance of each common criterion. Fourth, the best vendor is determined according to the overall aggregating score of each vendor using the fuzzy weights with fuzzy synthetic utilities. Fifth, they use an empirical example to show that the proposed method is preferred to the traditional method, especially when the sub-criteria are interdependent. Finally, their results provide valuable suggestions to vendors on how to improve each sub-criterion so that they can bridge the gap between actual and aspired performance values in the future.

Wang et al (2014) developed a method using case-based reasoning (CBR) to evaluate supplier. There are some evaluation factors such as price, quality, production capacity, network information level, networked condition and credit in supplier selection. Then the proposed method involves establishing source cases warehouse, describing historic suppliers, and retrieving the source case for the target case by calculating similarity degree. Also, the networked manufacturing-based supplier choosing process was analyzed from four aspects: demands generation, supplier selecting strategy analysis, supplier evaluation and supplier cooperation implement. At last, a numerical example is presented to illustrate the method.

Davari et al (2014) presented a fuzzy decision making approach to address this problem in a way that facilitates the process of decision making while not deteriorating its comprehensiveness. The main contributions of the paper are twofold: First, a model is developed to consider multiple suppliers 19 and multiple items. Moreover, a Piecewise Linear Membership Function (PLMF) is proposed for a specific criterion and is shown how it leads to better solutions. The model functions well in cases where decision maker is sensitive about a specific criterion, in other words, when there are some unequal weights for objectives of the problem. Although asymmetric methods proposed by Zimmerman are a way to tackle the above-mentioned situations; it is demonstrated that how the proposed model brings about both efficiency and simplicity for decision maker which is originated from the utilization of PLMF.

Desheng Wu et al (2014) considered three types of risk evaluation models within supply chains such as chance constrained programming (CCP), data envelopment analysis (DEA), and multi-objective programming (MOP) models. Kannan et al (2008) analysed the interaction of criteria that is used to select the green suppliers who address the environmental performance using Interpretive Structural Modeling (ISM) and Analytic Hierarchy Process (AHP). The effectiveness of the ISM and AHP model is illustrated using a automobile company in the southern part of India.

Jadidi et al (2014) developed an integration of TOPSIS approach and multi-objective mixed integer linear programming (MOMILP) to define the optimum quantities among the selected suppliers. They also applied TOPSIS approach to solve the MOMILP problem. In this solution, TOPSIS minimizes the measure of distance, providing that the closest solution should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS) as well. Therefore, a q-dimensional objective space is reduced to a two-dimensional space (PIS and NIS). Finally, a single objective function is then proposed as a suitable one to resolve the conflict between the new criteria (the shortest distance from the PIS and the longest distance from the NIS).

Pang (2015) proposed fuzzy comprehensive method for evaluating the suppliers based on AHP. The method combines AHP and fuzzy theory and provides a comprehensive evolution method for choosing partner of 22 supply chain. Finally, a case was applied to qualify its scientific and feasibility.

Kamran and Yazdian (2015) proposed a new fuzzy multiple criteria group decision making (FMCGDM) approach based on technique for order preference by similarity to ideal solution (TOPSIS) method for evaluating and selecting an appropriate vendor, where the ratings of each alternative and importance weight of each criterion are expressed in trapezoidal fuzzy numbers. Furthermore, they used the canonical representation of multiplication operation on three trapezoidal fuzzy numbers to construct the weighted normalized decision matrix. Finally, to clearly illustrate their approach a numerical example is conducted.

Kannan et al (2015) in this study, a multi-criteria group decision-making (MCGDM) model in fuzzy environment is developed to guide the selection process of best 3PRLP. The analysis is done through Interpretive Structural Modelling (ISM) and fuzzy technique for order preference by similarity to ideal solution (TOPSIS).

2.3 Summary

The problem with the current literature is that it doesn't address how multiple qualitative attributes are transformed into successful selection of a crane. However, these issues are addressed using fuzzy logic approach in this thesis.

Chapter 3

Methods and Methodology

3.1 General

Selection of machine depends upon the different attributes which are classified into subjective and objective attributes or beneficial and non-beneficial attributes. Subjective attributes are qualitative in nature. Some examples are operation flexibility, vendor’s service quality etc. whereas objective attributes are numerical values such as load capacity, cost etc. The beneficial attributes mean which provide us some profit so its higher value is always preferable. Some examples are load carrying capacity, boom movement distance and boom rotation. Non-beneficial attributes mean which makes us in loss so its lower value is preferable. Some examples cost, maintenance cost, acquisition cost etc.

3.2 Multi-criteria decision making

The multi criteria decision making process involves the following steps:

1. Identification of sufficient alternatives.
2. Identification of all the criteria that are available to the decision maker.
3. Determination of the consequences resulting from the different combination of alternatives and
4. Choosing the best possible alternative on the basis of some criteria.

There are several procedures, on the basis of which selection is made. The selection of appropriate alternative depends on factors like the size of project, nature of work, cost of machineries, and quantity of work

The selection of an alternative depends on many factors. The cost for unproductive time may impact severely on the ultimate cost of construction. The cost of keeping it idle is greater for large capacity one than for a smaller one. The contrary is true for the costs of production.

When selecting new alternative, it is advisable to consider the lifecycle cost of the machineries, not just the initial purchase price. What's really important is to minimize all of the direct and indirect expenses throughout the life of the machineries. Choosing the economical equipment in the market proves unfavorable in the future.

In multi-criteria decision problems, relevant alternatives are evaluated according to a number of criteria. Each criterion induces a particular ordering to the alternatives and a procedure is to be evolved for one overall preference ordering (Mac,1973). There is similarity between these decisions problems and problems of multi person decision making. In both cases, multiple ordering of relevant alternatives is involved and have to be integrated into one global preference ordering. The difference is that the multiple orderings represent either preference of different people or ratings based on different criteria. Direct and indirect costs associated with the equipment while purchasing are as shown in Figure 3.1.

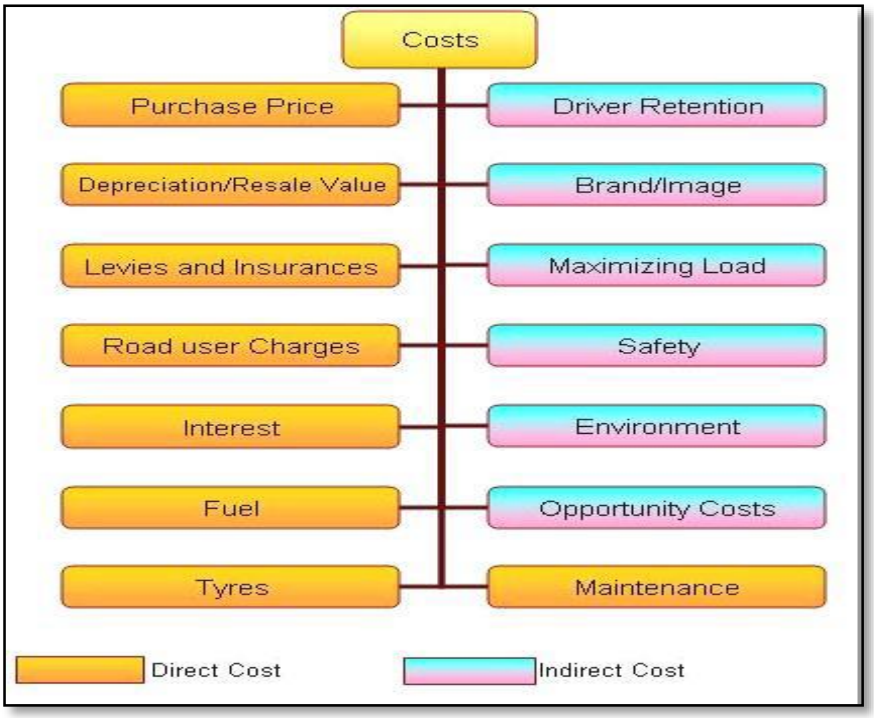

Fig 3.1- Factors for selecting an optimum machinery

The number of criteria in multi criteria decision making is virtually always assumed to be finite, and in addition, that the number of considered alternatives is also finite. The basic information involved in multi criteria decision making is expressed in matrix form. Then it is converted into single-criterion decision problems by finding a global criterion. In general, the entries of the matrix are fuzzy numbers, and weights are specified in terms of fuzzy numbers on $[0, 1]$. Then using the operations of fuzzy addition and fuzzy multiplication to calculate the weighted overage by suitable formula (Kaufmann and Gupta,1988).

Fuzzy multi criteria analysis has become more and more obvious that comparing different ways of action as to desirability, judging and the suitability of products, or determining "optimal" solutions in decisions problems can in many cases not be done by using a single criterion or a single objective function (Zeleny,1982). Hence multi criteria decision making has led to numerous evaluation schemes (e.g., in the areas of cost benefit analysis and marketing) and to the formulation of vector – maximum problems of mathematical programming. (Kondel,1986)

Two major areas have evolved, both of which concentrate on decision making with several criteria: Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM). The main difference between these two directions is: The former concentrates on continuous decision spaces, primarily on mathematical programming with several objective functions; the latter focuses on problems with discrete decision spaces. There are some exceptions to this rule (e.g. integer programming with multiple objectives), but for our purposes this distinction seems to be appropriate.

Multi objective decision making was first dealt by Hwang and Masud (1979) and multi attribute Decision Making was first dealt by Hwang and Yoon (1981). Fuzzy set has contributed to Multi Objective Decision Making as well as Multi Attribute Decision Making (Chen and Hwang,1992). There are three main steps in utilizing a decision-making technique involving numerical analysis of a set of discrete alternatives:

1. Determining the relevant criteria and alternatives.
2. Attaching numerical measures to the relative importance (i.e., weights) of the criteria and to the impacts (i.e., the measures of performance) of the alternatives in terms of these criteria.
3. Processing the numerical values to determine a ranking of each alternative.

Consider a decision-making problem with M alternatives and N criteria. In this paper alternatives, will be denoted as $Ai\ (for\ i = 1,2,3, \ldots, M)$ and criteria as $Cj\ \ (for\ j = 1, 2, 3, N)$. we assume that for each criterion Cj the decision maker has determined its importance or weight, Wj. It is also assumed that the following relationship is always true:

$$\sum_{i=1}^{N} W_j = 1 \qquad \ldots\ldots. \ 3.1$$

Furthermore, it is also assumed that the decision maker has determined $aij\ (for\ i = 1,2,3, \ldots, M\ and\ j = 1,2,3, \ldots, N)$; The importance (or measure of performance) of alternative Ai in terms of criterion Cj. Then, the core of the typical MCDM problem examined in this paper can be represented by the following decision matrix as shown below.

Criteria →

Alternatives ↓	C_1	C_2	C_3	$\cdots$	C_N	→
	W_1	W_2	W_3	$\cdots$	W_N	**Weights**
A_1	a_{11}	a_{12}	a_{13}	$\cdots$	a_{1N}	
A_2	a_{21}	a_{22}	a_{23}	$\cdots$	a_{2N}	
A_3	a_{31}	a_{32}	a_{33}	$\cdots$	a_{3N}	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	
A_m	a_{M1}	a_{M2}	a_{M3}	$\cdots$	a_{MN}	

Some decision methods for instance, the AHP require that the aij values represent relative importance. Given the above data and a decision-making method, the objective of the decision maker is to find the best alternative or to rank the entire set of alternatives (Choobineh and Li, 1993). Let Pi $(for\ i\ =\ 1,2,3,\ldots,M)$ represent the final preference of alternative Ai when all decision criteria are considered. Different decision methods apply different procedures in calculating the values Pi. Without loss of generality, it can be assumed by a simple rearrangement of the indexes that the M alternatives are arranged in such a way that the following relation ranking is satisfied that is, the first alternative is always the best alternative and so on:

$$P1 \geq\ P2 \geq\ P3 \ldots\ldots\ldots \geq PM$$

During the selection of a machine for an industrial application, the decision makers have to consider all attributes explained above. Whereas we have to sacrifice some features or attributes depending upon the requirement due to some reason that's why we need to optimize the selection of industrial machineries. That's why we approach to different multiple criteria decision making (MCDM) methods such as Weighted Sum Method (WSM), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP) Method, Revised Analytic Hierarchy Process (RAHP) Method, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method, Compromise Ranking Method (VIKOR) for the solving of this type of industrial problems which are shown in the Figure 3.2.

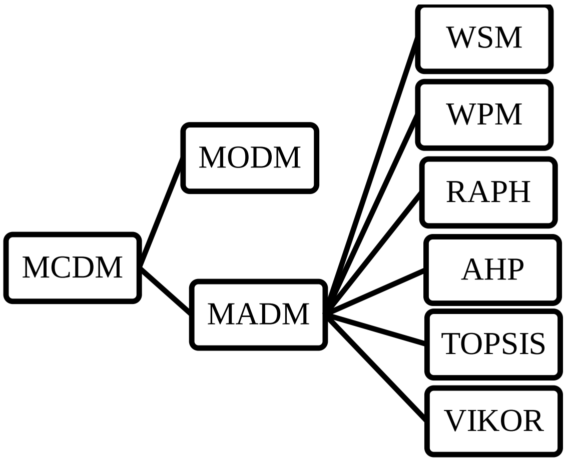

Fig 3.2- Flow chart showing various Multi-criteria decision making Methods

There are a large number of papers have proposed analytical models to give a suggestion in conflict management situations. Among the various approaches available to conflict management, one of the most appropriate is multi-criteria decision making. Multi-criteria decision making (MCDM). It may be considered as a complex and dynamic process including one manager level and one engineering level.

The main steps of multi criteria decision making are the following:

1. Obtaining system evaluation attributes that related system capability to achieve the goals;
2. Developing possible number of alternative systems for achieving the goals (generating alternatives);
3. Obtaining the alternatives in terms of different criteria (the values of the criterion functions);
4. Applying a normative multi-criterion to the analysis method;
5. Accepting one alternative as optimal which is to be preferred;
6. If the final solution is not satisfied, gather new information about the model and go to the next iteration of multi-criteria optimization technique.

Steps (a) and (e) are done at the upper level, where decision makers have the main role, and the other steps are mostly done by the engineers. For step (d), a decision maker expresses his/ her requirements in terms of the relative importance of different attributes and that's why needs to introduce criteria weights. These weights in MCDM do not have a perfect economic significance, but their use provides the chance to model the actual aspects of decision making i.e. preference structure.

The main efforts are given in the engineering level to generate and evaluate the alternatives in steps (b) and (c); these efforts are depending on the project of the person since projects depending to the needs. Generating alternatives can be a very complex process, since there is no general procedure or mathematical procedure that can replace human creativity in generating and evaluating alternatives.

3.2.1 Multiple objective decision making

Decision Making (MODM) problems, in which some objectives are conflicting and the utility function of the Decision Maker (DM) is imprecise or fuzzy in nature. MODM is believed to be one of the fastest growing areas in management science and operations research; and the main reason for such development is that many decision-making problems can be formulated in this category. Although different solution procedures have been introduced (Hwang and Li, 1987; Steuer, 1986; Szidarovszky *et.,* 1986; Tabucanon, 1988), the interactive approaches are generally believed to be the most promising ones, in which the preferred information of the decision maker is progressively articulated during the solution process and incorporated into it. The purpose of MODM problems in the mathematical programming framework is to optimize k different objective functions, subject to a set of system constraints.

A mathematical formulation of an MODM problem is also known as the vector maximization (or minimization) problem (VMP). Generally, MODM problems can be divided into four different categories. The first group of MODM problems does not need to get any information from DM during the process of finding an efficient solution. These types of algorithms rely solely on the pre-assumptions about DM's preferences. L-P Metric methods are among the most popular algorithms whose objectives are the minimization of deviations of the objective functions from an ideal solution named "utopian point". Since different objectives are different in nature, they must be normalized before the process of the minimization of deviations starts. Therefore, we actually minimize a new problem which has no scale (Zeleny, 1973; 1982). The second group of MODM problems includes gathering cardinal or ordinal preferred information before the solving process initiates.

Some of these techniques such as Utility Function and Bounded Objectives are just based on gathering cardinal preferences. In the method of Utility Function, which is the most popular one, we have to determine the DM's utility as a function of objective functions and then we maximize the overall function under the initial constraints. The other methods including, Goal Programming (GP) and Goal Attainment are accepting a mixture of both cardinal and ordinal information. In the method of GP, which is extensively used by many researchers, the DM determines the least (the most) acceptable level of Max (Min) functions. Since attaining these values might lead to an infeasible point, the constraints are allowed to exceed, but we try to minimize these weighted deviations.

The third group of MODM problems provides a set of efficient solutions in which DM has an opportunity to choose his/her preferred solution among the efficient solutions. Multiple Objective Linear Programming (MOLP) and Multiple-Criteria Simplex (Hwang and Masud, 1979), in this group, have been widely used. The last group provides solutions based on a continuous interaction with DM and tries to reach the preferred solution at the end of the algorithm. Based on this sound idea, there are many developed methods, categorized in this group such as: Simplified Interactive Multiple Objective Linear Programming (SIMOLP) (Reeves and Franc, 1983), Step Method (STEM) (Benayoun et.al, 1971), and Surrogate worth Trade off (SWT), Sequential Multiple Objective Problem Solving (SEMOPS), Satisfactory Goals (Hwang and Masud, 1979), and Game Theoretic Technique (Tabucanon, 1988).

3.2.2 Weighted Sum Method (WSM)

The weighted sum model (or WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are M alternatives and N criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression (Fish burn, 1967):

$$A^*_{WSM} = max_i \sum_{j=1}^{N} q_{ij}\, w_j\ ,\ \ for\ i = 1, 2, 3, \ldots, M. \qquad \ldots\ldots\ldots 3.2$$

Where: A_{wsm*} is the WSM score of the best alternative, N is the number of decision

criteria, a_{ij} is the actual value of the $i-th$ alternative in terms of the $j-th$ criterion, and W_j is the weight of importance of the $j-th$ criterion. The assumption that governs this model is the additive utility assumption. That is, the total value of each alternative is equal to the sum of products given from equation 3.1. In single-dimensional cases, in which all the units are the same (e.g., dollars, feet, and seconds), the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi-dimensional decision-making problems. Then, in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to "adding apples and oranges".

3.2.3 Weighted product Method (WPM)

The Weighted Product Method was introduced by (Bridgeman, 1922). According to (Yoon and Hwang, 1995), the method possesses sound logic, and is computationally simple, but has not been widely utilized. Contrary to the SAW method, the different measurement units here do not have to be transformed into a dimensionless scale by a normalization process. This is because in the WPM method, the attributes are connected by multiplication. The weights become exponents associated with each attribute value (positive power for benefit attributes, and negative power for cost attributes).

The multi-attribute utility function U of alternative X_j is given by:

$$U(X_j) = \frac{\prod_{i=1}^{7} x_{ij}^{w_i}}{\prod_{i=1}^{7} (x_i^*)^{w_i}} \qquad \text{………. 3.3}$$

Where x_i^* is the most favorable value (i.e. the best score among the four alternatives) for the i^{th} attribute, and belongs to X^* , the “ideal alternative”.

The use of X^* allows us to put a numerical upperbound to the alternative values obtained by this multiplicative method. Hence, by comparing each alternative with the ideal alternative we can see that U is here between 0 and 1. It is important to note that this method requires that all scores be greater than 1, because of the exponent property.

3.2.4 Revised analytic Hierarchy Process (RAHP)

The Analytic Hierarchy Process - A multi-criteria decision making approach in which factors is arranged in a hierarchic structure (Thomas, 1990). Belton and Gear, (1983) observed that the AHP may reverse the ranking of the alternatives when an alternative identical to one of the already existing alternatives is introduced. In order to overcome this deficiency, Belton and Gear proposed that each column of the AHP decision matrix to be divided by the maximum entry of that column. Thus, they introduced a variant of the original AHP, called the revised-AHP.

3.2.5 Analytic Hierarchy Process (AHP)

One of the most popular analytical techniques for complex decision-making problems is the analytical hierarchy process. (Saaty, 1980; 1994) developed AHP, which decomposes a decision-making problem into a system of hierarchies of objectives, attributes and alternatives. An AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. A number of functional characteristics make AHP a useful methodology. These include the ability to handle decision situations involving subjective judgments, multiple decision makers and the ability to provide measures of consistency of preference (Triantaphyllou, 2000). Designed to reflect the way people actually think, AHP continues to be the most highly regarded and widely used decision-making method. AHP can efficiently deal with tangible as well as non-tangible attributes, especially where the subjective judgments of different individuals constitute an important part of the decision process.

3.2.6 Technique for order preference by similarity to ideal solution (TOPSIS)

Hwang and Yoon, 1995 developed the TOPSIS technique based on the concept that "the chosen alternative should have the shortest distance from the positive–ideal solution and the longest distance from the negative-ideal solution". The ideal solution is the collection of ideal scores (or ratings) in all attributes considered. The TOPSIS technique defines a "similarity index" (or relative closeness) by combining the proximity to the positive-ideal solution and the remoteness of the negative-ideal solution.

3.2.7 Compromise Ranking Method (VIKOR)

The foundation for compromise solution was established by Yu (1973) and Zeleny (1982) and later advocated by (Oprocovic and Tzeng, 2002; 2004; 2007). The compromise solution is a feasible solution that is the closest to the identical solution and a compromise means an agreement established by manual concession (Serafim *et al.* 2012). The compromise solution method is also known as the VIKOR method, was introduced as one applicable technique to implement within MADM. The multiple attribute merit for compromise ranking was developed from the Lp-metric used in the compromise programming method (Zeleny, 1982). VIKOR is a helpful tool in MADM, particularly in a situation where the decision maker is not able or does not know how to express preference at the beginning of system design.

3.3 SDI tool

SDI Tools is a set of commercial software add-in tools for Microsoft Excel developed and distributed by Statistical Design Institute, LLC, a privately-owned company located in Texas, United States. SDI Tools were first developed in 2000 by Dr. George Chollar, Dr. Jesse Peplinski, and Garron Morris as several Add-Ins for Microsoft Excel to support a methodology for product development that combined elements of Design for Six Sigma and Systems Engineering.

Today, SDI Tools are split into two main Microsoft Excel Add-Ins called Triptych and Apogee.

3.3.1 SDI tool- Triptych

Triptych is a Microsoft Excel Add-in that provides support for documenting and clarifying the voice of the customer (VOC), identifying and flowing down requirements, and generating and selecting design alternatives. Triptych includes functionality for:

1. QFD: Captures the voice of the customer and translates it into engineering requirements using Quality Function Deployment methods.
2. Affinity Diagram: A Tool for sorting large number of ideas or concepts into logical groupings using the Affinity diagram method.
3. AHP (Importance): Prioritizes (or ranks) Items by performing pair-wise comparisons of Items against each other in terms of relative importance using a one-level Analytic Hierarchy Process.
4. TRIZ: Generates ideas for solving technical contradictions using the Theory of Inventive Problem Solving TRIZ.

3.3.2 SDI tool- Apogee

Apogee is a Microsoft Excel Add-In that integrates the capabilities of sensitivity analysis, Monte Carlo analysis, allocation, and multi-objective optimization into a single easy-to-use toolset. Apogee works with functions Y = f(x) that you create freeform in Microsoft Excel workbooks. Its functionality includes:

1. Sensitivity Analysis: Assesses the magnitude of response variation caused by the variation of the parameters using a Sensitivity analysis.
2. Monte Carlo Analysis: Assesses the magnitude and shape of response variation caused by the variation of the parameters using the Monte Carlo method.
3. Allocation: identifies the allowable amount of parameter variation that will improve response variation to a desired level. (Often referred to as statistical tolerance analysis or requirements flow down.)
4. Optimization: searches for new parameter values that will drive multiple response values to desired targets using statistical, multi-objective optimization driven by a custom genetic algorithm.
5. Pugh Matrix: Qualitative multi-criteria decision analysis using Pugh Concept Selection method.
6. TOPSIS: Goal-based multi-criteria decision analysis using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology.
7. SDI Matrix: Quantitative multi-criteria decision analysis developed by Statistical Design Institute using Value Assessments for product specifications.
8. FMEA: A risk assessment technique for systematically identifying potential failures in a system or a process using Failure mode and effects analysis.

3.4 Methodology

The methodology is the general research strategy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used in it. Methodology does not define specific methods, even though much attention is given to the nature and kinds of processes to be followed in a particular procedure or to attain an objective. Without a proper well- organized research plan, it is impossible to complete the project with the deadlines and also to reach to a conclusion. The methodology adopted to achieve the desired objective is as shown in Figure 3.3

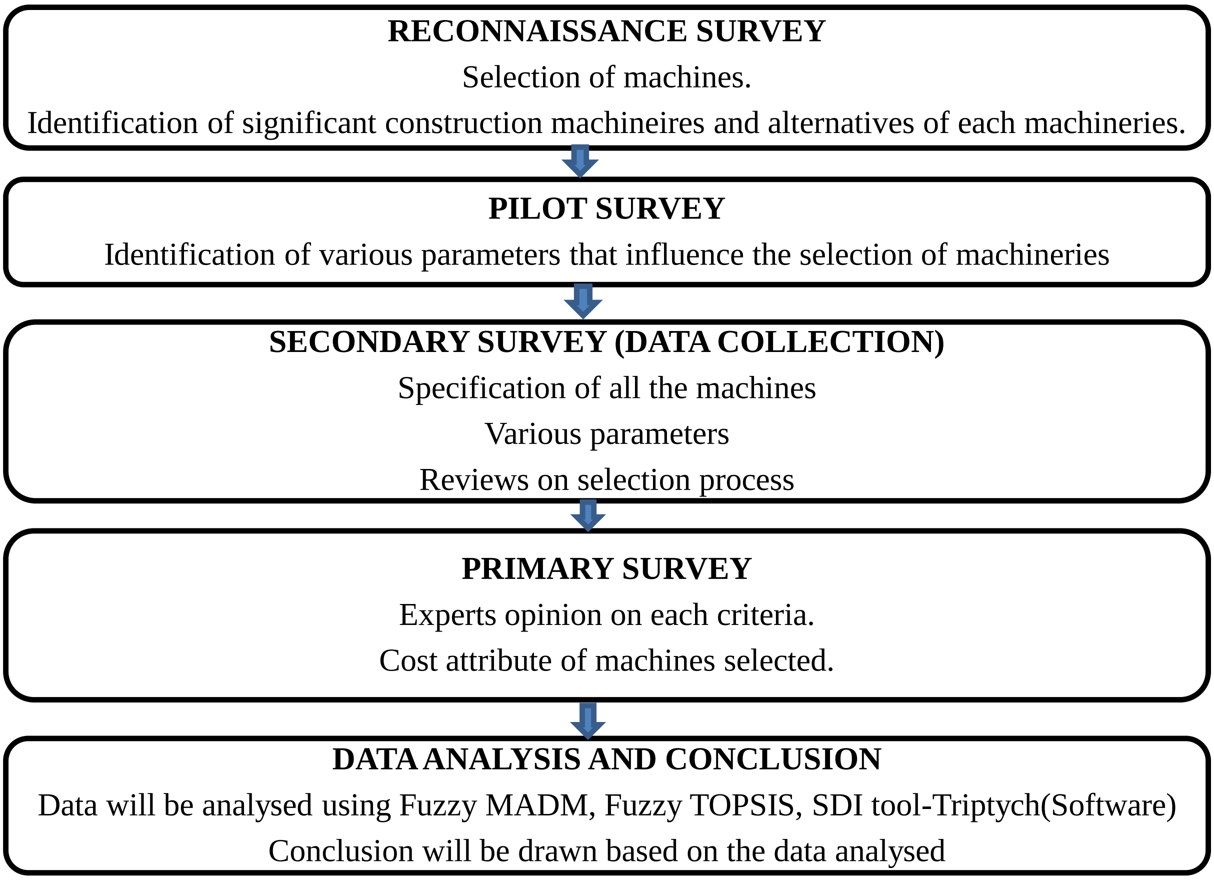

Fig 3.3- Flow chart showing Methodology adopted.

The above flow chart is explained in detail by the following steps: -

Step 1: Reconnaissance Surveys

Reconnaissance surveys represent a type of field survey that is often used to gather pre-primary information regarding the presence or absence of various Parameters to be considered within a scope of the work. It includes selection of the important machineries (limiting the scope of the Project to three major construction machineries), identification of alternatives to that machineries.

Step 2: Pilot Survey

Pilot survey, after the draft proforma preparation the pilot survey is done at the site to check if there are any information/ variable that has to be considered/ is missing on the data collection process. It is generally a trial survey done for a few samples to check the validity of survey proforma and inclusion/ exclusion of any variable(s). It includes Identification of various Parameters that influence the property rates.

Step 3: Secondary Survey (Data Collection)

Secondary survey, is the survey used to collect secondary data from various sources like internet, magazine, newspaper, offices or other. These secondary data are collected and recorded by various authenticated agencies/ organisations. Often, this type of data may be obtained from various manufacturers brochures. Data on specification of various construction machineries are available with manufacturer, vendors, site offices and websites.

Step 4: Primary Survey

Primary survey is the survey at which the information is directly collected from the site, based on the survey proforma related to the specification of the machineries. This step is to collect data in terms of rating from 0-1 from the various decision makers involved in construction project.

Step 5: Data Analysis and Conclusion

Once the data are collected and compiled, the next step is to statistically estimate the ranking of each machineries from all the three-adopted method and comparing the result among all three methods followed by validation and conclusion of the work.

3.5 Analysis Methodology

A systematic analysis methodology is proposed in this study to select the most appropriate machineries. The approach consists the following steps such as defining the problem, defining the evaluation criteria, initial screen, assigning the weights on evaluation criteria, multi criteria decision making method for selection, evaluation of alternatives, and sensitivity analysis and is illustrated in Figure 3.4.

3.5.1 Define the problem

The collected data is basis on which the appropriate multi criteria decision making (MCDM) technique is identified and utilized to solve the problem. The characteristics of the problem such as identifying the number of alternatives, tolerance limit, attributes, weights and constraints are addressed here.

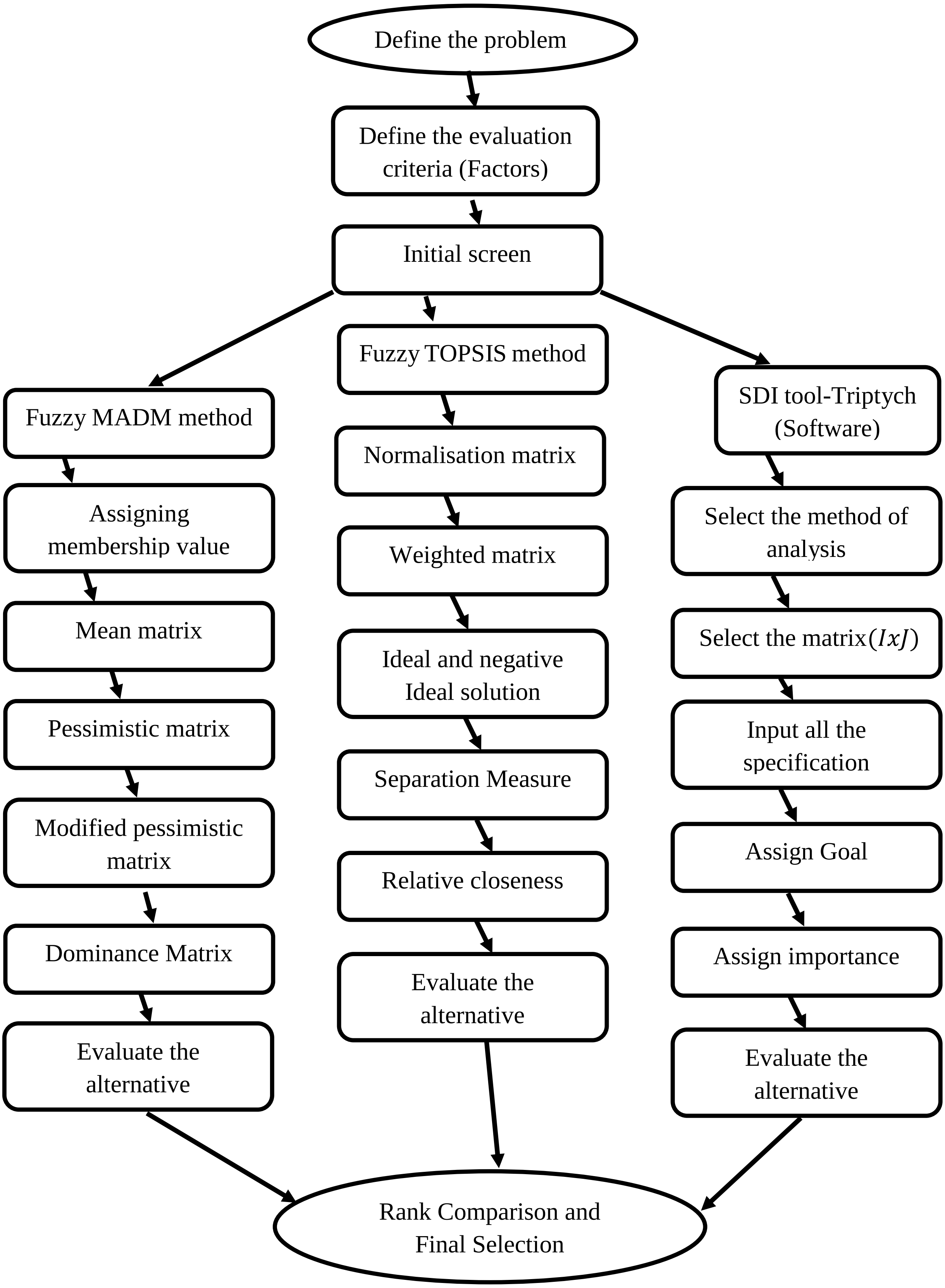

Fig 3.4- Flow chart showing procedure of MADM, TOPSIS, SDI Triptych

3.5.2 Define the evaluation criteria

The evaluation criteria are in terms of qualitative and quantitative. The criteria are identified based on applicability and computational complexity. The defined evaluation criteria will be used as the attributes of a MCDM formulation and is the input data of decision matrix for selection method.

3.5.3 Initial screen

In the initial screening, the infeasible alternatives and criteria are eliminated. Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked. The alternatives which possess unacceptable and infeasible attribute values are eliminated in the screening process. The conjunctive method is employed to remove the unacceptable alternatives. Any alternative which has an attribute value worse than the cutoff values will be eliminated. The cutoff values given by the decision maker plays a key role in eliminating the alternatives.

3.5.4 Fuzzy MADM Method

The multi criteria decision making process involves the following steps:

1. Identification of sufficient alternatives
2. Identification of all the criteria that are available to the decision maker
3. Determination of the consequences resulting from the different combination of alternatives and
4. Choosing the best possible alternative on the basis of some criteria.

There are several procedures, on the basis of which selection is made. The selection of appropriate alternative depends on factors like the size of project, nature of work, cost of machineries and quantity of work.

3.5.4.1 Assigning membership value

Criteria represent the different dimensions from which the alternatives can be viewed. If the number of criteria are large in some occasions, criteria may be arranged in a hierarchical manner. Some criteria may be major criteria and each major criterion may be associated with several sub-criteria. Similarly, each sub-criterion may be associated with several sub-sub-criteria and so on.

After the initial screening is completed, the decision makers' preference information on the evaluation criteria is defined. This will reflect which criterion is more important to the decision maker (DM). Relative weights are assigned to each evaluation criterion to describe the DM's preference information, the weights must be carefully considered based on the DM's preferences and experiences, Subjective scale between 0.0 to 1.0 is used with calibration that 0.0 stands for extremely unimportant while 1.0 represents extremely important.

3.5.4.2 Mean matrix

Dominance method for decision making is characterized by a set of alternatives, set of criteria and numerous decision makers, each with their own set of viewpoints. This process can be represented in a matrix form and is known as the evaluation matrix.

In judging the finite set of cranes $(A_1, A_2, \ldots, A_N)$ across a set of criteria $(C_1, C_2, \ldots, C_M)$ one can assign a value for each criterion and for each crane. Since one evaluation matrix would not adequately define the evaluation of all decision makers, a series of matrices are developed over a range of positions. Since the evaluation is based on subjective interpretations, there is no choice but to tolerate some level of imprecision and ambiguity. A mean matrix is obtaining by adding all the matrix having different viewpoints from decision makers.

3.5.4.3 Pessimistic matrix

After identifying the mean aggregated values, the pessimistic aggregated matrix should be formed to minimize the risk of taking the values of memberships given by all the experts from the different companies for each criteria against each alternative. To form pessimistic aggregated matrix minimum membership value of each criterion against each alternative from all the position matrices are taken and formed in a matrix. It is given by the equation

$$\mu_{ij} = \mu_{ij}^1 + \mu_{ij}^2 \ldots \ldots \ldots \ldots \ldots \mu_{ij}^3 \qquad \ldots\ldots\ldots\ldots 3.4$$

Here μ_{ij} = Minimum Membership value

3.5.4.4 Modified pessimistic matrix

These membership values of the experts are combined into a single matrix using modified pessimistic aggregation for each criterion against the alternatives. Since pessimistic aggregation attempts to minimize the risk, while the modified pessimistic aggregation may prove to be useful to have a spectrum of polarized opinions of the experts. The final aggregated membership values are from modified pessimistic aggregation, which is an average of arithmetic mean and pessimistic aggregation. These values are obtained by taking different membership values for the factors affecting machineries selection by experts and obtain by the following equation.

$$\mu_{ij} = \frac{1}{2}\{\mu_{ij}^{1} \cap \mu_{ij}^{2} \cap \ldots \ldots \mu_{ij}^{k} + \sum_{i=1}^{k} \mu_{ij}^{1}\} \qquad \ldots\ldots\ldots\ldots 3.5$$

3.5.4.5 Dominance matrix

The basis on which alternatives are ranked is based on dominance matrix. An alternative is said to dominate another alternative for any given feature if its aggregate membership values are greater than that of the other alternative. An alternative is to be superior to a second alternative if it dominates the second alternative in more features than the number of features in which the second dominates the first. In many cases, there may be alternatives which are very close to each other on the basis of the dominance matrix.

In order to display the dominance structure between all possible pairs of alternatives a N by N matrix, called the Dominance Matrix (D) is constructed. The element dij is the number of features for which the membership value of alternative j is greater than that of alternative i. Dimensionality N is equal to the number of alternatives under consideration. A hash (#) is entered in the diagonal cells as the dominance of an alternative over itself does not make sense. If the j^{th} column is summed, the total number of dominances of alternative j over all other alternative is obtained. Similarly, if the i^{th} row is summed, the number of times the j^{th} alternative is dominated by all other alternative is obtained. The sums of columns and rows can be compared and from this one can see that most favourable outcomes have higher column sums and lower row sums.

3.5.4.6 Evaluate the alternative

The basis on which alternatives are ranked is based on dominance matrix. An alternative is said to dominate another alternative for any given feature if its aggregate membership values are greater than that of the other alternative. An alternative is defined to be superior to a second alternative if it dominates the second alternative in more features than the number of features in which the second dominates the first.

3.5.5 Fuzzy TOPSIS Method

TOPSIS technique is based on the concept that “the chosen alternative should have the shortest distance from the positive–ideal solution and the longest distance from the negative-ideal solution”. The ideal solution is the collection of ideal scores (or ratings) in all attributes considered. The TOPSIS technique defines a “similarity index” (or relative closeness) by combining the proximity to the positive-ideal solution and the remoteness of the negative-ideal solution.

3.5.5.1 Normalisation Matrix

This step involves the development of matrix formats. The row of this matrix is allocated to one alternative and each column to one attribute. The decision-making matrix can be expressed as:

$$D = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{21} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{bmatrix}$$

Then using the above matrix to develop the normalized decision matrix with the help of the formula given below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij}^2}} \qquad \text{………..3.6}$$

3.5.5.2 Weighted Matrix

Depending upon the relative importance of different attributes obtain weight for each attribute using the formula given below and the sum of the weights should be 1.

$$v_{ij} = w_{ij} r_{ij} \qquad \text{…………3.7}$$

Here, v_{ij}= Weighted matrix value

r_{ij}=Normalisation value.

w = Assigned weight

i = row

j= column

3.5.5.3 Ideal and Negative Ideal solution

This step determines the ideal (best) and negative ideal (worst) solutions. The ideal and negative ideal solution given as:

$$A^* = \{v_1^*, \dots \dots . v_n^*\} \qquad \text{…………3.8}$$

$$A- = \{v_1^-, \dots \dots . v_n^-\} \qquad \text{…………3.9}$$

Where: $v_i^* = \{\max(v_{ij}) if \in I; \min(v_{ij}) if \in I'$

$v_i^- = \{\min(v_{ij}) if \in I; \text{maz}(v_{ij}) if \in I'$

3.5.5.4 Separation measures

Obtain separation (distance) of each alternative from the ideal solution and negative ideal solution which is given by the Euclidean distance given by the Equation 5.7 & Equation 5.8.

$$S_j^* = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^*\right)^2} \qquad \text{………3.10}$$

$$S_j^- = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^-\right)^2} \qquad \text{………3.11}$$

3.5.5.5 Relative closeness

After obtaining separation measure we need to calculate the relative closeness to the ideal solution of each alternative which is given by the Equation 5.9

$$C_j^* = \frac{S_j^-}{S_j^* + S_j^-} \qquad \text{.........3.12}$$

3.5.5.6 Evaluate the alternative

A set of value is generated for each alternative. Choose the best alternative having largest closeness to ideal solution. Arrange the alternative as an increasing order of C_i^+

3.5.6 SDI Tool-Triptych (Software)

Triptych is a Microsoft Excel Add-in that provides support for documenting and clarifying the voice of the customer (VOC), identifying and flowing down requirements, and generating and selecting design alternatives.

Triptych includes functionality for:

1. QFD: Captures the voice of the customer and translates it into engineering requirements using Quality Function Deployment methods.
2. Affinity Diagram: A Tool for sorting large number of ideas or concepts into logical groupings using the Affinity diagram method.
3. AHP (Importance): Prioritizes (or ranks) Items by performing pair-wise comparisons of Items against each other in terms of relative importance using a one-level Analytic Hierarchy Process.
4. TRIZ: Generates ideas for solving technical contradictions using the Theory of Inventive Problem Solving TRIZ.

3.5.6.1 Select the method of analysis

After opening the Microsoft excel based triptych there will we number of methods serving the different purpose, so accordingly we have to select one method to proceed further TOPSIS was the most suitable one for the nature of criteria and attributes.

3.5.6.2 Select the matrix$(\boldsymbol{IxJ})$

After selecting the method, the most important step is to select the size of the matrix which is based on the number of alternatives and their criteria taken into consideration for the selection process.

For example: We have four alternatives of a machine and each carry 10 criteria (specification) then the matrix should be 4x10 i.e. four columns and 10 rows.

3.5.6.3 Input all the specification

All the data which serve as the criteria for selection should be feed properly and precisely in the matrix form by the tool.

3.5.6.4 Assign Goal

After feeding the criteria, each criteria should be assign with a goal which consist of either maximisation or minimization i.e. All the profit attributes should be assign with a maximisation goal example: Capacity, Power, Speed and all the loss attribute should be assign with minimization goal example: Purchase cost, Maintenance cost, acquisition cost.

3.5.6.5 Assign Importance

As we provided weightage in different method to set priority for certain criteria, similarly here we provide importance in terms of rating to any criteria which is the most prior

3.5.6.6 Evaluate the alternative

A set of value is generated for each alternative. Choose the best alternative having largest scores, arrange the alternative in the descending order for obtaining rank sequence.

3.5.7 Rank Comparison and Final Selection

The result obtains form all three-method used for selection of optimum machineries should be compared and validated and final selection should be made based upon it.

3.6 Summary

This chapter provided the details of the various optimization and multi-attribute decision making methods and the methods involved in the present study i.e. Fuzzy MADM, Fuzzy TOPSIS, SDI tools-triptych. The methodology to be adopted is also briefly explained.

Chapter 4

Case Study- Construction projects, Mumbai and Navi Mumbai

4.1 General

Construction sites considered for the case study is in Mumbai and Navi Mumbai. Various surveys were carried out including data collection. These data were than analysed and based on the Fuzzy MADM and Fuzzy TOPSIS results conclusion was drawn. The list of various surveys that were carried out to achieve the objective has been explained in detail. The surveys that was carried out were:

1. Reconnaissance survey
2. Pilot survey
3. Secondary survey
4. Primary survey

4.2 Reconnaissance Survey

It includes:

1. Various Site Selection for Studying
2. Identification of Most Significant construction machines and their selection Process.

4.2.1 Site Selection

The following were the construction site where the study and various survey was carried out.

1. Rivali Park, Borivali
2. Dosti planet north, Mumbra.
3. Red Brick, malad.
4. Pratik gems, Thane.
5. Neel Orchid, Wadala
6. Alta Monte, Malad
7. Kusum heights, Andheri
8. Rising City,Ghatkopar
9. Clan City,Taloja

The sites considered is located all over Mumbai and Navi Mumbai region. The sites were in different stage of construction.

4.2.2 Identification of Machineries and their alternatives

Tower crane, Material hoist and concrete pump were identified as the one of the most important and commonly used machineries in every construction project. Though there were many more different machineries but we limited our scope of study to only these three because during the survey it was observed that these were the only three machineries which have a role in the execution right from start to the end and another factor was that there were many different models with different specification and function available to them in the market.

The following are the different models of tower crane, concrete pump and material hoist selection for the study as shown in Table 4.1

Table 4.1- Models of Tower Crane, Concrete Pump and Material Hoist

Machines	Tower Crane	Concrete Pump	Material hoist
Alternatives Model	STC-6010	SP 8800	SMH 200V
	STC-5512	SP 2800	SMH 150V
	STC-5013	SP 500	SMH 120V
	STC-4010	BPN 300	SMH 100V
	STC-5010	SP305	SMH 50V

Each model has different function and specification precisely manufactures to serve specific task in specific condition.

4.2.2.1 Tower Crane

A crane is defined as a mechanism for lifting and lowering loads with a hoisting mechanism. On many construction sites a crane is needed to lift small to medium loads such as concrete skips, reinforcement, and formwork. As the lifting needs of the construction industry have increased and diversified, a large number of general and special purpose cranes have been designed and manufactured. Generally equipped with a hoist, wire ropes or chains, and sheaves, that can be used both to lift and lower materials and to move them horizontally. It is mainly used for lifting heavy things and transporting them to other places. It uses one or more simple machines to create mechanical advantage and thus move loads beyond the normal capability of human being.

These cranes are normally operated by an operating engineer working with a rigger, who rigs and guide loads and possibly a signalman, who guide loads. Truck-mounted cranes are used frequently to deliver materials in the site. These cranes are usually operated by the truck's driver, who may not be adequately trained on proper crane operation. Crane operators lift and carry unfamiliar and often unstable loads over and around large numbers of construction works, often depositing loads in very close proximity. A tipped, dropped, or mishandled load can directly injure workers or even potentially upset a critical section of the construction project, possibly resulting in the collapse of the structure. This risk is not only limited to those directly involved in construction operations, as evidenced by several recent crane accidents, in which pedestrians are killed. Self-erecting type of tower crane has been shown in Figure 4.1 which is considered for study.

Fig 4.1 – Tower Crane

(Source: Sale advertising brochure cum catalog of Spartan India)

4.2.2.2 Concrete Pump

A concrete pump is a machine used for transferring liquid concrete by pumping. There are two types of concrete pumps.

The first type of concrete pump is attached to a truck or longer units are on semi-trailers. It is known as a boom concrete pump because it uses a remote controlled articulating robotic arm (called a *boom*) to place concrete accurately. Boom pumps are used on most of the larger construction projects as they are capable of pumping at very high volumes and because of the labour saving nature of the placing boom. They are a revolutionary alternative to truck-mounted concrete pumps.

The second main type of concrete pump is either mounted on a truck or placed on a trailer, and it is commonly referred to as a line pump or trailer-mounted concrete pump. This pump requires steel or flexible concrete placing hoses to be manually attached to the outlet of the machine. Those hoses are linked together and lead to wherever the concrete needs to be placed. Line pumps normally pump concrete at lower volumes than boom pumps and are used for smaller volume concrete placing applications such as swimming pools, sidewalks, and single family home concrete slabs and most ground slabs.

Figure 4.2 shows the second type of pump which is mounted on wheel and most commonly used in normal construction condition.

Fig 4.2 – Concrete Pump

(Source: Sale advertising brochure cum catalog of schwing stetter India)

4.2.2.3 Material hoist

It is also known as a Man-Lift, temporary elevator, builder hoist, passenger hoist or construction elevator, this type of hoist is commonly used on large scale construction projects, such as high-rise buildings or major hospitals. There are many other uses for the construction elevator. The purpose being to carry personnel, materials, and equipment quickly between the ground and higher floors, or between floors in the middle of a structure. There are three types: Utility to move material, to move personnel, and dual-rated, which can do both.

The construction hoist is made up of either one or two cars (cages) which travel vertically along stacked mast tower sections. The mast sections are attached to the structure or building every 25 feet (7.62 m) for added stability. For precisely controlled travel along the mast sections, modern construction hoists use a motorized rack-and-pinion system that climbs the mast sections at various speeds.

Figure 4.3 shows the various component parts and attachment of material hoist which serve different purpose of construction operation.

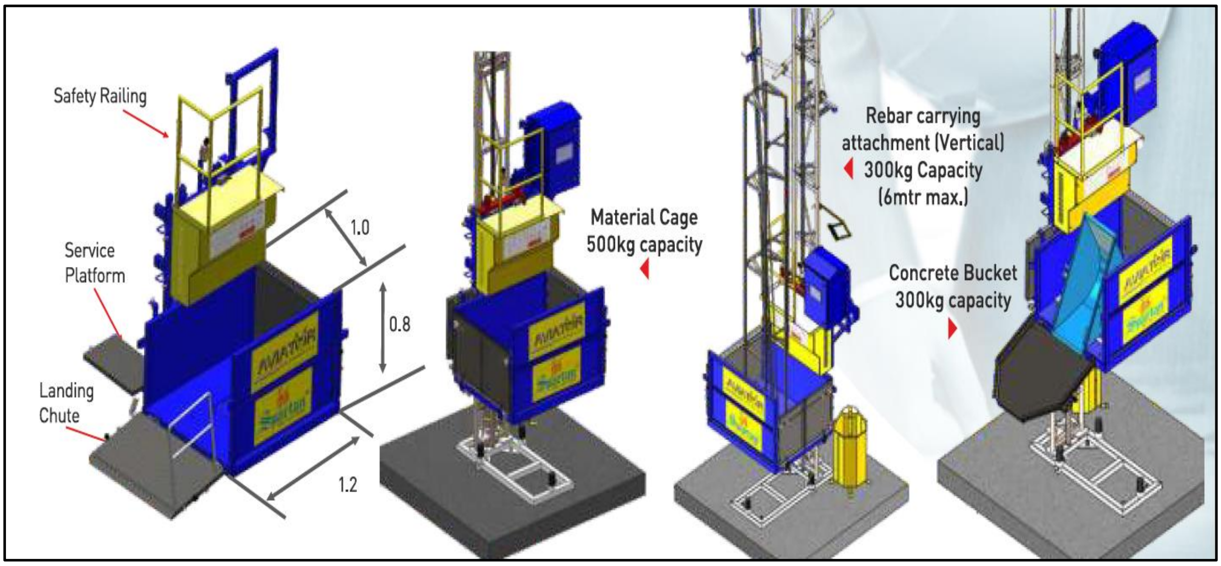

Fig 4.3 – Component Parts of Material Hoist

(Source: Sale advertising brochure cum catalog of Spartan India)

4.3 Pilot Survey

Pilot survey was conducted to study the various parameters which governed and affects the selection of machineries on construction site. In this survey, 10 construction site are surveyed and attributes which will govern the selection process and other miscellaneous criteria are identified. From the pilot survey the following specification of each machineries were selected which is serve as attribute or criteria of selection in our work.

1. **Tower Crane:** Max. Lifting capacity(Ton), Tip load(Ton), Jib Length (m), Free standing height(m), Max height external(m), Drum capacity (Ton.m), Wire rope size (mm), Hoisting motor capacity (kw), Slewing motor capacity (kw), Trolley motor capacity (kw), Total power consumption (kva), Purchase price(rs), Maintenance cost/monthly(rs), Acquisition cost on site(rs), Machine life(years).
2. **Concrete Pump:** Max concrete pressure (bar), Max output volume(m^3/hr), Max horizontal pumping distance(meters), Max vertical pumping distance (meters), Maximum pump stroke (per min), Pumping cylinder stroke (mm) Pumping cylinder

stroke length (mm), Hydraulic tank capacity(litres), Fuel tank capacity (litres), Purchase price(Rs), Feeder pipe diameter(cm), Maintenance cost(Rs), Life of machine(years).

3. **Material Hoist:** capacity (ton), Max height (m), Speed (m/min), Motor capacity (kw), Safety device Cage size (m^3), Rebar carrying capacity (ton), Purchase price(Rs), Maintenance cost/monthly(Rs), Machine life(years).

4.4 Secondary Survey (Data collection)

The secondary data is collected from various construction, decision maker manufacturers and dealers. Data collected are listed below:

4.4.1 Specification of Selected models of Tower Crane

The most important specification of tower crane is the maximum lifting capacity and the height to which the crane can be erected, many other specifications which governs it selection is given below in Table 4.2.

Table 4.2- Specification of Tower Crane Alternatives

Models Specification	STC-4010	STC-5010	STC-5013	STC-5512	STC-6010
Max. Lifting capacity(Ton)	4	4	5	6	6
Tip load(Ton)	1	1	1.3	1.2	1
Jib Length (m)	40	50	50	55	60
Free standing height(m)	30	40	40	40	50
Max height external(m)	100	115	140	140	180
Drum capacity(Ton)	280	280	360	360	430
Wire rope size (mm)	10	10	10	12	12
Hoisting motor capacity (kw)	11	15	15	22	22
Slewing motor capacity (kw)	4	4	4	8	8
Trolley motor capacity (kw)	2.4	2.4	4	4	4
Total power consumption (kva)	21	27	27	40	40
Purchase price(Rs)	1.3	1.35	1.4	1.5	1.58
Maintenance cost/monthly(Rs)	30	35	35	30	30
Acquisition cost on site(Rs)	1	1.2	1.3	1.4	1.35
Machine life (years)	30	35	35	40	40

4.4.2 Specification of Selected models of Concrete Pump

The most important specification of concrete pump is the output pressure and the distance to which it can pump the concrete vertically as well as horizontally, many other specifications which governs it selection is given below in Table 4.3

Table 4.3- Specification of Concrete Pump Alternatives

Models Specification	SP305	BPN 300	SP 500	SP 2800	SP 8800
Max Concrete Pressure (Bar)	43	60	76	108	163
Max Output Volume(m^3/hr)	23	34	35	100	116
max horizontal pumping distance(meters)	244	305	354	520	600
Max vertical pumping distance (meters)	60	80	100	120	150
Maximum pump stroke per min	44	40	32.5	35	31
Pumping Cylinder Stroke (mm)	125	180	150	200	200
Pumping Cylinder stroke length (mm)	762	630	1000	1600	2000
Hydraulic tank capacity(litres)	150	170	190	200	220
Fuel tank capacity(litres)	57	60	75.7	80	85
Purchase Price(RS)	25	28	30	35	40
Feeder pipe diameter(cm)	15	20	20	25	25
Maintenance Cost(RS)	20	20	22	25	30
Life Of Machine(Years)	20	20	25	25	28

4.4.3 Specification of Selected models of Material Hoist

The most important specification of Material Hoist is lifting capacity and the speed by which it can move the load of material or personnel, many other specifications which governs it selection is given below in Table 4.4

Table 4.4- Specification of Material Hoist Alternatives

Criteria	SMH 200V	SMH 150V	SMH 120V	SMH 100V	SMH 50V
Capacity (ton)	2	1.5	1.2	1	0.5
Max height (m)	150	120	120	100	70
Speed (m/min)	30	30	30	30	20
Motor capacity (kw)	18.2	14	10.4	10.4	2.7
Safety device	9	9	7	7	7
Cage size (m^3)	9	9	9	9	7
Rebar carrying capacity (ton)	1	1	0.5	0.5	0.3
Purchase price(Rs)	7	6	5.5	5	4
Maintenance cost/monthly(Rs)	15	15	15	15	15
Machine life(years)	30	30	25	25	20

These specifications keep on changing subject to modification for improvisation. There are many other manufacturers which may have got machine with better specification but we have selected product of Spartan India and Schwing Stetter India as our main scope and objection is to have a systematic approach of selecting and optimum machinery.

4.5 Primary Survey

In primary Survey the opinion of experts who are the decision makers on site were recorded in terms of rating from 1-10 for each specification of each alternative. These was done to have every specification in single unit which is also known as fuzzy numbers.

Based on study and the Primary Survey, Data was recorded from 10 experts in Survey Proforma and in Excel Sheet for further analysis. A sample of collected data (Survey Proforma) is shown in Figure 4.4, Figure 4.5 and Figure 4.6

4.6 Summary

This chapter briefly describes the Various Surveys carried on the study area for finding the Parameters that influences the selection process of machineries, collecting the secondary data, recording the views of different experts and decision makers on the specification and various criteria on the selection process.

A sample of collected data (Survey Proforma) is shown in Figure 4.4, Figure 4.5 and Figure 4.6

Survey Proforma

- Membership value for Tower Crane

Models Specification	STC-4010	STC-5010	STC-5013	STC-5512	STC-6010
Max. Lifting capacity(Ton)	4	4	5	6	6
Tip load(Ton)	1	1	1.3	1.2	.1
Jib Length (m)	40	50	50	55	60
Free standing height(m)	30	40	40	40	50
Max height external(m)	100	115	140	140	180
Drum capacity(Ton.m)	280	280	360	360	430
Wire rope size (mm)	10	10	10	12	12
Hoisting motor capacity (kw)	11	15	15	22	22
Slewing motor capacity (kw)	4	4	4	8	8
Trolley motor capacity (kw)	2.4	2.4	4	4	4
Total power consumption (kva)	21	27	27	40	40
Purchase price(Rs)	1.3	1.35	1.4	1.5	1.58
Maintenance cost/monthly(Rs)	30	35	35	30	30
Acquisition cost on site(Rs)	1	1.2	1.3	1.4	1:35
Machine life (years).	30	35	35	40	40

Criteria	Expert 1 (Membership Value ranging from 0-1)				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.35	0.35	0.9	0.9
X2	0.8	0.9	0.9	0.6	0.9
X3	0.1	0.3	0.3	0.6	0.9
X4	0.6	0.7	0.7	0.5	0.8
X5	0.5	0.6	0.6	0.7	0.9
X6	0.4	0.5	0.5	0.7	0.8
X7	0.9	0.9	0.35	0.9	0.9
X8	0.8	0.8	0.9	0.6	0.9
X9	0.1	0.6	0.3	0.6	0.9
X10	0.6	0.5	0.7	0.5	0.8
X11	0.5	0.7	0.6	0.7	0.9
X12	0.4	0.7	0.5	0.7	0.8
X13	0.4	0.7	0.5	0.7	0.8
X14	0.4	0.5	0.5	0.7	0.8
X15	0.9	0.9	0.35	0.9	0.9

Fig 4.4 – Survey Proforma for Tower Crane

(Source: Primary Survey, Neel Orchid, Wadala. Date January 2015- March 2016.)

Survey Proforma

- Membership value for Concrete Pump.

Criteria	SP-305	BPN-300	SP-500	SP-2800	SP-8800
Max concrete pressure (bar)	43	60	76	108	163
Max Output Volume(m^3/hr)	23	34	35	100	116
Max horizontal pumping distance(M)	244	305	354	520	600
Max vertical pumping distance (M)	60	80	100	120	150
Maximum pump (stroke per min)	44	40	32.5	35	31
Pumping Cylinder Stroke (mm)	125	180	150	200	200
Pumping Cylinder stroke length (mm)	762	630	1000	1600	2000
Hydraulic tank capacity(litres)	150	170	190	200	220
Fuel tank capacity(litres)	57	60	75.7	80	85
Purchase price(rs)	25	28	30	35	40
Feeder pipe diameter(cm)	15	20	20	25	25
Maintenance cost(rs)	20	20	22	25	30
Life of machine(years)	20	20	25	25	28

Criteria	Expert 1 (Membership Value ranging from 0-1)				
	CP1	CP2	CP3	CP4	CP5
X1	0.35	0.9	0.35	0.9	0.9
X2	0.9	0.8	0.9	0.6	0.9
X3	0.3	0.1	0.3	0.6	0.9
X4	0.7	0.6	0.7	0.5	0.8
X5	0.6	0.5	0.6	0.7	0.9
X6	0.5	0.4	0.5	0.7	0.8
X7	0.9	0.9	0.35	0.9	0.9
X8	0.6	0.8	0.9	0.6	0.9
X9	0.6	0.1	0.3	0.6	0.9
X10	0.5	0.6	0.7	0.5	0.8
X11	0.7	0.5	0.6	0.7	0.9
X12	0.7	0.4	0.5	0.7	0.8
X13	0.7	0.4	0.5	0.7	0.8

Fig 4.5 – Survey Proforma for Concrete Pump

(Source: Primary Survey, Neel Orchid, Wadala. Date January 2015- March 2016.)

Survey Proforma

- Membership value for Material Hoist

Criteria	SMH 200V	SMH 150V	SMH 120V	SMH 100V	SMH 50V
Capacity (ton)	2	1.5	1.2	1	0.5
Max height (m)	150	120	120	100	70
Speed (m/min)	30	30	30	30	20
Motor capacity (kw)	18.2	14	10.4	10.4	2.7
Safety device	SSD 3500	SSD 3500	SSD 1000	SSD 1000	SSD 1000
Cage size (m^3)	2*1.2*1.5	2*1.2*1.5	2*1.2*1.5	2*1.2*1.5	1.2*1*0.8
Rebar carrying capacity (ton)	1	1	0.5	0.5	0.3
Purchase price(Rs)	7	6	5.5	5	4
Maintenance cost/monthly(Rs)	15	15	15	15	15
Machine life(years)	30	30	25	25	20

Criteria	Expert 1 (Membership Value ranging from 0-1)				
	MH1	MH2	MH3	MH4	MH5
X1	0.9	0.9	0.35	0.9	0.35
X2	0.9	0.6	0.9	0.8	0.9
X3	0.9	0.6	0.3	0.1	0.3
X4	0.8	0.5	0.7	0.6	0.7
X5	0.9	0.7	0.6	0.5	0.6
X6	0.8	0.7	0.5	0.4	0.5
X7	0.9	0.9	0.35	0.9	0.9
X8	0.9	0.6	0.9	0.8	0.6
X9	0.9	0.6	0.3	0.1	0.6
X10	0.8	0.5	0.7	0.6	0.5

Fig 4.6 – Survey Proforma for Material Hoist

(Source: Primary Survey, Neel Orchid, Wadala. Date January 2015- March 2016.)

Chapter 5

Statistical Analysis

5.1 General

Contractors generally aim at both profit and reputation when bidding for a project. To achieve reasonable profit, contractors try to minimize the cost of using equipment especially cranes on site. Normally they prefer to use the smallest size crane capable of completing the task. However, contractors rely on their in-house professional advice concerning the type of the machineries to be used.

The process starts with a field details along with design professionals, architects, finance department representatives. It contains details for selecting a particular machinery together with the factors considered during the selection process. Based on this report, and additional information on the construction requirements which include shape of the building, type of the structure, i.e. concrete or steel, construction program, site constraints, and the method of financing, and alternatives of similar cases from the company's previous work. Based on this analysis the experts will select the size and type of machineries i.e. tower or mobile crane. For a mobile crane the decision is made based on project manager and site supervisor requirements.

They decide type of a mobile crane, its attachments, location, positions of cranes, and operational costs. This output is further validated by studying the effect of the contractual and the economic factors such as availability of the selected crane, whether the selected crane can meet the construction program in terms of capacity and production rates, the effect of the selected crane on the structural and architectural design, and finally the cost of the selected crane. In the case, when changes to the construction requirements due to the crane selection is needed, the owner is notified, and the process is repeated for any other machineries like concrete pump, material hoist etc.

5.2 Objectives of Analysis

The objective of the research work is to establish a methodology to select an optimum machinery using Artificial Intelligence approach by considering the viewpoints of the experts in the relevant fields. The main objectives are:

1. To identify any three important construction machineries out of various machineries available for construction industries.
2. To identify the set of alternatives for selected machineries, set of criteria and numerous decision makers, each with their own set of viewpoints.
3. To select an optimum machinery using Fuzzy TOPSIS through Microsoft excel and statistical design institute (Software).
4. Validating the result obtain from Fuzzy TOPSIS with fuzzy dominance matrix.
5. Discussion, Comparison and Conclusion obtain from Fuzzy TOPSIS and Fuzzy MADM.

To achieve the above objectives, the following analysis methodology is used in this research work.

5.3 Optimum selection of Tower Crane

Decision making for selection of optimum crane is carried out by fuzzy MADM method in this section. This method is generally based on dominance matrix where it converts all the criteria into fuzzy number by taking membership value from experts against in criteria and find the most dominating alternative among them.

5.3.1 Optimum selection of Tower Crane by Fuzzy MADM method

The factors related to the project and its cost are contingent on the exact function of the crane. The following Table 5.1 shows all the specification of all the models of tower crane which govern the selection of appropriate tower crane model.

Table 5.1- Tower crane alternatives and their criteria for selection

Models Specification	STC-4010	STC-5010	STC-5013	STC-5512	STC-6010
Max. Lifting capacity(Ton)	4	4	5	6	6
Tip load(Ton)	1	1	1.3	1.2	1
Jib Length (m)	40	50	50	55	60
Free standing height(m)	30	40	40	40	50
Max height external(m)	100	115	140	140	180
Drum capacity (Ton.m)	280	280	360	360	430
Wire rope size (mm)	10	10	10	12	12
Hoisting motor capacity (kw)	11	15	15	22	22
Slewing motor capacity (kw)	4	4	4	8	8
Trolley motor capacity (kw)	2.4	2.4	4	4	4
Total power consumption (kva)	21	27	27	40	40
Purchase price(Rs)	1.3	1.35	1.4	1.5	1.58
Maintenance cost/monthly(Rs)	30	35	35	30	30
Acquisition cost on site(Rs)	1	1.2	1.3	1.4	1.35
Machine life (years).	30	35	35	40	40

The quantitative data relating to the selection of tower cranes such as load lifting capacity, tip load, total power consumption, purchase price etc. are given in the Table 5.1 as shown in the first row STC-4010, STC-5010 etc. are the model numbers of the crane which will be further denoted as TC1, TC2, TC3, TC4 and TC5 similarly column represent the various criteria on which the selection of tower crane is made and further it will be denoted as X1, X2, X3, X4…...Xn. All the criteria of different alternatives are compared graphically which is shown in Figure 5.1.

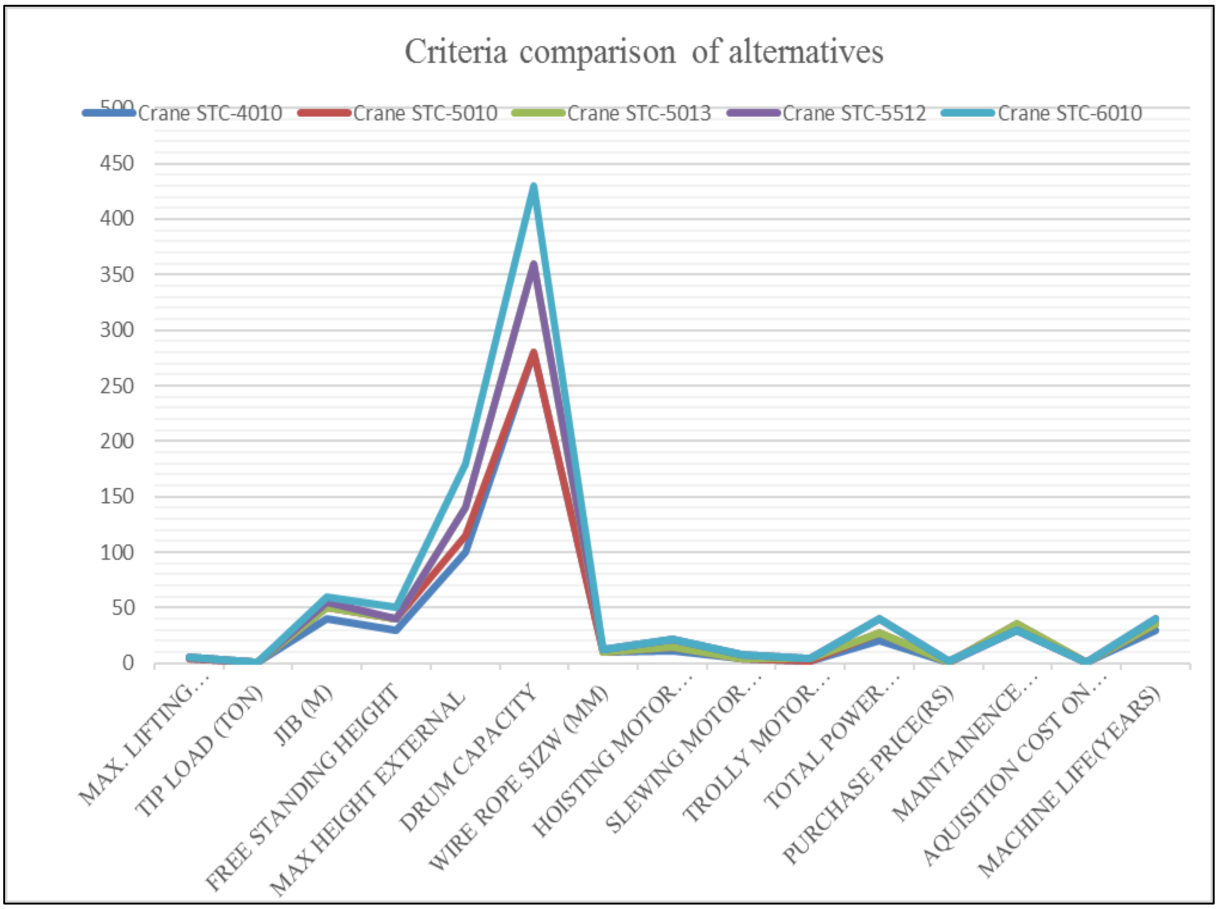

Figure 5.1- Criteria comparison of alternatives for Tower Crane

In the comparison graph of Figure 5.1 we can observed clearly that tower crane model STC-6010 is most dominating in all criteria followed by STC-5512, STC-5013, STC-4010 and STC-5010.

The concept of membership plays a central role in the selection process. Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention low represents the least desirable end of the scale and high represents the most desirable end of the scale. The cranes are to be ranked based on the qualitative and quantitative criteria. A questionnaire proforma has been prepared to evaluate the cranes against these criteria. The questionnaire proforma was circulated to experts to have their opinions in terms of membership values.

The questionnaire proforma deals with qualitative criteria and quantitative criteria such as load lifting capacity, tip load, total power consumption, purchase price.

An interview with the crane experts was also conducted to collect data for evaluating the "qualitative criteria" and "quantitative criteria" affecting the crane selection. A correspondence between the qualitative and quantitative factors and the available cranes was made explicit, and a numerical scale between 0.0 and 1.0 was established. A value of 0.5 indicates a neutral effect while a value of 1.0 is defined as complete satisfaction.

To assess the impact of qualitative and quantitative factors, the construction firms are approached and their membership values are placed in different matrices. In response to the questionnaire proforma each expert has given his/her degree of belief about the cranes in terms of 0 - 1 with respect to the criteria. The transformed results of the Questionnaire proforma are tabulated into position matrices for each expert and expert and is given in Appendix I

After placing the membership values given to all the qualitative and quantitative features against alternative cranes by experts from the prominent companies of Mumbai and Navi-Mumbai in position matrices, which is shown in Appendix I the membership values are aggregated using mean aggregation for every feature against for every alternative and tabulated in the following Table 5.2.

For example, the membership value of ' A_{41}' in mean aggregated Table 5.2 is obtained as follows, here '41' indicates 4^{th} row of 1^{st} column of above matrix which is formed by using the following Equation 5.1.

$$\mu_{ij} = \frac{1}{k}\sum_{i=1}^{k} \mu_{ij}^{1} \qquad \text{………...5.1}$$

Here, μ_{ij}=Mean aggregated membership value.
K = number of position matrices.
i = row
j= column.

And, the procedure for obtaining the above value is as follows.

$$A_{41} = [\, a_{41}^{1} + \; a_{41}^{2} + \cdots \ldots \ldots \ldots \ldots \ldots \ldots + \; a_{41}^{10}] \,/\, 10.$$

A_{41} = Mean aggregated membership value = 0.62

$a_{41}^1 + \; a_{41}^2 + \cdots \ldots\ldots\ldots\ldots\ldots\ldots + \; a_{41}^{10}$ Are the membership values of criteria against each alternative from the position matrices of the various experts from the Table 1 to 10 given in Appendix- I

Now A_{41} is calculated as shown below:

$$A_{41} = \{[\,0.60 + 0.55 + 0.55 + 0.60 + 0.65 + 0.70 + 0.60 + 0.65 + 0.65 + 0.65]\,/10\}$$
$$= 0.62$$

And, is tabulated in the mean aggregated matrix Table 5.2 at 4^{th} row of 1^{st} column. Remaining membership values are also calculated in same manner and are positioned in the Table 5.2 of mean aggregated matrix as shown below.

Table 5.2- Mean matrix for Tower crane

Criteria	Mean value matrix				
	TC1	TC2	TC3	TC4	TC5
X1	0.91	0.56	0.36	0.89	0.96
X2	0.81	0.84	0.89	0.61	0.92
X3	0.11	0.37	0.29	0.60	0.91
X4	0.62	0.73	0.77	0.53	0.82
X5	0.55	0.62	0.62	0.75	0.94
X6	0.48	0.52	0.51	0.72	0.82
X7	0.82	0.74	0.48	0.79	0.91
X8	0.73	0.67	0.78	0.64	0.92
X9	0.24	0.66	0.35	0.64	0.88
X10	0.65	0.61	0.74	0.56	0.83
X11	0.58	0.63	0.66	0.72	0.93
X12	0.46	0.74	0.48	0.72	0.84
X13	0.53	0.75	0.51	0.70	0.87
X14	0.48	0.52	0.51	0.72	0.82
X15	0.82	0.74	0.48	0.79	0.91

Table 5.3- Pessimistic matrix for Tower crane

Criteria	Pessimistic matrix				
	TC1	TC2	TC3	TC4	TC5
X1	0.85	0.35	0.3	0.8	0.9
X2	0.7	0.55	0.8	0.5	0.9
X3	0.05	0.15	0.25	0.55	0.9
X4	0.55	0.65	0.7	0.5	0.75
X5	0.5	0.5	0.55	0.7	0.85
X6	0.4	0.35	0.45	0.65	0.8
X7	0.6	0.35	0.3	0.5	0.8
X8	0.55	0.05	0.6	0.5	0.9
X9	0.05	0.35	0.25	0.55	0.8
X10	0.55	0.1	0.35	0.5	0.75
X11	0.5	0.05	0.55	0.5	0.85
X12	0.05	0.5	0.25	0.65	0.8
X13	0.1	0.45	0.25	0.55	0.8
X14	0.4	0.35	0.45	0.65	0.8
X15	0.6	0.35	0.3	0.5	0.8

After identifying the mean aggregated values, the pessimistic aggregated matrix should be formed to minimize the risk of taking the values of memberships given by all the experts from the different companies for each criteria against each alternative.

To form pessimistic aggregated matrix minimum membership value of each criterion against each alternative from all the position matrices are taken and formed in a matrix shape as shown in the Table.5.3.

For example, membership value of 'A_{54}' of pessimistic aggregated matrix is obtained as follows, here '54' indicates 5th row of 4th column of pessimistic aggregated matrix which can be calculated by using the following Equation 5.2

$$\mu_{ij} = \min(\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3 \ldots\ldots\ldots\ldots\ldots \mu_{ij}^k) \qquad \ldots\ldots\ldots 5.2$$

Here μ_{ij} = Minimum Membership value.

In $\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3$ i & j are row and column respectively, and $1, 2, \ldots\ldots\ldots\ldots\ldots.. k$, indicates the number of matrices formed. Minimum value among all the values of each criterion is taken and formed as single matrix as shown in Table 5.3, and $A_{54} = 0.70$ is calculated as shown below.

A_{54} = min of $[a_{54}^1, a_{54}^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, a_{54}^{10}]$

Here $a_{54}^1, a_{54}^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, a_{54}^{10}$ are the minimum membership values of criteria against alternatives.

$$A_{54} = min\,[\,0.70, 0.75.0.75, 0.75, 0.80, 0.75, 0.70, 0.75, 0.75, 0.75] = 0.70.$$

So, minimum value is '0.70' among all the membership values and is positioned in the matrix, at 5th row of 4th column of the matrix, and remaining minimum membership values for all the criteria against alternatives are tabulated as pessimistic aggregated matrix as shown in Table 5.3

These membership values of the experts are combined into a single matrix using modified pessimistic aggregation for each criterion against the alternatives. Since pessimistic aggregation attempts to minimize the risk, while the modified pessimistic aggregation may prove to be useful to have a spectrum of polarized opinions of the experts.

The final aggregated membership values are from modified pessimistic aggregation, which is an average of arithmetic mean and pessimistic aggregation. Table 5.4 is the modified pessimistic aggregation table for the position matrices of various experts. These values are obtained by taking different membership values for the factors affecting crane selection by experts.

Table 5.4- Modified pessimistic matrix for Tower Crane

Criteria	Modified pessimistic matrix				
	TC1	TC2	TC3	TC4	TC5
X1	0.88	0.46	0.33	0.85	0.93
X2	0.76	0.69	0.84	0.55	0.91
X3	0.08	0.26	0.27	0.58	0.90
X4	0.59	0.69	0.74	0.52	0.79
X5	0.53	0.56	0.59	0.72	0.89
X6	0.44	0.44	0.48	0.68	0.81
X7	0.71	0.55	0.39	0.65	0.86
X8	0.64	0.36	0.69	0.57	0.91
X9	0.14	0.50	0.30	0.60	0.84
X10	0.60	0.36	0.54	0.53	0.79
X11	0.54	0.34	0.60	0.61	0.89
X12	0.25	0.62	0.36	0.68	0.82
X13	0.32	0.60	0.38	0.62	0.84
X14	0.44	0.44	0.48	0.68	0.81
X15	0.71	0.55	0.39	0.65	0.86

Table 5.5- Weighted matrix for Tower Crane

Criteria	Weighted matrix					WT
	TC1	TC2	TC3	TC4	TC5	
X1	0.59	0.30	0.22	0.57	0.62	0.07
X2	0.51	0.46	0.56	0.37	0.61	0.07
X3	0.05	0.17	0.18	0.39	0.60	0.07
X4	0.39	0.46	0.49	0.35	0.53	0.07
X5	0.35	0.37	0.39	0.48	0.60	0.07
X6	0.29	0.29	0.32	0.46	0.54	0.07
X7	0.48	0.37	0.26	0.43	0.57	0.07
X8	0.43	0.24	0.46	0.38	0.61	0.07
X9	0.10	0.34	0.20	0.40	0.56	0.07
X10	0.40	0.24	0.36	0.36	0.53	0.07
X11	0.36	0.23	0.40	0.41	0.60	0.07
X12	0.17	0.42	0.24	0.46	0.55	0.07
X13	0.21	0.40	0.25	0.42	0.56	0.07
X14	0.29	0.29	0.32	0.46	0.54	0.07
X15	0.48	0.37	0.26	0.43	0.57	0.07

For example, membership value of 'A34' of modified pessimistic aggregation is obtained by using the following Equation 5.3

$$\mu_{ij} = \frac{1}{2}\{\mu_{ij}^{1} \dots \dots \mu_{ij}^{k} + \sum_{i=1}^{k} \mu_{ij}^{1} \dots \dots \sum_{i=1}^{k} \mu_{ij}^{k}\} \qquad \dots\dots 5.3$$

And, the procedure for obtaining the above membership value is as follows.

$A34$ = Average of every membership value of criteria against alternative of mean aggregated matrix and pessimistic aggregated matrix.

$$\text{So}, A34 = \{[a_{34}ma + a_{34}pa] / 2\},$$

Here, $_{34}ma$, $a_{34}pa$ are membership values of criteria against alternative of 3rd row of 4th column of mean aggregated matrix and pessimistic aggregated matrix respectively.

Here ma = Mean aggregation

pa = pessimistic aggregation

So, A34 = {[0.69 + 0.60] /2}

A34 = 0.64, is tabulated in the modified pessimistic aggregated matrix Table 5.4, remaining aggregated membership values are also calculated in the same manner and are positioned in the above Table 5.4

The membership values given for qualitative and quantitative factors are of equal importance. To overcome certain draw backs given by different experts, before evaluating the alternatives, weightages for each criteria has been introduced to get accuracy in selecting optimum alternative among available alternatives, the weightages are assigned and is given in Table 5.5 and are tabulated as follows.

After identifying the weightages to be assigned to the membership values of features of available alternatives from the experts these weightages are multiply to each and every criterion from the Table 5.4 of modified pessimistic matrix and is placed in the following Table 5.5.

For example, weighted aggregated value of A_{11}, value of 1^{st} row of 1^{st} column 0.89 is calculated as (0.88×0.067), 0.067 is weight assigned to 0.88 which was taken from the Table 5.5. Accordingly, remaining values are also calculated by assigning weights in multiplication and placed in above Table.5.5 after forming the weighted matrix, dominance matrix procedure is carried out to rank the alternatives for weighted values and is shown in Table 5.6.

Table 5.6 - Dominance matrix for Tower crane

Alternatives	TC1	TC2	TC3	TC4	TC5	**ROW SUM**				
TC1	#	5	12	8	15	40	25	17	5	#
TC2	7	#	9	13	15	44	29	16	7	0
TC3	4	6	#	11	15	36	21	10	#	#
TC4	7	2	3	#	15	27	12	#	#	#
TC5	0	0	0	0	#	0	#	#	#	#
COLUMN SUM	18	13	24	32	60					
	18	13	24	32	#					
	11	11	21	#	#					
	7	5	#	#	#					
	#	0	#	#	#					

In order to display the dominance structure between all possible pairs of cranes and N *by* N matrix, called the Dominance Matrix (D) is constructed. The element d_{ij} is the number of features for which the membership value of crane j is greater than that of crane i. For example in weighted matrix as shown in Table 5.5 the element X_{12} indicates that how many times criteria of alternative 2 dominates on criteria of alternative 1 and is tabulated in dominance matrix at X_{12}.

The dimensionality N is equal to the number of cranes under consideration. A hash (#) is entered in the diagonal cells as the dominance of a crane over itself does not make sense. If the j^{th} column is summed, the total number of dominances of crane j over all other cranes is obtained. Similarly, if the i^{th} row is summed, the number of times the j^{th} crane is dominated by all other cranes is obtained. The sums of columns and rows can be compared and from this one can see that most favorable outcomes have higher column sums and lower row sums.

Based on the above dominance matrix the best alternative is identified as follows:

1. Sum up all the column and row values
2. Choose the column with highest value and low row totals to select the best crane
3. If two alternatives column sums are same, choose the alternative with minimum row sum
4. If sums of columns and rows are same, choose an alternative arbitrarily,
5. To choose the next best, delete the values of the best crane and repeat the procedure.

In Table 5.6 highest column sum is 60 and lowest row sum is 0 for the alternative TC5. Therefore, using dominance matrix the alternative TC5 is the best alternative and corresponding to STC-6010. To choose the next best the values of these alternatives values are removed and the procedure is repeated. Using the dominance matrix following ranks sequence are obtain as shown in Table 5.7

Table 5.7 - Tower crane sequence for selection from Dominance matrix

Alternatives	Model name	Dominance
TC5	STC-6010	(60,0)
TC4	STC-5512	(32,12)
TC3	STC-5013	(21,10)
TC1	STC-4010	(7,5)
TC2	STC-5010	(0,0)

5.3.2 Optimum selection of Tower Crane by Fuzzy TOPSIS method

The following Table 5.8 shows decision matrix of all the specification of all the models of tower crane which govern the selection of appropriate tower crane model where the criteria which are represented in red colours are cost attribute and those with green colours are benefits attribute. The reason it has been highlighted unlike previous method is because in this method we will decide optimization based on the distance from positive ideal and negative ideal solution where we need to look for high values of benefits attribute and low values of cost attributes.

Table 5.8 - Decision matrix for Tower crane

Criteria	Tower crane alternatives				
	TC1	TC2	TC3	TC4	TC5
X1	4	4	5	6	6
X2	1	1	1.3	1.2	1
X3	40	50	50	55	60
X4	30	40	40	40	50
X5	100	115	140	140	180
X6	280	280	360	360	430
X7	10	10	10	12	12
X8	11	15	15	22	22
X9	4	4	4	8	8
X10	2.4	2.4	4	4	4
X11	21	27	27	40	40
X12	1.3	1.35	1.4	1.5	1.58
X13	30	35	35	30	30
X14	1	1.2	1.3	1.4	1.35
X15	30	35	35	40	40

The first step of the TOPSIS method involves the construction of a Decision Matrix (DM) as explain below.

$$\text{DM} = = \begin{array}{c|cccc} & TC_1 & TC_2 & \cdots & TC_n \\ \hline X_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ X_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ X_3 & \vdots & \vdots & \ddots & \\ X_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{array}$$

Where i the criterion index is $(i = 1 \ldots m)$; m is the number of potential criteria and j is the alternative index $(j = 1 \ldots. \ldots n)$; n is the number of alternatives. The elements $X_1, X_2 \ldots \ldots X_m$ refer to the criteria: while $TC_1, TC_2 \ldots \ldots TC_n$ refer to the alternative of tower crane. The elements of the matrix are related to the values of criteria i with respect to alternative j.

After developing the decision matrix, normalization matrix is develop using the Equation 5.5 given and explain below.

For example, the normalization value of ' A_{41}' in normalization matrix Table 5.19 is obtained as follows, here '41' indicates 4^{th} row of 1^{st} column of above matrix which is formed by using the Equation 5.4

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \qquad \ldots\ldots\ldots..5.4$$

Here, r_{ij}=Normalisation value.
m = number of tower crane alternatives.
i = row
j= column.

And, the procedure for obtaining the above value is as follows.

$$A_{41} = a_{41}\sqrt{[a_{41}^2 + a_{42}^2 + a_{43}^2 + a_{44}^2 + a_{45}^2]}.$$

Normalization value of A_{41} = 0.331295

$a_{41} + a_{42} + a_{43} + a_{44} + a_{45}$ are the specification values of criteria against each alternative from decision matrix fro Table 5.8.

Now A_{41} is calculated as shown below:

$$A_{41} = 30\sqrt{[30^2 + 40^2 + 40^2 + 40^2 + 50^2]}.$$

and is tabulated in the normalization matrix Table 5.9 at 4^{th} row of 1^{st} column. Remaining normalization values are also calculated in same manner and are positioned in the Table 5.9 of normalization matrix as shown below.

Table 5.9 – Normalization Matrix for Tower crane

Criteria	Normalization of matrix				
	TC1	TC2	TC3	TC4	TC5
X1	0.35218	0.35218	0.440225	0.528271	0.528271
X2	0.403896	0.403896	0.525065	0.484675	0.403896
X3	0.347826	0.434783	0.434783	0.478261	0.521739
X4	0.331295	0.441726	0.441726	0.441726	0.552158
X5	0.324742	0.373453	0.454639	0.454639	0.584536
X6	0.361208	0.361208	0.46441	0.46441	0.554712
X7	0.412393	0.412393	0.412393	0.494872	0.494872
X8	0.280397	0.38236	0.38236	0.560794	0.560794
X9	0.301511	0.301511	0.301511	0.603023	0.603023
X10	0.311086	0.311086	0.518476	0.518476	0.518476
X11	0.294088	0.378113	0.378113	0.560167	0.560167
X12	0.406669	0.42231	0.437951	0.469234	0.494259
X13	0.41804	0.487713	0.487713	0.41804	0.41804
X14	0.355503	0.426603	0.462154	0.497704	0.479929
X15	0.370681	0.432461	0.432461	0.494242	0.494242

Not all of the selection criteria may be of equal importance and hence weighting was introduced to quantify the relative importance of the different selection criteria. The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights.

For example, membership value of 'A_{54}' of weighted matrix is obtained as follows, here '54' indicates 5th row of 4th column of weighted aggregated matrix which can be calculated by using the following Equation 5.5

$$v_{ij} = w_{ij} r_{ij} \qquad \text{.........5.5}$$

Here, v_{ij}= Weighted matrix value
r_{ij}=Normalisation value.
w = Assigned weight
i = row
j= column.

And, the procedure for obtaining the above value is as follows.

$$A_{54} = w_{54} r_{54}$$

Weighted value of A_{54} = 0.030461

w_{54} and r_{54} are the weightage and normalization values of criteria against each alternative from Table 5.10 and normalization matrix Table 5.9.

Now A_{54} is calculated as shown below:

$$A_{54} = 0.067 \times 0.454639$$

And, is tabulated in the Table 5.20 at 5^{th} row of 4^{th} column.

Remaining normalization values are also calculated in same manner and are positioned in the Table no 5.10 of optimum selection of tower crane by fuzzy TOPSIS method as shown below.

The positive ideal (A*) and the negative ideal (A-) solutions are defined according to the weighted decision matrix via equations where I is associated with the beneficial attributes and I' is associated with the non-beneficial attributes.

The positive ideal (A*) and the negative ideal (A-) solution value for criteria X3 is given by Equation 5.6 & Equation 5.7 and explain below

$$A^* = \{v_1^*, \dots \dots . v_n^*\} \qquad \dots\dots\dots\dots\dots 5.6$$

$$A- = \{v_1^-, \dots \dots . v_n^-\} \qquad \dots\dots\dots\dots\dots 5.7$$

Where: $v_i^* = \{\max(v_{ij}) if \in I; \min(v_{ij}) if \in I'$

$$v_i^- = \{\min(v_{ij}) if \in I; \text{maz}(v_{ij}) if \in I'$$

The procedure for obtaining the (A*) and (A-) value for criteria X3 above value is as follows:

$$v_3^* = \max\{0.023304;\ 0.02913;\ 0.02913;\ 0.032044;\ 0.034957\}=0.034957$$

$$v_3^- = \min\{0.023304;\ 0.02913;\ 0.02913;\ 0.032044;\ 0.034957\}=0.023304$$

Remaining normalization values are also calculated in same manner and are positioned in the Table 5.10 as shown below. Then we calculate the separation distance of each competitive alternative from the ideal and non-ideal solution which is given by the Equation 5.9 & Equation 5.10 given below

$$S_j^* = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^*\right)^2} \text{ ... ...5.8} \qquad S_j^- = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^-\right)^2} \text{ ....5.9}$$

Here, S_j^*= Separation measure from positive ideal solution
S_j^-= Separation measure from negative ideal solution
v_i^*= Positive ideal solution
v_i^-= Negative ideal solution
i = row
j= column.

Now S_1^* and S_1^- is calculated as shown below:

$$S_1^* = \sqrt{\begin{array}{c}[0.023596 - 0.0353941]^2 + [0.027061 - 0.035179]^2 + [0.023304 - 0.034957]^2 \\ +[0.022197 - 0.036995]^2 + [0.021758 - 0.039164]^2 + [0.024201 - 0.037166]^2 \\ +[0.02763 - 0.033156]^2 + [0.018787 - 0.37573]^2 + [0.020201 - 0.04043]^2 \\ +[0.020843 - 0.034738]^2 + [0.019704 - 0.01704]^2 + [0.027247 - 0.027247]^2 \\ +[0.028009 - 0.028009]^2 + [0.023819 - 0.023819]^2 + [0.024836 - 0.024836]^2\end{array}}$$

$$= 0.0449$$

Similarly, S_1^- is calculated, the only difference is here replaced v_i^* with v_i^-

$$S_1^- = \sqrt{\begin{array}{c}[0.023596 - 0.023596]^2 + [0.027061 - 0.027061]^2 + [0.023304 - 0.023304]^2 \\ +[0.022197 - 0.022197]^2 + [0.021758 - 0.021758]^2 + [0.024201 - 0.024201]^2 \\ +[0.02763 - 0.02763]^2 + [0.018787 - 0.018787]^2 + [0.020201 - 0.020201]^2 \\ +[0.020843 - 0.020843]^2 + [0.019704 - 0.037531]^2 + [0.027247 - 0.033115]^2 \\ +[0.028009 - 0.032677]^2 + [0.023819 - 0.033346]^2 + [0.024836 - 0.033114]^2\end{array}}$$

$$= 0.02309$$

Remaining separation measure values are also calculated in same manner and are positioned in the Table no 5.10 of optimum selection of tower crane by fuzzy TOPSIS method as shown below.

For each competitive alternative, the relative closeness of the potential criteria with respect to the ideal solution is computed by the Equation 5.10 given below:

$$C_j^* = \frac{S_j^-}{S_j^* + S_j^-} \qquad \text{......5.10}$$

Here, C_j^* = Relative closeness
S_j^* = Separation measure from positive ideal solution
S_j^- = Separation measure from negative ideal solution

Now C_5^* is calculated as shown below:

$$C_5^* = \left[\frac{0.04442}{0.02358+0.04442}\right] = 0.65318$$

Remaining relative closeness values are also calculated in same manner and are positioned in the Table 5.10 as shown below.

Table 5.10 - Optimum selection of Tower crane by Fuzzy TOPSIS method

weightage	Criteria	Tower crane alternatives					Positive ideal solution	Negative ideal solution
		TC1	TC2	TC3	TC4	TC5	A*	A-
0.07	X1	0.023596	0.023596	0.029495	0.035394	0.035394	0.035394	0.023596
0.07	X2	0.027061	0.027061	0.035179	0.032473	0.027061	0.035179	0.027061
0.07	X3	0.023304	0.02913	0.02913	0.032044	0.034957	0.034957	0.023304
0.07	X4	0.022197	0.029596	0.029596	0.029596	0.036995	0.036995	0.022197
0.07	X5	0.021758	0.025021	0.030461	0.030461	0.039164	0.039164	0.021758
0.07	X6	0.024201	0.024201	0.031116	0.031116	0.037166	0.037166	0.024201
0.07	X7	0.02763	0.02763	0.02763	0.033156	0.033156	0.033156	0.02763
0.07	X8	0.018787	0.025618	0.025618	0.037573	0.037573	0.037573	0.018787
0.07	X9	0.020201	0.020201	0.020201	0.040403	0.040403	0.040403	0.020201
0.07	X10	0.020843	0.020843	0.034738	0.034738	0.034738	0.034738	0.020843
0.07	X11	0.019704	0.025334	0.025334	0.037531	0.037531	0.019704	0.037531
0.07	X12	0.027247	0.028295	0.029343	0.031439	0.033115	0.027247	0.033115
0.07	X13	0.028009	0.032677	0.032677	0.028009	0.028009	0.028009	0.032677
0.07	X14	0.023819	0.028582	0.030964	0.033346	0.032155	0.023819	0.033346
0.07	X15	0.024836	0.028975	0.028975	0.033114	0.033114	0.024836	0.033114
Separation measure	S*	0.0449	0.03913	0.03072	0.02603	0.02358		
	S-	0.02309	0.01892	0.02718	0.03785	0.04442		
Relative closeness		C1*	C2*	C3*	C4*	C5*		
		0.33968	0.32591	0.46942	0.59249	0.65318		

According to the value of Ci the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared as tabulated in Table 5.11 below.

Table 5.11 - Tower crane sequence for selection from Fuzzy TOPSIS

Alternatives	Model name	Relative closeness(C^*)
TC5	STC-6010	0.65318
TC4	STC-5512	0.59249
TC3	STC-5013	0.46942
TC1	STC-4010	0.32591
TC2	STC-5010	0.33968

5.3.3 Optimum selection of Tower Crane by SDI Tool-Triptych (Software)

In Figure 5.2, Workspace of the SDI tool is shown which is based on the fuzzy TOPSIS technique. In which third column are the criteria on which the selection of tower crane depends followed by its units, in fourth column we have to assign the weightage to each criteria depending upon decision maker priorities and preferences.

				Options							
				1	2	3	4	5			
Criteria:		Units	Importance	STC-4010	STC-5010	STC-5013	STC-5512	STC-6010	Goal	- Ideal	+ Ideal
1	MAX. LIFTING CAPACITY	Tons	1	4	4	5	6	6	maximize	4	6
2	TIP LOAD	Tons	1	1	1	1.3	1.2	1	maximize	1	1.3
3	JIB length	Meters	1	40	50	55	55	60	maximize	40	60
4	FREE STANDING HEIGHT	Meters	1	30	40	40	50	50	maximize	30	50
5	MAX HEIGHT EXTERNAL	Meters	1	100	115	140	140	180	maximize	100	180
6	DRUM CAPACITY	kilograms	1	280	280	360	360	430	maximize	280	430
7	WIRE ROPE SIZE	mm	1	10	10	10	12	12	maximize	10	12
8	HOISTING MOTOR CAPACITY	KW	1	11	15	15	22	22	maximize	11	22
9	SLEWING MOTOR CAPACITY	KW	1	4	4	4	8	8	maximize	4	8
10	TROLLY MOTOR CAPACITY	KW	1	2.4	2.4	4	4	4	maximize	2.4	4
11	TOTAL POWER CONSUMPTION	KVA	1	21	27	27	40	40	minimize	40	21
12	PURCHASE PRIC	RS	1	1.3	1.35	1.4	1.5	1.58	minimize	1.58	1.3
13	MAINTAINENCE	RS	1	30	35	35	30	30	minimize	35	30
14	AQUI SITION COST ON SITE	RS	1	1	1.2	1.3	1.4	1.35	minimize	1.4	1
15	MACHINE LIFE	YEARS	1	30	35	35	40	40	minimize	40	30
			Score	0.34	0.32	0.48	0.61	0.65			

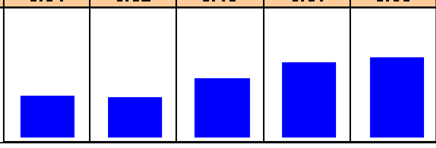

Fig. 5.2-Optimum selection of Tower crane in SDI tool

Further all the parameters value is assign and goal are given to each criteria for e.g. the quantity and capacity criteria are best when they are maximum and cost criterions are best when they are minimum. After the input sheet is completed the tool automatically calculate the negative ideal solution (-IDEAL) and positive ideal solution (+IDEAL) as shown in Figure 5.2. Score indicates the relative closeness of positive ideal solution to negative ideal solution on which the final ranking is obtain.

5.4 Optimum selection of Concrete Pump

Decision making for selection of optimum concrete pump is carried out by fuzzy MADM method in this section. This method is generally based on dominance matrix where it converts all the criteria into fuzzy number by taking membership value from experts against in criteria and find the most dominating alternative among them.

5.4.1 Optimum selection of Concrete Pump by Fuzzy MADM method

The factors related to the project and its cost are contingent on the exact function of the concrete pump. The following Table 5.12 shows all the specification of all the models of concrete pump which govern the selection of appropriate concrete pump model.

Table 5.12- Concrete pump alternatives and their criteria for selection

Criteria	SP-305	BPN-300	SP-500	SP-2800	SP-8800
Max concrete pressure (bar)	43	60	76	108	163
Max Output Volume (m^3/hr)	23	34	35	100	116
Max horizontal pumping	244	305	354	520	600
Max vertical pumping distance (M)	60	80	100	120	150
Maximum pump stroke per min	44	40	32.5	35	31
Pumping Cylinder Stroke (mm)	125	180	150	200	200
Pumping Cylinder stroke length	762	630	1000	1600	2000
Hydraulic tank capacity (litres)	150	170	190	200	220
Fuel tank capacity (litres)	57	60	75.7	80	85
Purchase price (Rs)	25	28	30	35	40
Feeder pipe diameter (cm)	15	20	20	25	25
Maintenance cost (Rs)	20	20	22	25	30
Life of machine (Years)	20	20	25	25	28

The quantitative data relating to the selection of concrete pump such as load maximum concrete pressure, maximum output value pumping cylinder stroke, purchase price etc. are given in the Table 5.12.As shown in the first row SP-305, BPN-300 etc. are the model numbers of the concrete pump which will be further denoted as CP1, CP2, CP3, CP4 and CP5 similarly column represent the various criteria on which the selection of concrete pump is made and further it will be denoted as X1, X2, X3, X4…….$X_{N.}$ All the criteria of different alternatives are compared graphically which is shown in Figure 5.3.

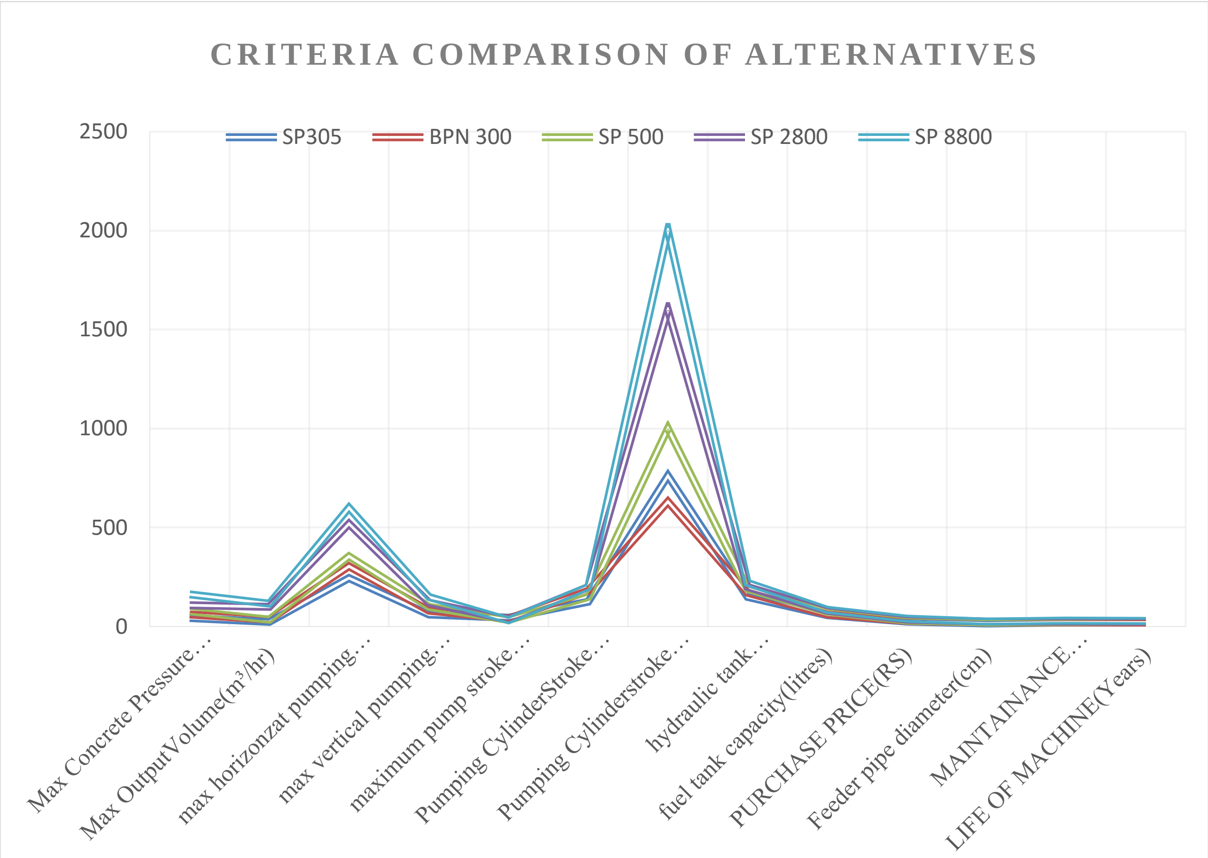

Figure 5.3- Criteria comparison of alternatives for Concrete Pump

In the comparison graph Figure 5.3 we can have observed clearly than concrete pump model SP-8800 is most dominating in all criteria followed by SP-2800, SP-500, BPN-30 and SP-305.

The concept of membership plays a central role in the selection process. Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention low represents the least desirable end of the scale and high represents the most desirable end of the scale.

Concrete pump is to be ranked based on the qualitative and quantitative criteria. A questionnaire proforma has been prepared to evaluate the concrete pump against these criteria. The questionnaire proforma was circulated to experts to have their opinions in terms of membership values.

Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention low represents the least desirable end of the scale and high represents the most desirable end of the scale. The questionnaire proforma deals with qualitative criteria and quantitative criteria such as load maximum concrete pressure, maximum output value pumping cylinder stroke, and purchase price.

An interview with the concrete pump experts was also conducted to collect data for evaluating the "qualitative criteria" and "quantitative criteria" affecting the concrete pump selection. A correspondence between the qualitative and quantitative factors and the available concrete pump was made explicit, and a numerical scale between 0.0 and 1.0 was established. A value of 0.5 indicates a neutral effect while a value of 1.0 is defined as complete satisfaction.

To assess the impact of qualitative and quantitative factors, the construction firms are approached and their membership values are placed in different matrices. In response to the questionnaire proforma each expert has given his/her degree of belief about the concrete pump in terms of 0 - 1 with respect to the criteria. The transformed results of the questionnaire proforma are tabulated into position matrices for each expert and is given in Appendix-II

After placing the membership values given to all the qualitative and quantitative features against alternative concrete pump by experts from the prominent companies of Mumbai and Navi-Mumbai in position matrices, which is shown in Appendix-II.The membership values are aggregated using mean aggregation for every feature against for every alternative and tabulated in the following Table 5.13. For example, the membership value of 'A_{93}' in mean aggregated table 5.13 is obtained as follows, here '41' indicates 9^{th} row of 3^{rd} column of above matrix which is formed by using the following equation 5.1

$$\mu_{ij} = \frac{1}{k}\sum_{i=1}^{k} \mu_{ij}{}^{1} \qquad \ldots\ldots\ldots 5.1$$

Here, μ_{ij}=Mean aggregated membership value
K = number of position matrices
i = row

j= column

And, the procedure for obtaining the above value is as follows.

$$A_{93} = [\, a_{93}^{1} + \; a_{93}^{2} + \cdots \ldots\ldots\ldots\ldots\ldots\ldots + \; a_{93}^{10}] \,/\, 10$$

A_{93} = Mean aggregated membership value = 0.35

$a_{93}^{1} + \; a_{93}^{2} + \cdots \ldots\ldots\ldots\ldots\ldots\ldots + \; a_{93}^{10}$ are the membership values of criteria against each alternative from the position matrices of the various experts from the Table 1 to 10 given in Appendix- II

Now A_{93} is calculated as shown below:

$$A_{93} \;=\; \{[\,0.30 + 0.25 + 0.25 + 0.30 + 0.30 + 0.30 + 0.25 + 0.50 + 0.55 + 0.50]\,/10\} \\ = 0.35$$

and, is tabulated in the mean aggregated matrix Table 5.13 at 9^{th} row of 3^{rd} column. Remaining membership values are also calculated in same manner and are positioned in the Table 5.13 of mean aggregated matrix as shown below.

Table 5.13- Mean matrix for Concrete pump

Criteria	mean value matrix				
	CP1	CP2	CP3	CP4	CP5
X1	0.56	0.91	0.36	0.89	0.96
X2	0.84	0.81	0.89	0.61	0.92
X3	0.37	0.11	0.29	0.60	0.91
X4	0.73	0.62	0.77	0.53	0.82
X5	0.62	0.55	0.62	0.75	0.94
X6	0.52	0.48	0.51	0.72	0.82
X7	0.74	0.82	0.48	0.79	0.91
X8	0.67	0.73	0.78	0.64	0.92
X9	0.66	0.24	0.35	0.64	0.88
X10	0.61	0.65	0.74	0.56	0.83
X11	0.63	0.58	0.66	0.72	0.93
X12	0.74	0.46	0.48	0.72	0.84
X13	0.75	0.53	0.51	0.70	0.87

Table 5.14- Pessimistic matrix for Concrete pump

Criteria	pessimistic matrix				
	CP1	CP2	CP3	CP4	CP5
X1	0.35	0.85	0.30	0.80	0.90
X2	0.55	0.70	0.80	0.50	0.90
X3	0.15	0.05	0.25	0.55	0.90
X4	0.65	0.55	0.70	0.50	0.75
X5	0.50	0.50	0.55	0.70	0.85
X6	0.35	0.40	0.45	0.65	0.80
X7	0.35	0.60	0.30	0.50	0.80
X8	0.05	0.55	0.60	0.50	0.90
X9	0.35	0.05	0.25	0.55	0.80
X10	0.10	0.55	0.35	0.50	0.75
X11	0.05	0.50	0.55	0.50	0.85
X12	0.50	0.05	0.25	0.65	0.80
X13	0.45	0.10	0.25	0.55	0.80

After identifying the mean aggregated values, the pessimistic aggregated matrix should be formed to minimize the risk of taking the values of memberships given by all the experts from the different companies for each criteria against each alternative. To form pessimistic aggregated matrix minimum membership value of each criterion against each alternative from all the position matrices are taken and formed in a matrix shape as shown in the Table.5.14.

For example, membership value of 'A_{72}' of pessimistic aggregated matrix is obtained as follows, here '72' indicates 7th row of 2nd column of pessimistic aggregated matrix which can be calculated by using the following Equation 5.2

$$\mu_{ij} = \min(\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3 \ldots \ldots \ldots \ldots \ldots \mu_{ij}^k) \qquad \ldots\ldots\ldots..5.2$$

Here μ_{ij} = Minimum Membership value.

In $\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3$

i & j are row and column respectively, and $1, 2, \ldots \ldots \ldots \ldots \ldots .. k,$ indicates the number of matrices formed.

Minimum value among all the values of each criterion is taken and formed as single matrix shown in Table 5.14, and $A_{72} = 0.60$ is calculated as shown below.

A_{72} = min of $[a_{72}^1,\ a_{72}^2, \ldots \ldots \ldots \ldots \ldots \ldots \ldots, a_{72}^{10}]$

Here $a_{72}^1,\ a_{72}^2, \ldots \ldots \ldots \ldots \ldots \ldots \ldots, a_{72}^{10}$ are the minimum membership values of criteria against alternatives.

$$A_{72} = min\,[\,0.72, 0.85.0.85, 0.90, 0.90, 0.95, 0.95, 0.60, 0.65, 0.65] = 0.60.$$

So, minimum value is '0.60' among all the membership values and is positioned in the matrix, at 7th row of 2nd column of the matrix, and remaining minimum membership values for all the criteria against alternatives are tabulated as pessimistic aggregated matrix as shown in Table 5.14

These membership values of the experts are combined into a single matrix using modified pessimistic aggregation for each criterion against the alternatives. Since pessimistic aggregation attempts to minimize the risk, while the modified pessimistic aggregation may prove to be useful to have a spectrum of polarized opinions of the experts. The final aggregated membership values are from modified pessimistic aggregation, which is an average of arithmetic mean and pessimistic aggregation. Table 5.15 is the modified pessimistic aggregation table for the position matrices of various experts. These values are obtained by taking different membership values for the factors affecting concrete pump selection by experts.

Table 5.15- Modified pessimistic matrix for Concrete Pump

Criteria	modified pessimistic matrix				
	CP1	CP2	CP3	CP4	CP5
X1	0.46	0.88	0.33	0.85	0.93
X2	0.69	0.76	0.84	0.55	0.91
X3	0.26	0.08	0.27	0.58	0.90
X4	0.69	0.59	0.74	0.52	0.79
X5	0.56	0.53	0.59	0.72	0.89
X6	0.44	0.44	0.48	0.68	0.81
X7	0.55	0.71	0.39	0.65	0.86
X8	0.36	0.64	0.69	0.57	0.91
X9	0.50	0.14	0.30	0.60	0.84
X10	0.36	0.60	0.54	0.53	0.79
X11	0.34	0.54	0.60	0.61	0.89
X12	0.62	0.25	0.36	0.68	0.82
X13	0.60	0.32	0.38	0.62	0.84

Table 5.16- Weighted matrix for Concrete Pump

Criteria	Weighted matrix					WT
	CP1	CP2	CP3	CP4	CP5	
X1	0.03	0.07	0.02	0.06	0.07	0.08
X2	0.05	0.06	0.06	0.04	0.07	0.08
X3	0.02	0.01	0.02	0.04	0.07	0.08
X4	0.05	0.04	0.06	0.04	0.06	0.08
X5	0.04	0.04	0.04	0.05	0.07	0.08
X6	0.03	0.03	0.04	0.05	0.06	0.08
X7	0.04	0.05	0.03	0.05	0.06	0.08
X8	0.03	0.05	0.05	0.04	0.07	0.08
X9	0.04	0.01	0.02	0.05	0.06	0.08
X10	0.03	0.05	0.04	0.04	0.06	0.08
X11	0.03	0.04	0.05	0.05	0.07	0.08
X12	0.05	0.02	0.03	0.05	0.06	0.08
X13	0.05	0.02	0.03	0.05	0.06	0.08

For example, membership value of 'A14' of modified pessimistic aggregation is obtained by using the following Equation 5.3

$$\mu_{ij} = \frac{1}{2}\{\mu_{ij}{}^{1} \ldots \ldots \mu_{ij}{}^{k} + \sum_{i=1}^{k} \mu_{ij}{}^{1} \ldots \ldots \sum_{i=1}^{k} \mu_{ij}{}^{k}\} \qquad \ldots\ldots 5.3$$

And, the procedure for obtaining the above membership value is as follows.

$A14$ = Average of every membership value of criteria against alternative of mean aggregated matrix and pessimistic aggregated matrix.

So, $A14 = \{[a_{14}ma + a_{14}pa] / 2\}$,

Here $_{14}ma$, $a_{14}pa$ are membership values of criteria against alternative of 1st row of 4th column of mean aggregated matrix and pessimistic aggregated matrix respectively.

Here ma = Mean aggregation

pa = pessimistic aggregation

So, A14 = {[0.89 + 0.80] /2}

A14 = 0.85, and is tabulated in the modified pessimistic aggregated matrix table no 5.15, remaining aggregated membership values are also calculated in the same manner and are positioned in the above Table. 5.15

The membership values given for qualitative and quantitative factors are of equal importance. To overcome certain draw backs given by different experts, before evaluating the alternatives, weightages for each criteria has been introduced to get accuracy in selecting optimum alternative among available alternatives. And the weightages are assigned and is given in Table 5.16 and are tabulated as follows.

After identifying the weightages to be assigned to the membership values of features of available alternatives from the experts these weightages are multiply to each and every criterion from the table 5.15 of modified pessimistic matrix and is placed in the following Table 5.16.

For example, weighted aggregated value of A_{14}, value of 1^{st} row of 4^{th} column 0.06 is calculated as (0.85×0.8), 0.08 is weight assigned to 0.85 which was taken from the table 5.16. Accordingly, remaining values are also calculated by assigning weights in multiplication and placed in above Table.5.16. After forming the weighted matrix, dominance matrix procedure is carried out to rank the alternatives for weighted values and is shown in Table 5.17.

Table 5.17 - Dominance matrix for Concrete pump

	CP1	CP2	CP3	CP4	CP5	ROW SUM				
CP1	#	6	6	9	13	34	21	12	6	0
CP2	5	#	7	7	13	32	19	12	5	#
CP3	5	3	#	8	13	29	16	8	#	#
CP4	2	4	3	#	13	22	9	#	#	#
CP5	0	0	0	0	#	0	#	#	#	#
COLUMN SUM	12	13	16	24	52					
	12	13	16	24	#					
	10	9	13	#	#					
	5	6	#	#	#					
	0	#	#	#	#					

In order to display the dominance structure between all possible pairs of concrete pump and *N by N* matrix, called the Dominance Matrix (D) is constructed. The element d_{ij} is the number of features for which the membership value of concrete pump j is greater than that of concrete pump i. For example in weighted matrix as shown in Table 5.16 the element X_{21} indicates that how many times criteria of alternative 1 dominates on criteria of alternative 2 and is tabulated in dominance matrix at X_{21}.

The dimensionality N is equal to the number of concrete pump under consideration. A hash (#) is entered in the diagonal cells as the dominance of a concrete pump over itself does not make sense. If the j^{th} column is summed, the total number of dominances of concrete pump j over all other concrete pump is obtained. Similarly, if the i^{th} row is summed, the number of times the j^{th} concrete pump is dominated by all other concrete pump is obtained. The sums of columns and rows can be compared and from this one can see that most favorable outcomes have higher column sums and lower row sums. Based on the above dominance matrix the best alternative is identified as follows:

1. Sum up all the column and row values.
2. Choose the column with highest value and low row totals to select the best concrete pump.
3. If two alternatives column sums are same, choose the alternative with minimum row sum.
4. If sums of columns and rows are same, choose an alternative arbitrarily.
5. To choose the next best, delete the values of the best crane and repeat the procedure.

In Table 5.17 highest column sum is 52 and lowest row sum is 0 for the alternative CP5. Therefore, using dominance matrix the alternative CP5 is the best alternative and corresponding to SP-8800. To choose the next best the values of these alternatives values are removed and the procedure is repeated. Using the dominance matrix following ranks sequence are obtain as shown in Table 5.18.

Table 5.18 – Concrete Pump sequence for selection from Dominance matrix

Alternatives	Model name	Dominance
CP5	SP-8800	(52,0)
CP4	SP-2800	(24,09)
CP3	SP-500	(13,8)
CP2	BPN-300	(6,5)
CP1	SP-305	(0,0)

5.4.2 Optimum selection of Concrete Pump by Fuzzy TOPSIS method

The following Table 5.19 shows decision matrix of all the specification of all the models of concrete pump which govern the selection of appropriate concrete pump model where the criteria which are represented in red colours are cost attribute and those with green colours are benefits attribute.

The reason it has been highlighted unlike previous method is because in this method we will decide optimization based on the distance from positive ideal and negative ideal solution where we need to look for high values of benefits attribute and low values of cost attributes.

Table 5.19 - Decision matrix for Concrete pump

Criteria	Concrete Pump alternatives				
	CP1	CP2	CP3	CP4	CP5
X1	43	60	76	108	163
X2	23	34	35	100	116
X3	244	305	354	520	600
X4	60	80	100	120	150
X5	44	40	32.5	35	31
X6	125	180	150	200	200
X7	762	630	1000	1600	2000
X8	150	170	190	200	220
X9	57	60	75.7	80	85
X10	25	28	30	35	40
X11	15	20	20	25	25
X12	20	20	22	25	30
X13	20	20	25	25	28

The first step of the TOPSIS method involves the construction of a Decision Matrix (DM) as explain below.

$$DM = = \begin{array}{c|cccc} & CP_1 & CP_2 & \cdots & CP_n \\ \hline X_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ X_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ X_3 & \vdots & \vdots & \ddots & \\ X_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{array}$$

Where i the criterion index is $(i = 1 \ldots m)$; m is the number of potential criteria and j is the alternative index $(j = 1 \ldots .n)$; n is the number of alternatives. The elements

$X_1, X_2 \ldots \ldots X_m$ refer to the criteria: while $CP_1, CP_2 \ldots \ldots CP_n$ refer to the alternative of concrete pump. The elements of the matrix are related to the values of criteria i with respect to alternative j.

After developing the decision matrix, normalization matrix is develop using the Equation 5.4 given and explain below

For example, the normalization value of ' A_{61}' in normalization matrix Table 5.20 is obtained as follows, here '61' indicates 6^{th} row of 1^{st} column of above matrix which is formed by using the following Equation 5.4

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \qquad \ldots\ldots\ldots 5.4$$

Here, r_{ij}=Normalisation value
m = number of concrete pump alternatives
i = row
j= column

And, the procedure for obtaining the above value is as follows.

$$A_{61} = a_{61}\sqrt{[a_{61}^2 + \ a_{62}^2 + a_{63}^2 + a_{64}^2 + a_{65}^2]}.$$

Normalisation value of A_{61} = 0.322185

$a_{61} + a_{62} + a_{63} + a_{64} + a_{65}$ are the specification values of criteria against each alternative from decision matrix from Table 5.39. Now A_{61} is calculated as shown below:

$$A_{61} = 125\sqrt{[125^2 + 180^2 + 150^2 + 200^2 + 200^2]}.$$

and, is tabulated in the normalisation matrix Table 5.40 at 6^{th} row of 1^{st} column.

Remaining normalisation values are also calculated in same manner and are positioned in the Table 5.20 of normalisation matrix as shown below.

Table 5.20 - Normalisation Matrix for Concrete Pump

Criteria	Normalization of matrix				
	CP1	CP2	CP3	CP4	CP5
X1	0.193353	0.269794	0.34174	0.48563	0.732942
X2	0.141646	0.20939	0.215549	0.615854	0.714391
X3	0.256024	0.32003	0.371445	0.545625	0.629567
X4	0.251533	0.335377	0.419222	0.503066	0.628833
X5	0.534434	0.485849	0.394752	0.425118	0.376533
X6	0.322185	0.463947	0.386622	0.515496	0.515496
X7	0.260789	0.215613	0.342242	0.547587	0.684484
X8	0.35765	0.405337	0.453023	0.476867	0.524553
X9	0.352117	0.370649	0.467636	0.494199	0.525087
X10	0.348909	0.390778	0.418691	0.488472	0.558254
X11	0.314485	0.419314	0.419314	0.524142	0.524142
X12	0.377358	0.377358	0.415094	0.471698	0.566038
X13	0.37569	0.37569	0.469613	0.469613	0.525967

Not all of the selection criteria may be of equal importance and hence weighting was introduced to quantify the relative importance of the different selection criteria. The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights.

For example, membership value of 'A_{94}' of weighted matrix is obtained as follows, here '94' indicates 9th row of 4th column of weighted aggregated matrix which can be calculated by using the following Equation 5.5

$$v_{ij} = w_{ij} r_{ij} \qquad \text{……...5.5}$$

Here, v_{ij}= Weighted matrix value
r_{ij}=Normalisation value
w = Assigned weight
i = row
j= column

And, the procedure for obtaining the above value is as follows.

$$A_{94} = w_{94} r_{94}$$

Weighted value of A_{94} = 0.038053

$w_{94}$and r_{94} are the weightage and normalization values of criteria against each alternative from Table 5.21 and normalization matrix Table 5.20.

Now A_{94} is calculated as shown below:

$$A_{94} = 0.076 \times 0.494199$$

And, is tabulated in the Table 5.21 at 9^{th} row of 4^{th} column.

Remaining normalization values are also calculated in same manner and are positioned in the Table 5.21 of optimum selection of concrete pump by fuzzy TOPSIS method as shown below.

The positive ideal (A*) and the negative ideal (A-) solutions are defined according to the weighted decision matrix via equations where I is associated with the beneficial attributes and I' is associated with the non-beneficial attributes.

The positive ideal (A*) and the negative ideal (A-) solution value for criteria X9 is given by Equation 5.6 & Equation 5.7 and explain below

$$A^* = \{v_1^*, \ldots \ldots . v_n^*\} \qquad \ldots\ldots\ldots\ldots\ldots 5.6$$

$$A-= \{v_1^-, \ldots \ldots . v_n^-\} \qquad \ldots\ldots\ldots\ldots\ldots 5.7$$

Where: $v_i^* = \{\max(v_{ij}) if \in I; \min(v_{ij}) if \in I'$

$$v_i^- = \{\min(v_{ij}) if \in I; \mathrm{maz}(v_{ij}) if \in I'$$

The procedure for obtaining the (A*) and (A-) value for criteria X3 above value is as follows:

$$v_9^* = \max\{0.027113; 0.02854; 0.036008; 0.038053; 0.040432\}=0.040432$$

$$v_9^- = \min\{0.027113; 0.02854; 0.036008; 0.038053; 0.040432\}=0.027113$$

Remaining normalization values are also calculated in same manner and are positioned in the Table 5.21 as shown below. Then we calculate the separation distance of each competitive alternative from the ideal and non-ideal solution which is given by the Equation 5.8 & Equation 5.9 given below:

$$S_j^* = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^*\right)^2} \ldots \ldots 5.8 \qquad S_j^- = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^-\right)^2} \ldots\ldots 5.9$$

Here, S_j^*= Separation measure from positive ideal solution
S_j^- = Separation measure from negative ideal solution
v_i^*= Positive ideal solution
v_i^- = Negative ideal solution
i = row
j= column

Now S_4^* and S_4^- is calculated as shown below:

$$S_4^*=\sqrt{\begin{array}{c}[0.037394-0.056436]^2+[0.047421-0.055008]^2+[0.042013-0.048477]^2\\+[0.038736-0.04842]^2+[0.032734-0.041151]^2+[0.039693-0.039693]^2\\+[0.042164-0.052705]^2+[0.036719-0.040391]^2+[0.038053-0.040432]^2\\+[0.037612-0.026866]^2+[0.040359-0.040359]^2+[0.036321-0.029057]^2\\+[0.03616-0.040499]^2\end{array}}$$

$$=0.03072$$

Similarly S_4^- is calculated, the only difference is here replaced v_i^* with v_i^-

$$S_4^-=\sqrt{\begin{array}{c}[0.037394-0.014888]^2+[0.047421-0.010907]^2+[0.042013-0.019714]^2\\+[0.038736-0.019368]^2+[0.032734-0.028993]^2+[0.039693-0.024808]^2\\+[0.042164-0.016602]^2+[0.036719-0.027539]^2+[0.038053-0.027113]^2\\+[0.037612-0.042986]^2+[0.040359-0.024215]^2+[0.036321-0.043585]^2\\+[0.03616-0.028928]^2\end{array}}$$

$$=0.06480$$

Remaining separation measure values are also calculated in same manner and are positioned in the Table no 5.21 of optimum selection of concrete pump by fuzzy TOPSIS method as shown below.

For each competitive alternative, the relative closeness of the potential criteria with respect to the ideal solution is computed by the Equation 5.10 given below:

$$C_j^* = \frac{S_j^-}{S_j^*+S_j^-} \qquad \text{…Eq. 5.10}$$

Here, C_j^*= Relative closeness
S_j^*= Separation measure from positive ideal solution
S_j^- = Separation measure from negative ideal solution

Now C_3^* is calculated as shown below:

$$C_3^* = \left[\frac{0.03211}{0.06417+0.03211}\right] = 0.33353$$

Remaining relative closeness values are also calculated in same manner and are positioned in the Table no 5.21 of normalization matrix as shown below.

Table 5.21 - Optimum selection of Concrete pump by Fuzzy TOPSIS method

weightage	Criteria	Concrete Pump alternatives					Positive ideal solution	Negative ideal solution
		CP1	CP2	CP3	CP4	CP5	A*	A-
0.08	X1	0.014888	0.020774	0.026314	0.037394	0.056436	0.056436	0.014888
0.08	X2	0.010907	0.016123	0.016597	0.047421	0.055008	0.055008	0.010907
0.08	X3	0.019714	0.024642	0.028601	0.042013	0.048477	0.048477	0.019714
0.08	X4	0.019368	0.025824	0.03228	0.038736	0.04842	0.04842	0.019368
0.08	X5	0.041151	0.03741	0.030396	0.032734	0.028993	0.041151	0.028993
0.08	X6	0.024808	0.035724	0.02977	0.039693	0.039693	0.039693	0.024808
0.08	X7	0.020081	0.016602	0.026353	0.042164	0.052705	0.052705	0.016602
0.08	X8	0.027539	0.031211	0.034883	0.036719	0.040391	0.040391	0.027539
0.08	X9	0.027113	0.02854	0.036008	0.038053	0.040432	0.040432	0.027113
0.08	X10	0.026866	0.03009	0.032239	0.037612	0.042986	0.026866	0.042986
0.08	X11	0.024215	0.032287	0.032287	0.040359	0.040359	0.040359	0.024215
0.08	X12	0.029057	0.029057	0.031962	0.036321	0.043585	0.029057	0.043585
0.08	X13	0.028928	0.028928	0.03616	0.03616	0.040499	0.040499	0.028928
Separation measure	s1*	0.08582	0.07504	0.06417	0.03072	0.02487		
	s1-	0.02512	0.02785	0.03211	0.06480	0.08720		
Relative closeness		C1*	C2*	C3*	C4*	C5*		
		0.22640	0.27071	0.33353	0.67838	0.77806		

According to the value of Ci the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared as tabulated in Table 5.22 below.

Table 5.22 – Concrete Pump sequence for selection from Fuzzy TOPSIS

Alternatives	Model name	Relative closeness(C^*)
CP5	SP-8800	0.77806
CP4	SP-2800	0.67838
CP3	SP-500	0.33353
CP1	BPN-300	0.27071
CP2	SP-305	0.226408

5.4.3 Optimum selection of Concrete Pump by SDI Tool-Triptych (Software)

In Figure 5.4, Workspace of the SDI tool is shown which is based on the fuzzy TOPSIS technique. In which third column are the criteria on which the selection of concrete pump depends followed by its units, in fourth column we have to assign the weightage to each criteria depending upon decision maker priorities and preferences.

				Options							
				1	2	3	4	5			
Criteria:		Units	Importance	SP305	BPN 300	SP 500	SP 2800	SP 8800	Goal	- Ideal	+ Ideal
1	Max Concrete Pressure	Bar	0.077	43	60	76	108	163	maximize	43	163
2	Max OutputVolum	m³/hr	0.077	23	34	35	100	116	maximize	23	116
3	max horizonzat pumping distance	meters	0.077	244	305	354	520	600	maximize	244	600
4	max vertical pumping distance	meters	0.077	60	80	100	120	150	maximize	60	150
5	maximum pump stroke per min	count/min	0.077	44	40	32.5	35	31	maximize	31	44
6	Pumping CylinderStroke	mm	0.077	125	180	150	200	200	maximize	125	200
7	Pumping Cylinderstroke lenght	mm	0.077	762	630	1000	1600	2000	maximize	630	2000
8	hydraulic tank capacity	litres	0.077	150	170	190	200	220	maximize	150	220
9	fuel tank capacity	litres	0.077	57	60	75.7	80	85	maximize	57	85
10	PURCHASE PRICE	Rs	0.077	50	50	50	50	50	minimize	50	50
11	Feeder pipe diameter	cm	0.077	15	15	15	15	15	maximize	15	15
12	MAINTAINANCE COST	Rs	0.077	30	30	30	30	30	minimize	30	30
13	LIFE OF MACHINE	Years	0.077	40	40	40	40	40	maximize	40	40
			Score	0.24	0.27	0.34	0.70	0.78			

Fig. 5.4- Optimum selection of Concrete pump in SDI tool

Further all the parameters value are assign and goal are given to each criteria for e.g. the quantity and capacity criteria are best when they are maximum and cost criteria's are best when they are minimum. After the input sheet is completed the tool automatically calculate the negative ideal solution (-IDEAL) and positive ideal solution (+IDEAL) as shown in figure 5.4.

Score indicates the relative closeness of positive ideal solution to negative ideal solution on which the final ranking is obtain.

5.5 Optimum selection of Material Hoist

Decision making for selection of material hoist is carried out by fuzzy MADM method in this section. This method is generally based on dominance matrix where it convert all the criteria into fuzzy number by taking membership value from experts against in criteria and find the most dominating alternative among them.

5.5.1 Optimum selection of Material Hoist by Fuzzy MADM method

The factors related to the project and its cost are contingent on the exact function of the material hoist. The following Table 5.23 shows all the specification of all the models of material hoist which govern the selection of appropriate material hoist model.

Table 5.23- Material hoist alternatives and their criteria for selection

Criteria	SMH	SMH	SMH	SMH	SMH
Capacity (ton)	2	1.5	1.2	1	0.5
Max height (m)	150	120	120	100	70
Speed (m/min)	30	30	30	30	20
Motor capacity (kw)	18.2	14	10.4	10.4	2.7
Safety device	SSD 3500	SSD 3500	SSD 1000	SSD 1000	SSD
Cage size (m^3)	2*1.2*1.5	2*1.2*1.5	2*1.2*1.5	2*1.2*1.5	1.2*1*0.
Rebar carrying capacity (ton)	1	1	0.5	0.5	0.3
Purchase price(Rs)	7	6	5.5	5	4
Maintenance	15	15	15	15	15
Machine life(years)	30	30	25	25	20

The quantitative data relating to the selection of Material hoist such as load maximum capacity, maximum height, motor capacity, purchase price etc. are given in the Table 5.23.As shown in the first row SMH 200V, SMH 150V etc. are the model numbers of the Material hoist which will be further denoted as MH1, MH2, MH3, MH4 and MH5 similarly columns represent the various criteria on which the selection of material hoist is made and further it will be denoted as X1X2,X3, X4…….$X_{N.}$ All the criteria of different alternatives are compared graphically which is shown in Figure 5.5.

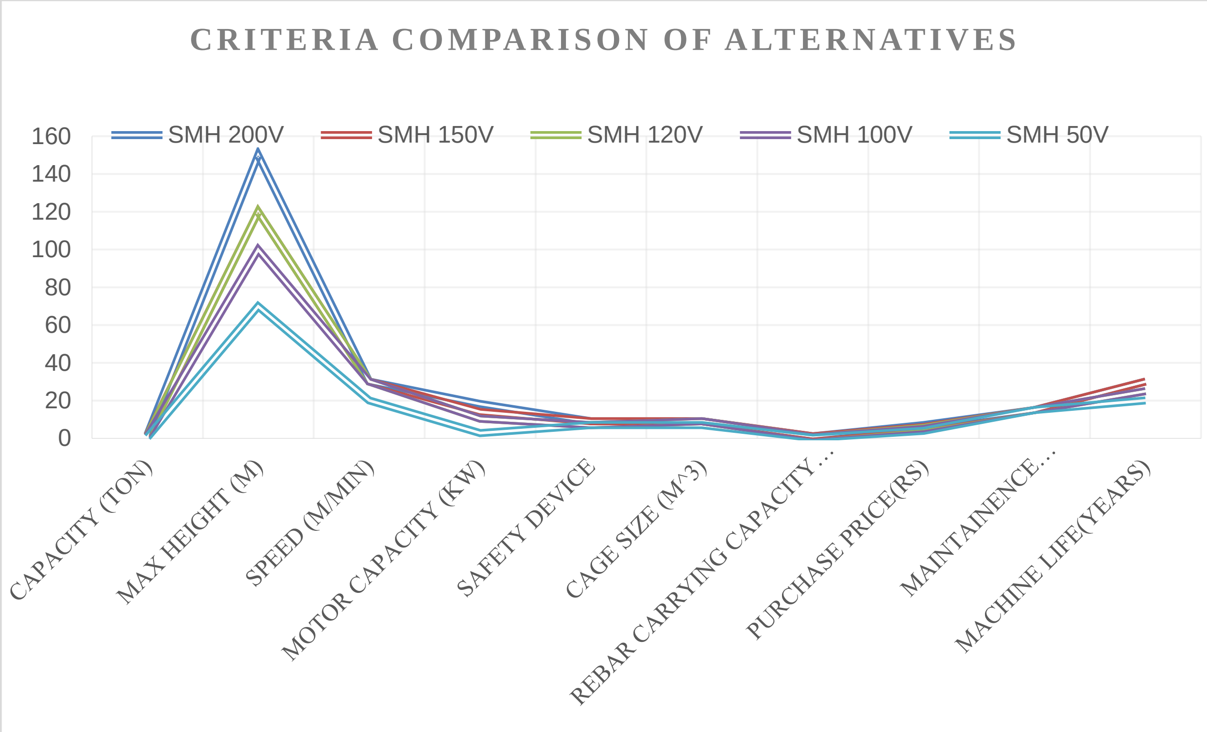

Figure 5.5-Criteria comparison of alternatives for Material Hoist

In the comparison graph Figure 5.5 we can have observed clearly than Material Hoist model SMH-200V is most dominating in all criteria followed by SMH-150V, SMH-120V, SMH-100V and SMH-50V. The concept of membership plays a central role in the selection process. Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention low represents the least desirable end of the scale and high represents the most desirable end of the scale.

Material hoist are to be ranked based on the qualitative and quantitative criteria. A questionnaire proforma has been prepared to evaluate the material hoist against these criteria. The questionnaire proforma was circulated to experts to have their opinions in terms of membership values. The concept of membership plays a central role in the selection process. Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention low represents the least desirable end of the scale and high represents the most desirable end of the scale. The questionnaire proforma deals with qualitative criteria and quantitative criteria such as load maximum capacity, maximum height, motor capacity, purchase price.

An interview with the material hoist experts was also conducted to collect data for evaluating the "qualitative criteria" and "quantitative criteria" affecting the material hoist selection. A correspondence between the qualitative and quantitative factors and the available cranes was made explicit, and a numerical scale between 0.0 and 1.0 was established. A value of 0.5 indicates a neutral effect while a value of 1.0 is defined as complete satisfaction.

To assess the impact of qualitative and quantitative factors, the construction firms are approached and their membership values are placed in different matrices. In response to the questionnaire proforma each expert has given his/her degree of belief about the material hoist in terms of 0 - 1 with respect to the criteria. The transformed results of the questionnaire proforma are tabulated into position matrices for each expert and is given in Appendix-III

After placing the membership values given to all the qualitative and quantitative features against alternative material hoist by experts from the prominent companies of Mumbai and Navi-Mumbai in position matrices, which is shown in Appendix-III. The membership values are aggregated using mean aggregation for every feature against for every alternative and tabulated in the following Table 5.24

For example, the membership value of '$A25$' in mean aggregated Table 5.24 is obtained as follows, here '25' indicates 2^{nd} row of 5^{th} column of above matrix which is formed by using the following Eq. 5.1.

$$\mu_{ij} = \frac{1}{k}\sum_{i=1}^{k} \mu_{ij}{}^{1} \qquad \text{...........Eq. 5.1}$$

Here, μ_{ij}=Mean aggregated membership value
K = number of position matrices
i = row
j= column

And, the procedure for obtaining the above value is as follows.

$$A25 = [\, a25^{1} + \ a25^{2} + \cdots \ldots \ldots \ldots \ldots \ldots \ldots + \ a25^{10}] \,/\, 10.$$

$A25$ = Mean aggregated membership value = 0.84

$a25^1 + \ a25^2 + \cdots \ldots\ldots\ldots\ldots\ldots\ldots + \ a25^{10}$ are the membership values of criteria against each alternative from the position matrices of the various experts from the Table 1 to 10 given in Appendix- III

Now $A25$ is calculated as shown below:

$$A25 \ = \{[\ 0.90 + 0.8 + 0.9 + 0.80 + 0.80 + 0.90 + 0.90 + 0.95 + 0.55 + 0.85]\ /10\}$$
$$= 0.84$$

And, is tabulated in the mean aggregated matrix Table 5.24 at 2^{nd} row of 5^{th} column.

Remaining membership values are also calculated in same manner and are positioned in the Table 5.24 of mean aggregated matrix as shown below.

Table 5.24- Mean matrix for Material Hoist

Criteria	mean value matrix				
	MH1	MH2	MH3	MH4	MH5
X1	0.96	0.89	0.36	0.91	0.56
X2	0.92	0.61	0.89	0.81	0.84
X3	0.91	0.60	0.29	0.11	0.37
X4	0.82	0.53	0.77	0.62	0.73
X5	0.94	0.75	0.62	0.55	0.62
X6	0.82	0.72	0.51	0.48	0.52
X7	0.91	0.79	0.48	0.82	0.74
X8	0.92	0.64	0.78	0.73	0.67
X9	0.88	0.64	0.35	0.24	0.66
X10	0.83	0.56	0.74	0.65	0.61

Table 5.25- Pessimistic matrix for Material Hoist

Criteria	pessimistic matrix				
	MH1	MH2	MH3	MH4	MH5
X1	0.90	0.80	0.30	0.85	0.35
X2	0.90	0.50	0.80	0.70	0.55
X3	0.90	0.55	0.25	0.05	0.15
X4	0.75	0.50	0.70	0.55	0.65
X5	0.85	0.70	0.55	0.50	0.50
X6	0.80	0.65	0.45	0.40	0.35
X7	0.80	0.50	0.30	0.60	0.35
X8	0.90	0.50	0.60	0.55	0.05
X9	0.80	0.55	0.25	0.05	0.35
X10	0.75	0.50	0.35	0.55	0.10

After identifying the mean aggregated values, the pessimistic aggregated matrix should be formed to minimize the risk of taking the values of memberships given by all the experts from the different companies for each criteria against each alternative. To form pessimistic aggregated matrix minimum membership value of each criteria against each alternative from all the position matrices are taken and formed in a matrix shape as shown in the Table.5.25.

For example, membership value of 'A_{65}' of pessimistic aggregated matrix is obtained as follows, here '65' indicates 6^{th} row of 5^{th} column of pessimistic aggregated matrix which can be calculated by using the following Equation.5.2

$$\mu_{ij} = \min(\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3 \ldots\ldots\ldots\ldots\ldots \mu_{ij}^k) \qquad \text{………...Eq. 5.2}$$

Here μ_{ij} = Membership value.

In $\mu_{ij}^1, \mu_{ij}^2, \mu_{ij}^3$

i & j are row and column respectively, and $1, 2, \ldots\ldots\ldots\ldots\ldots..k$, indicates the number of matrices formed.

Minimum value among all the values of each criterion is taken and formed as single matrix shown in Table 5.25, and $A_{65} = 0.35$ is calculated as shown below.

$A_{65} = \min$ of $[a_{65}^1, a_{65}^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, a_{65}^{10}]$

Here $a_{65}^1, a_{65}^2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, a_{65}^{10}$ are the minimum membership values of criteria against alternatives.

$$A_{65} = min\ [0.50, 0.45.0.45, 0.50, 0.50, 0.55, 0.95, 0.55, 0.35, 0.40] = 0.35.$$

So, minimum value is '0.35' among all the membership values and is positioned in the matrix, at 6th row of 5th column of the matrix, and remaining minimum membership values for all the criteria against alternatives are tabulated as pessimistic aggregated matrix as shown in Table 5.25

These membership values of the experts are combined into a single matrix using modified pessimistic aggregation for each criterion against the alternatives. Since pessimistic aggregation attempts to minimize the risk, while the modified pessimistic aggregation may prove to be useful to have a spectrum of polarized opinions of the experts.

The final aggregated membership values are from modified pessimistic aggregation, which is an average of arithmetic mean and pessimistic aggregation. Table 5.26 is the modified pessimistic aggregation table for the position matrices of various experts. These values are obtained by taking different membership values for the factors affecting material hoist selection by experts.

Table 5.26- Modified pessimistic matrix for Material Hoist

Criteria	modified pessimistic matrix				
	MH1	MH2	MH3	MH4	MH5
X1	0.93	0.85	0.33	0.88	0.46
X2	0.91	0.55	0.84	0.76	0.69
X3	0.90	0.58	0.27	0.08	0.26
X4	0.79	0.52	0.74	0.59	0.69
X5	0.89	0.72	0.59	0.53	0.56
X6	0.81	0.68	0.48	0.44	0.44
X7	0.86	0.65	0.39	0.71	0.55
X8	0.91	0.57	0.69	0.64	0.36
X9	0.84	0.60	0.30	0.14	0.50
X10	0.79	0.53	0.54	0.60	0.36

Table 5.27- Weighted matrix for Material Hoist

Criteria	Weighted matrix					WT
	MH1	MH2	MH3	MH4	MH5	
X1	0.09	0.08	0.03	0.09	0.05	0.10
X2	0.09	0.06	0.08	0.08	0.07	0.10
X3	0.09	0.06	0.03	0.01	0.03	0.10
X4	0.08	0.05	0.07	0.06	0.07	0.10
X5	0.09	0.07	0.06	0.05	0.06	0.10
X6	0.08	0.07	0.05	0.04	0.04	0.10
X7	0.09	0.06	0.04	0.07	0.05	0.10
X8	0.09	0.06	0.07	0.06	0.04	0.10
X9	0.08	0.06	0.03	0.01	0.05	0.10
X10	0.08	0.05	0.05	0.06	0.04	0.10

For example, membership value of ‘A15’ of modified pessimistic aggregation is obtained by using the following Equation 5.3

$$\mu_{ij} = \frac{1}{2}\{\mu_{ij}{}^{1} \ldots \ldots \mu_{ij}{}^{k} + \sum_{i=1}^{k} \mu_{ij}{}^{1} \ldots \ldots \sum_{i=1}^{k} \mu_{ij}{}^{k}\} \qquad \ldots\ldots\ldots 5.3$$

And, the procedure for obtaining the above membership value is as follows.

$A15$ = Average of every membership value of criteria against alternative of mean aggregated matrix and pessimistic aggregated matrix. .

So, $A15 = \{[a_{15}ma + a_{15}pa] / 2\}$,

Here $_{15}ma$, $a_{15}pa$ are membership values of criteria against alternative of 1st row of 5th column of mean aggregated matrix and pessimistic aggregated matrix respectively.

Here ma = Mean aggregation

pa = pessimistic aggregation

So, A15 = {[0.56 + 0.35] /2}

A15 = 0.46, and is tabulated in the modified pessimistic aggregated matrix Table 5.26, remaining aggregated membership values are also calculated in the same manner and are positioned in the above Table 5.26.

The membership values given for qualitative and quantitative factors are of equal importance. To overcome certain draw backs given by different experts, before evaluating the alternatives, weightages for each criteria has been introduced to get accuracy in selecting optimum alternative among available alternatives. And the weightages are assigned and is given in Table 5.27 and are tabulated as follows.

After identifying the weightages to be assigned to the membership values of features of available alternatives from the experts these weightages are multiply to each and every criteria from the Table 5.26 of modified pessimistic matrix and is placed in the following Table 5.27.

For example, weighted aggregated value of A_{23}, value of 2^{nd} row of 3^{srd} column 0.08 is calculated as (0.84×0.08), 0.08 is weight assigned to 0.84 which was taken from the Table 5.27. Accordingly, remaining values are also calculated by assigning weights in multiplication and placed in above Table 5.27 after forming the weighted matrix dominance matrix procedure is carried out to rank the alternatives for weighted values and is shown in Table 5.28.

Table 5.28 - Dominance matrix for Material Hoist

	MH1	MH2	MH3	MH4	MH5	**ROW SUM**				
MH1	#	0	0	0	0	0	#	#	#	#
MH2	10	#	3	5	2	20	10	#	#	#
MH3	10	6	#	3	3	22	12	6	#	#
MH4	9	4	6	#	4	23	14	10	4	#
MH5	10	8	4	5	#	27	17	9	5	0
COLUMN SUM	39	18	13	13	9					
	#	18	13	13	9					
	#	#	10	8	7					
	#	#	#	5	4					
	#	#	#	#	0					

In order to display the dominance structure between all possible pairs of material hoist and *N by N* matrix, called the Dominance Matrix (D) is constructed. The element d_{ij} is the number of features for which the membership value of material hoist j is greater than that of material hoist i. For example in weighted matrix as shown in Table 5.27 the element X_{14} indicates that how many times criteria of alternative 4 dominates on criteria of alternative 1 and is tabulated in dominance matrix at X_{14}.

The dimensionality N is equal to the number of material hoist under consideration. A hash (#) is entered in the diagonal cells as the dominance of a crane over itself does not make sense. If the j^{th} column is summed, the total number of dominances of material hoist j over all other material hoist is obtained. Similarly, if the i^{th} row is summed, the number of times the j^{th} material hoist is dominated by all other material hoist is obtained. The sums of columns and rows can be compared and from this one can see that most favorable outcomes have higher column sums and lower row sums.

Based on the above dominance matrix the best alternative is identified as follows:

1. Sum up all the column and row values.
2. Choose the column with highest value and low row totals to select the best material hoist.
3. If two alternatives column sums are same, choose the alternative with minimum row sum.
4. If sums of columns and rows are same, choose an alternative arbitrarily.
5. To choose the next best, delete the values of the best crane and repeat the procedure.

In the above table highest column sum is 39 and lowest row sum is 0 for the alternative MH1. Therefore, using dominance matrix the alternative MH1 is the best alternative and corresponding to SMH 200V. To choose the next best the values of these alternatives values are removed and the procedure is repeated. Using the dominance matrix following ranks sequence are obtain as shown in Table 5.29

Table 5.29 – Material Hoist sequence for selection from Dominance matrix

Alternatives	Model name	Dominance
MH1	SMH 200V	(39,0)
MH2	SMH 150V	(18,10)
MH3	SMH 120V	(10,6)
MH4	SMH 100V	(5,4)
MH5	SMH 50V	(0,0)

5.5.2 Optimum selection of Material Hoist by Fuzzy TOPSIS method.

The following Table 5.30 shows decision matrix of all the specification of all the models of material hoist which govern the selection of appropriate material hoist model where the criteria which are represented in red colours are cost attribute and those with green colours are benefits attribute. The reason it has been highlighted unlike previous method is because in this method we will decide optimization based on the distance from positive ideal and negative ideal solution where we need to look for high values of benefits attribute and low values of cost attributes.

Table 5.30 - Decision matrix for Material Hoist

Criteria	Material Hoist alternatives				
	MH1	MH2	MH3	MH4	MH5
X1	2	1.5	1.2	1	0.5
X2	150	120	120	100	70
X3	30	30	30	30	20
X4	18.2	14	10.4	10.4	2.7
X5	9	9	7	7	7
X6	9	9	9	9	7
X7	1	1	0.5	0.5	0.3
X8	7	6	5.5	5	4
X9	15	15	15	15	15
X10	30	30	25	25	20

The first step of the TOPSIS method involves the construction of a Decision Matrix (DM) as explain below.

$$DM = \begin{array}{c|cccc} & MH_1 & MH_2 & \cdots & MH_n \\ \hline X_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ = X_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ X_3 & \vdots & \vdots & \ddots & \\ X_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{array}$$

Where i the criterion index is $(i = 1 \ldots m)$; m is the number of potential criteria and j is the alternative index $(j = 1 \ldots . n)$; n is the number of alternatives. The elements $X_1, X_2 \ldots \ldots X_m$ refer to the criteria: while $MH_1, MH_2 \ldots \ldots MH_n$ refer to the alternative of material hoist. The elements of the matrix are related to the values of criteria i with respect to alternative j.

After developing the decision matrix, normalization matrix is develop using the Equation 5.4 given and explain below

For example, the normalization value of ‘ A_{71}’ in normalization matrix table 5.31 is obtained as follows, here ‘71’ indicates 7^{th} row of 1^{st} column of above matrix which is formed by using the following Equation 5.4.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \qquad \text{………..Eq. 5.4}$$

Here, r_{ij}=Normalisation value
m = number of material hoist alternatives
i = row
j= column

And, the procedure for obtaining the above value is as follows.

$$A_{71} = a_{71}\sqrt{[a_{71}^2 + \ a_{72}^2 + a_{73}^2 + a_{74}^2 + a_{75}^2]}.$$

Normalisation value of A_{71} = 0.621370

$a_{71} + a_{72} + a_{73} + a_{74} + a_{75}$ are the specification values of criteria against each alternative from decision matrix from Table 5.30. Now A_{71} is calculated as shown below:

$$A_{71} \ = \ 1\sqrt{[1^2 + \ 1^2 + \ 0.5^2 + \ 0.5^2 + \ 0.3^2\,]} = 0.621370$$

Table 5.31 – Normalisation Matrix for Material Hoist

Criteria	Normalization of matrix				
	MH1	MH2	MH3	MH4	MH5
X1	0.668900	0.501675	0.401340	0.334450	0.167225
X2	0.582992	0.466393	0.466393	0.388661	0.272063
X3	0.474342	0.474342	0.474342	0.474342	0.316228
X4	0.664194	0.510918	0.379539	0.379539	0.098534
X5	0.511992	0.511992	0.398216	0.398216	0.398216
X6	0.466002	0.466002	0.466002	0.466002	0.362446
X7	0.621370	0.621370	0.310685	0.310685	0.186411
X8	0.560000	0.480000	0.440000	0.400000	0.320000
X9	0.447214	0.447214	0.447214	0.447214	0.447214
X10	0.510754	0.510754	0.425628	0.425628	0.340503

And, is tabulated in the normalization matrix Table 5.31 at 7^{th} row of 1^{st} column. Remaining normalization values are also calculated in same manner and are positioned in the Table 5.31 of normalization matrix as shown above.

Not all of the selection criteria may be of equal importance and hence weighting was introduced to quantify the relative importance of the different selection criteria. The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights.

For example, membership value of 'A_{44}' of weighted matrix is obtained as follows, here '44' indicates 4^{th} row of 4^{th} column of weighted aggregated matrix which can be calculated by using the following Equation 5.5

$$v_{ij} = w_{ij} r_{ij} \quad \text{…….. Eq. 5.5}$$

Here, v_{ij}= Weighted matrix value
r_{ij}=Normalisation value
w = Assigned weight
i = row
j= column

And, the procedure for obtaining the above value is as follows.

$$A_{44} = w_{44} r_{44}$$

Weighted value of A_{54} =0.037954

$w_{44}$and r_{44} are the weightage and normalization values of criteria against each alternative from Table 5.32 and normalization matrix Table 5.31.

Now A_{44} is calculated as shown below:

$$A_{44} = 0.10 \times 0.379539 = 0.037954$$

And, is tabulated in the Table 5.32 at 4^{th} row of 4^{th} column.

Remaining normalization values are also calculated in same manner and are positioned in the Table 5.32 of optimum selection of material hoist by fuzzy TOPSIS method as shown below.

The positive ideal (A*) and the negative ideal (A-) solutions are defined according to the weighted decision matrix via equations where I is associated with the beneficial attributes and I' is associated with the non-beneficial attributes.

The positive ideal (A*) and the negative ideal (A-) solution value for criteria X1 is given by Equation 5.6 & Equation 5.7 and explain below

$$A^* = \{v_1^*, \dots \dots . v_n^*\} \quad \dots\dots\dots\dots\dots\dots \text{ Eq. 5.6}$$

$$A- = \{v_1^-, \dots \dots . v_n^-\} \quad \dots\dots\dots\dots\dots\dots \text{ Eq. 5.7}$$

Where: $v_i^* = \{\max(v_{ij}) if \in I; \min(v_{ij}) if \in I'$

$$v_i^- = \{\min(v_{ij}) if \in I; \text{maz}(v_{ij}) if \in I'$$

The procedure for obtaining the (A*) and (A-) value for criteria X3 above value is as follows:

$$v_1^* = \max\{0.06689; 0.050168; 0.040134; 0.033445; 0.016723\}=0.06689$$

$$v_1^- = \min\{0.06689; 0.050168; 0.040134; 0.033445; 0.016723\}=0.016723$$

Remaining normalization values are also calculated in same manner and are positioned in the Table no 5.32 as shown below:

Then we calculate the separation distance of each competitive alternative from the ideal and non-ideal solution which is given by the Equation 5.8 & Equation 5.9 given below

$$S_j^* = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^*\right)^2} \dots \dots 5.8 \qquad S_j^- = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_i^-\right)^2} \dots\dots 5.9$$

Here, S_j^*= Separation measure from positive ideal solution
S_j^-= Separation measure from negative ideal solution
v_i^*= Positive ideal solution
v_i^-= Negative ideal solution
i = row
j= column

Now S_2^* and S_2^- is calculated as shown below:

$$S_2^* = \sqrt{\begin{matrix}[0.050168-0.06689]^2+[0.046639-0.058299]^2+[0.047434-0.047434]^2 \\ +[0.051092-0.066419]^2+[0.051199-0.051199]^2+[0.0466-0.0466]^2 \\ +[0.062137-0.062137]^2+[0.048000-0.032]^2+[0.044721-0.044721]^2 \\ +[0.051075-0.051075]^2\end{matrix}}$$

$$= 0.03011$$

Similarly S_2^- is calculated, the only difference is here replaced v_i^* with v_i^-

$$S_2^- = \sqrt{\begin{matrix}[0.050168-0.016723]^2+[0.046639-0.027206]^2+[0.047434-0.031623]^2 \\ +[0.051092-0.009853]^2+[0.051199-0.039822]^2+[0.0466-0.036245]^2 \\ +[0.062137-0.018641]^2+[0.048000-0.056]^2+[0.044721-0.044721]^2 \\ +[0.051075-0.03405]^2\end{matrix}}$$

$$= 0.07700$$

Remaining separation measure values are also calculated in same manner and are positioned in the Table 5.32 of optimum selection of tower crane by fuzzy TOPSIS method as shown below.

For each competitive alternative the relative closeness of the potential criteria with respect to the ideal solution is computed by the Equation 5.10 given below:

$$C_j^* = \frac{S_j^-}{S_j^* + S_j^-} \qquad \text{......Eq. 5.10}$$

Here, C_j^*= Relative closeness
S_j^*= Separation measure from positive ideal solution
S_j^-= Separation measure from negative ideal solution

Now C_4^* is calculated as shown below:

$$C_4^* = \left[\frac{0.04523}{0.05948+0.04523}\right] = 0.43194$$

Remaining relative closeness values are also calculated in same manner and are positioned in the Table 5.32 as shown below.

Table 5.32 - Optimum selection of Material Hoist by Fuzzy TOPSIS method

weightage	Criteria	Material Hoist alternatives					Positive ideal solution	Negative ideal solution
		MH1	MH2	MH3	MH4	MH5	A*	A-
0.10	X1	0.06689	0.050168	0.040134	0.033445	0.016723	0.06689	0.016723
0.10	X2	0.058299	0.046639	0.046639	0.038866	0.027206	0.058299	0.027206
0.10	X3	0.047434	0.047434	0.047434	0.047434	0.031623	0.047434	0.031623
0.10	X4	0.066419	0.051092	0.037954	0.037954	0.009853	0.066419	0.009853
0.10	X5	0.051199	0.051199	0.039822	0.039822	0.039822	0.051199	0.039822
0.10	X6	0.0466	0.0466	0.0466	0.0466	0.036245	0.0466	0.036245
0.10	X7	0.062137	0.062137	0.031068	0.031068	0.018641	0.062137	0.018641
0.10	X8	0.056000	0.048000	0.044000	0.040000	0.032000	0.032	0.056
0.10	X9	0.044721	0.044721	0.044721	0.044721	0.044721	0.044721	0.044721
0.10	X10	0.051075	0.051075	0.042563	0.042563	0.03405	0.051075	0.03405
Separation measure	s1*	0.02400	0.03011	0.05453	0.05948	0.09670		
	s1-	0.09670	0.07700	0.04943	0.04523	0.02400		
Relative closeness		C1*	C2*	C3*	C4*	C5*		
		0.80117	0.71890	0.47549	0.43194	0.19883		

According to the value of Ci the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared as tabulated in Table 5.33 below.

Table 5.33 – Material Hoist sequence for selection from Fuzzy TOPSIS

Alternatives	**Model name**	**Relative closeness(C^*)**
MH1	SMH 200V	0.80117
MH2	SMH 150V	0.71890
MH3	SMH 120V	0.47549
MH4	SMH 100V	0.43194
MH5	SMH 50V	0.19883

5.5.3 Optimum selection of Material Hoist by SDI Tool-Triptych (Software)

In Figure 5.6, Workspace of the SDI tool is shown which is based on the fuzzy TOPSIS technique. In which third column are the criteria on which the selection of material hoist depends followed by its units, in fourth column we have to assign the weightage to each criteria depending upon decision maker priorities and preferences

				Options							
				1	2	3	4	5			
Criteria:		Units	Importance	SMH 200V	SMH 150V	SMH 120V	SMH 100V	SMH 50V	Goal	- Ideal	+ Ideal
1	CAPACITY	Ton	0.1	2	1.5	1.2	1	0.5	maximize	0.5	2
2	MAX HEIGHT	meters	0.1	150	120	120	100	70	maximize	70	150
3	SPEED	M/MIN	0.1	30	30	30	30	20	maximize	20	30
4	MOTOR CAPACITY	(KW	0.1	18.2	14	10.4	10.4	2.7	maximize	2.7	18.2
5	SAFETY DEVICE	-	0.1	7	7	9	9	9	maximize	7	9
6	CAGE SIZE	meter	0.1	9	9	9	9	7	maximize	7	9
7	REBAR CARRYING CAPACITY	Ton	0.1	1	1	0.5	0.5	0.3	maximize	0.3	1
8	PURCHASE PRICE	RS	0.1	5	5.5	6	6.2	7	minimize	7	5
9	MAINTAINENCE COST/MONTHLY	RS	0.1	15	15	15	15	15	minimize	15	15
10	MACHINE LIFE	Years	0.1	30	30	30	35	35	maximize	30	35
			Score	0.88	0.72	0.48	0.43	0.12			

Fig. 5.6-Optimum selection of Material Hoist in SDI tool

Further all the parameters value is assign and goal are given to each criteria for e.g. the quantity and capacity criteria are best when they are maximum and cost criteria's are best when they are minimum. After the input sheet is completed the tool automatically calculate the negative ideal solution (-IDEAL) and positive ideal solution (+IDEAL) as shown in Figure 5.7. Score indicates the relative closeness of positive ideal solution to negative ideal solution on which the final ranking is obtain.

5.6 Summary

This chapters describes the various statistical analysis carried out and the various findings based on the survey.

Chapter 6

Results and Discussions

6.1 General

Optimum selection of equipment for construction projects generally involves tangible, quantitative, intangible, qualitative factors. Random examples include safety considerations, company policies regarding purchase and rental, market fluctuations, and environmental constraints. The research work considers intuition, uncertainty, and the subjectivity that are rooted in construction decision making and identifies an organized set of criteria for the selection of machineries based on artificial intelligence approach. This study has attempted to raise the issue of soft considerations in the selection of machineries in construction industry to increase awareness to their nature, variety, and richness for evaluating and integrating them within a comprehensive selection process. Selecting the “right” machine is usually crucial for the success of any project.

6.2 Result comparison of Tower Crane

Sequence ranking for tower crane obtain from all the three methods with values and are tabulated below in the Table 6.1. The models of tower crane has been arrange in descending order following the score obtain from different methods.

Table 6.1- Result comparison for Tower crane

Models	Fuzzy MADM	Fuzzy TOPSIS	SDI
STC-6010	(60,0)	0.65318	0.65
STC-5512	(31,13)	0.59249	0.61
STC-5013	(20,10)	0.46942	0.48
STC-4010	(9,6)	0.33968	0.34
STC-5010	(0,0)	0.32591	0.32

The comparison of Sequence ranking obtains from all the three methods namely Fuzzy MADM, Fuzzy TOPSIS and SDI Tool are shown in Table 6.1. Although the techniques used is based on different approaches but the ranking obtain from each of them is same.

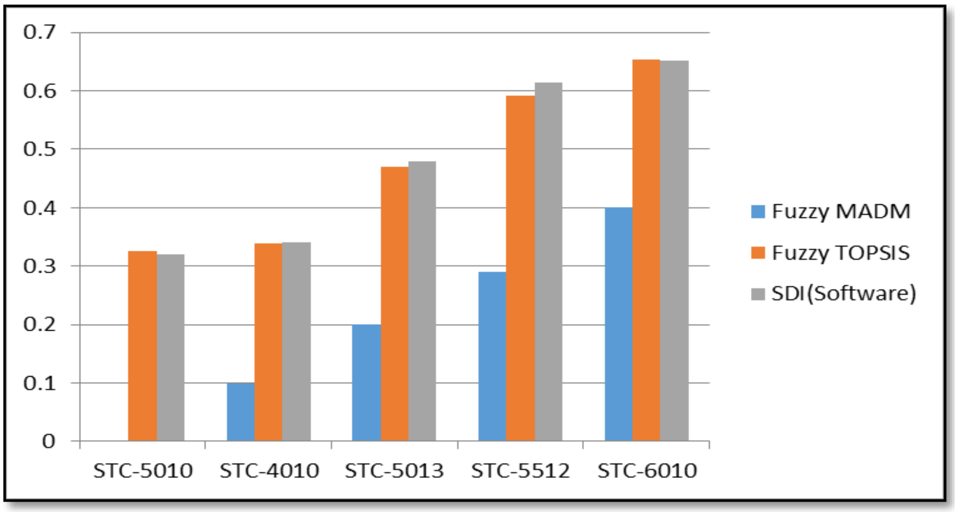

Figure- 6.1 Graphical representation of result comparison for Tower crane

In Graphical Representation Figure 6.1 it is observed that the final values obtain from SDI tool and Fuzzy TOPSIS is almost similar but the final values obtain from Fuzzy MADM is very less throughout though the sequence obtain is same from all the three techniques.

6.3 Result comparison of Concrete Pump

Sequence ranking for concrete pump obtain from all the three methods with values and are tabulated below in the Table 6.2. The models of concrete pump has been arrange in descending order following the score obtain from different methods.

Table 6.2- Result comparison for Concrete Pump

Models	Fuzzy MADM	Fuzzy TOPSIS	SDI
SP 8800	(52,0)	0.778062	0.781831
SP 2800	(27,11)	0.678381	0.699642
SP 500	(17,9)	0.333532	0.339148
BPN 300	(7,6)	0.270712	0.265341
SP305	(0,0)	0.226399	0.236904

The comparison of Sequence ranking obtain from all the three methods namely Fuzzy MADM, Fuzzy TOPSIS and SDI Tool are shown in Table 6.2. Although the techniques used is based on different approaches but the ranking obtain from each of them is same.

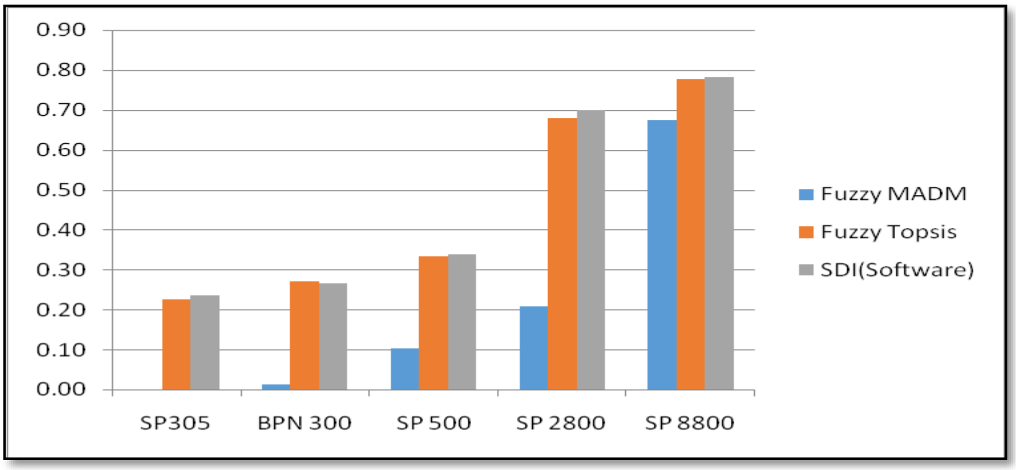

Fig. 6.2 Graphical representation of result comparison for Concrete pump

In Graphical Representation Figure 6.2 it is observed that the final values obtain from SDI tool and Fuzzy TOPSIS is almost similar but the final values obtain from Fuzzy MADM is very less throughout though the sequence obtain is same from all the three techniques.

6.4 Result comparison of Material Hoist

Sequence ranking for material hoist obtain from all the three methods with values and are tabulated below in the Table 6.3. The models of material hoist has been arrange in descending order following the score obtain from different methods.

Table 6.3- Result comparison for Material Hoist

Models	Fuzzy MADM	Fuzzy TOPSIS	SDI
SMH 200V	(0,0)	0.801167	0.88138
SMH 150V	(6,4)	0.718901	0.721479
SMH 120V	(14,6)	0.475491	0.483833
SMH 100V	(18,12)	0.43194	0.43069
SMH 50V	(40,0)	0.198833	0.11862

The comparison of Sequence ranking obtains from all the three methods namely Fuzzy MADM, Fuzzy TOPSIS and SDI Tool are shown in Table 6.3. Although the techniques used is based on different approaches but the ranking obtain from each of them is same.

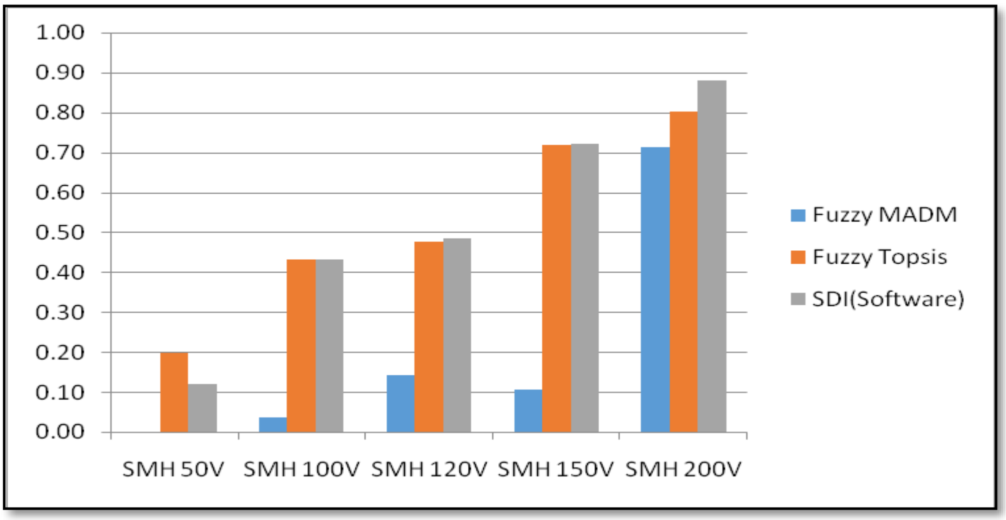

Fig. 6.3 Graphical representation of result comparison for Material Hoist

In Graphical Representation Figure 6.3 it is observed that the final values obtain from SDI tool and Fuzzy TOPSIS is almost similar but the final values obtain from Fuzzy MADM is very less throughout though the sequence obtain is same from all the three techniques.

6.5 Summary

Lifting, hoisting and placing concrete is an important task in construction industry. Due to the diverse needs of construction industry various machines are available for implementation in the industry such as tower crane, whirler, portable concrete placing boom and many others. The selection of appropriate machine plays a vital role for the cost and safety of construction personnel. Based on the available data and machine information the important criteria is identified and optimum machine is selected. The criteria applied are numerous and are subjective and difficult to quantify. The expert's subjective knowledge is converted into numerical measures and used to select the alternatives using different MCDM method such as fuzzy MADM, Fuzzy TOPSIS and MCDM based software

Chapter 7

Conclusions

7.1 General

On large construction projects several machine undertake many major tasks and dominate the site as significant and central working equipment. They are used for various tasks like excavating, pile driving, lifting hoisting, concrete placing, and concrete demolition and undertake the projects, mainly buildings such as public, private, commercial and industrial. High raised buildings, congested sites, and non-supportive terrains, necessitates and invites the right choice of cranes and other machineries for economic reasons. Planning culture, operating style, contracting policy, and market organizations as well as wide common denominator of whole project population are inseparable from the physical and organizational features of each particular project. Project homogeneity, environmental characteristics, availability and technical support, supporting terrain, and other characteristics are studied in this case study for selecting an optimum machine for its implementation. Various conventional decision making methods, commonly used by engineering and construction firms, address mainly the technical aspects of machine location and work planning but none of them accommodates the consideration of soft factors. These models provide no structured, comprehensive method that allows the systematic treatment of soft considerations.

7.2 Conclusion

1. Tower Crane Model STC-6010 is most dominating in all criteria followed by STC-5512, STC-5013, STC-4010 and STC-5010 from all the techniques used in the study.
2. Concrete Pump Model SP-8800 is most dominating in all criteria followed by SP-2800, SP-500, BPN-30 and SP-305 from all the techniques used in the study.
3. Material Hoist model SMH-200V is most dominating in all criteria followed by SMH-150V, SMH-120V, SMH-100V and SMH-50V from all the techniques used in the study.
4. Artificial Intelligence approach provides several valuable tools for representing and appropriately manipulating qualitative and linguistic information in a wide range of construction activities and their associated complexities encountered in the present day construction management practices.
5. In the conventional relationship on the communication and incorporation of the effects of qualitative factors the fact remains that these are retained only with the experts who may have intuition on them. On the other hand, the evaluation of the Artificial Intelligence approach dealt in the present study highlights explicit communication.
6. In the traditional analysis a difference of opinion, bias or prejudice that may be present can pose problems affecting the particular decision making process whereas since Artificial Intelligence approach incorporates qualitative factors, and the ill factors are easily eliminated. There is no doubt that many real life problems can be dealt with as MCDM problems. Although the mathematical procedures for processing the pertinent data are rather simple, the real challenge is in quantifying these data.
7. This case study revealed that the consideration of soft factors in current practices is essentially unstructured and is not integrated within the selection process in a systematic manner.
8. Uncertain data in terms of linguistic variables was incorporated for solving multiple attribute problems in a fuzzy environment.

9. The fuzzy dominance method considered relevant criteria for fuzzy multiple attribute decision making along with weights. Thus, selection results derived from fuzzy multiple attribute decision making methods are comparatively more significant than those obtained by other decision making methods.

7.3 Summary

From the detailed discussion of the results as mentioned in Chapter 6, the conclusions pointed out in the afore-mentioned section and from some of the findings emerged from the present investigation, it can be concluded that the improper selection of machineries lead to many direct and indirect cost which cut down the profits of the project and sometimes even create delay and fatal accident. An optimum selected machines serves the organisation in every single manner whether it may be good productivity or it may be low Maintenance cost.

7.4 Future Scope

The present investigation study was confined to only three construction machinery. This investigation can be extended in future to incorporate some of the following aspects which have not been covered in the present study:

1. Other construction industry machineries like Concrete placing boom, Mivan shuttering, Mobile cranes etc. can be undertaken for the optimum selection.
2. Qualitative criteria’s like site condition, safety, suitability, acquisition, difficulty etc. can be consider for the research as fuzzy logic gives the freedom to have linguistic variables.
3. Other techniques like Simple additive weighting method (SAW), Multi-attribute utility theory (MAUT), VIKOR and analytical hierarchy process (AHP) can also be adopted for the optimum selection.
4. Microsoft excel extension tool can we developed for solving all MADM method incorporating fuzzy techniques.
5. Case study on the methods used on site for selection of machinery can be done and this systematic and effective approach can be recommended where improper selection of machineries is done.

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APPENDIX-I

Table 1- Position Matrix of an expert no.1 for Tower Crane

Criteria	Expert 1				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.35	0.35	0.9	0.9
X2	0.8	0.9	0.9	0.6	0.9
X3	0.1	0.3	0.3	0.6	0.9
X4	0.6	0.7	0.7	0.5	0.8
X5	0.5	0.6	0.6	0.7	0.9
X6	0.4	0.5	0.5	0.7	0.8
X7	0.9	0.9	0.35	0.9	0.9
X8	0.8	0.6	0.9	0.6	0.9
X9	0.1	0.6	0.3	0.6	0.9
X10	0.6	0.5	0.7	0.5	0.8
X11	0.5	0.7	0.6	0.7	0.9
X12	0.4	0.7	0.5	0.7	0.8
X13	0.4	0.7	0.5	0.7	0.8
X14	0.4	0.5	0.5	0.7	0.8
X15	0.9	0.9	0.35	0.9	0.9

Table 2 - Position Matrix of an expert no.2 for Tower Crane

Criteria	Expert 2				
	TC1	TC2	TC3	TC4	TC5
X1	0.85	0.4	0.4	0.85	0.9
X2	0.75	0.8	0.8	0.65	0.9
X3	0.1	0.25	0.25	0.55	0.9
X4	0.55	0.75	0.75	0.5	0.75
X5	0.5	0.55	0.55	0.75	0.85
X6	0.45	0.45	0.45	0.65	0.85
X7	0.85	0.4	0.4	0.85	0.9
X8	0.75	0.85	0.7	0.65	0.9
X9	0.1	0.75	0.25	0.55	0.9
X10	0.55	0.1	0.75	0.5	0.75
X11	0.5	0.55	0.55	0.75	0.85
X12	0.45	0.5	0.45	0.65	0.85
X13	0.1	0.45	0.25	0.55	0.9
X14	0.45	0.45	0.45	0.65	0.85
X15	0.85	0.4	0.4	0.85	0.9

Table 3- Position Matrix of an expert no.3 for Tower Crane

Criteria	Expert 3				
	TC1	TC2	TC3	TC4	TC5
X1	0.85	0.35	0.35	0.95	1
X2	0.7	0.9	0.9	0.65	0.95
X3	0.15	0.25	0.25	0.6	0.9
X4	0.55	0.8	0.8	0.55	0.8
X5	0.6	0.6	0.6	0.75	1
X6	0.5	0.45	0.45	0.7	0.85
X7	0.85	0.35	0.35	0.95	1
X8	0.7	0.95	0.9	0.65	0.95
X9	0.15	0.65	0.25	0.6	0.9
X10	0.55	0.6	0.8	0.55	0.8
X11	0.6	0.55	0.6	0.75	1
X12	0.5	0.75	0.45	0.7	0.85
X13	0.15	0.7	0.25	0.6	0.9
X14	0.5	0.45	0.45	0.7	0.85
X15	0.85	0.35	0.35	0.95	1

Table 4- Position Matrix of an expert no.4 for Tower Crane

Criteria	Expert 4				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.4	0.4	0.9	0.95
X2	0.85	0.8	0.8	0.55	0.95
X3	0.1	0.3	0.3	0.6	0.9
X4	0.6	0.75	0.75	0.55	0.85
X5	0.55	0.65	0.65	0.75	1
X6	0.45	0.5	0.5	0.7	0.8
X7	0.9	0.9	0.4	0.9	0.95
X8	0.85	0.55	0.8	0.55	0.95
X9	0.1	0.6	0.3	0.6	0.9
X10	0.6	0.55	0.75	0.55	0.85
X11	0.55	0.75	0.65	0.75	1
X12	0.45	0.7	0.5	0.7	0.8
X13	0.9	0.9	0.4	0.9	0.95
X14	0.45	0.5	0.5	0.7	0.8
X15	0.9	0.9	0.4	0.9	0.95

Table 5- Position Matrix of an expert no.5 for Tower Crane

Criteria	Expert 5				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.9	0.3	0.9	1
X2	0.8	0.8	0.85	0.6	0.9
X3	0.15	0.15	0.3	0.6	0.9
X4	0.65	0.65	0.85	0.55	0.85
X5	0.5	0.5	0.65	0.8	0.95
X6	0.5	0.5	0.5	0.75	0.8
X7	0.9	0.9	0.3	0.9	1
X8	0.8	1	0.85	0.6	0.9
X9	0.15	0.9	0.3	0.6	0.9
X10	0.65	0.9	0.85	0.55	0.85
X11	0.5	0.85	0.65	0.8	0.95
X12	0.5	0.95	0.5	0.75	0.8
X13	0.5	0.8	0.5	0.75	0.8
X14	0.5	0.5	0.5	0.75	0.8
X15	0.9	0.9	0.3	0.9	1

Table 6- Position Matrix of an expert no.6 for Tower Crane

Criteria	Expert 6				
	TC1	TC2	TC3	TC4	TC5
X1	0.95	0.35	0.35	0.95	0.9
X2	0.85	0.9	0.9	0.65	0.9
X3	0.1	0.3	0.3	0.6	0.9
X4	0.7	0.8	0.8	0.5	0.8
X5	0.55	0.7	0.7	0.75	0.95
X6	0.5	0.55	0.55	0.75	0.85
X7	0.95	0.95	0.35	0.95	0.9
X8	0.85	0.65	0.9	0.65	0.9
X9	0.1	0.6	0.3	0.6	0.9
X10	0.7	0.5	0.8	0.5	0.8
X11	0.55	0.75	0.7	0.75	0.95
X12	0.5	0.75	0.55	0.75	0.85
X13	0.55	0.95	0.7	0.75	0.95
X14	0.5	0.55	0.55	0.75	0.85
X15	0.95	0.95	0.35	0.95	0.9

Table 7- Position Matrix of an expert no.7 for Tower Crane

Criteria	Expert 7				
	TC1	TC2	TC3	TC4	TC5
X1	0.95	0.95	0.35	0.85	0.95
X2	0.8	0.9	0.9	0.5	0.9
X3	0.05	0.9	0.25	0.65	0.9
X4	0.6	0.8	0.8	0.55	0.8
X5	0.6	0.9	0.65	0.7	0.9
X6	0.55	0.95	0.5	0.75	0.85
X7	0.95	0.8	0.35	0.85	0.95
X8	0.8	0.05	0.9	0.5	0.9
X9	0.05	0.6	0.25	0.65	0.9
X10	0.6	0.6	0.8	0.55	0.8
X11	0.6	0.55	0.65	0.7	0.9
X12	0.55	0.95	0.5	0.75	0.85
X13	0.55	0.8	0.5	0.75	0.85
X14	0.55	0.95	0.5	0.75	0.85
X15	0.95	0.8	0.35	0.85	0.95

Table 8- Position Matrix of an expert no.8 for Tower Crane

Criteria	Expert 8				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.4	0.4	0.8	1
X2	0.85	0.95	0.95	0.55	0.9
X3	0.05	0.3	0.3	0.6	0.9
X4	0.65	0.75	0.75	0.5	0.85
X5	0.6	0.6	0.6	0.75	0.95
X6	0.6	0.55	0.55	0.75	0.8
X7	0.6	0.8	0.8	0.55	0.8
X8	0.6	0.9	0.65	0.7	0.9
X9	0.55	0.95	0.5	0.75	0.85
X10	0.95	0.8	0.35	0.85	0.95
X11	0.8	0.05	0.9	0.5	0.9
X12	0.05	0.6	0.25	0.65	0.9
X13	0.6	0.6	0.8	0.55	0.8
X14	0.6	0.55	0.55	0.75	0.8
X15	0.6	0.8	0.8	0.55	0.8

Table 9- Position Matrix of an expert no.9 for Tower Crane

Criteria	Expert 9				
	TC1	TC2	TC3	TC4	TC5
X1	0.95	0.6	0.3	0.9	1
X2	0.85	0.55	0.9	0.65	0.95
X3	0.15	0.8	0.25	0.6	0.95
X4	0.65	0.65	0.75	0.55	0.85
X5	0.55	0.5	0.6	0.75	0.95
X6	0.45	0.35	0.5	0.7	0.8
X7	0.65	0.75	0.75	0.5	0.85
X8	0.6	0.6	0.6	0.75	0.95
X9	0.6	0.55	0.55	0.75	0.8
X10	0.6	0.8	0.8	0.55	0.8
X11	0.6	0.9	0.65	0.7	0.9
X12	0.55	0.95	0.5	0.75	0.85
X13	0.95	0.8	0.35	0.85	0.95
X14	0.45	0.35	0.5	0.7	0.8
X15	0.65	0.75	0.75	0.5	0.85

Table 10- Position Matrix of an expert no.10 for Tower Crane

Criteria	Expert 10				
	TC1	TC2	TC3	TC4	TC5
X1	0.9	0.9	0.35	0.9	1
X2	0.85	0.85	0.95	0.65	0.95
X3	0.15	0.15	0.35	0.6	0.9
X4	0.65	0.65	0.75	0.55	0.85
X5	0.55	0.55	0.6	0.75	0.9
X6	0.4	0.4	0.55	0.7	0.8
X7	0.65	0.65	0.75	0.55	0.85
X8	0.55	0.5	0.6	0.75	0.95
X9	0.45	0.35	0.5	0.7	0.8
X10	0.65	0.75	0.75	0.5	0.85
X11	0.6	0.6	0.6	0.75	0.95
X12	0.6	0.55	0.55	0.75	0.8
X13	0.6	0.8	0.8	0.55	0.8
X14	0.4	0.4	0.55	0.7	0.8
X15	0.65	0.65	0.75	0.55	0.85

APPENDIX-II

Table 1- Position Matrix of an expert no.1 for Material Hoist

Criteri a	Expert 1				
	MH	MH	MH	MH	MH
X1	0.9	0.9	0.35	0.9	0.35
X2	0.9	0.6	0.9	0.8	0.9
X3	0.9	0.6	0.3	0.1	0.3
X4	0.8	0.5	0.7	0.6	0.7
X5	0.9	0.7	0.6	0.5	0.6
X6	0.8	0.7	0.5	0.4	0.5
X7	0.9	0.9	0.35	0.9	0.9
X8	0.9	0.6	0.9	0.8	0.6
X9	0.9	0.6	0.3	0.1	0.6
X10	0.8	0.5	0.7	0.6	0.5

Table 2- Position Matrix of an expert no.2 for Material Hoist

Criteri a	Expert 2				
	MH	MH	MH	MH	MH
X1	0.9	0.85	0.4	0.85	0.4
X2	0.9	0.65	0.8	0.75	0.8
X3	0.9	0.55	0.25	0.1	0.25
X4	0.75	0.5	0.75	0.55	0.75
X5	0.85	0.75	0.55	0.5	0.55
X6	0.85	0.65	0.45	0.45	0.45
X7	0.9	0.85	0.4	0.85	0.4
X8	0.9	0.65	0.7	0.75	0.85
X9	0.9	0.55	0.25	0.1	0.75
X10	0.75	0.5	0.75	0.55	0.1

Table 3- Position Matrix of an expert no.3 for Material Hoist

Criteria	Expert 3				
	MH1	MH2	MH3	MH4	MH5
X1	1	0.95	0.35	0.85	0.35
X2	0.95	0.65	0.9	0.7	0.9
X3	0.9	0.6	0.25	0.15	0.25
X4	0.8	0.55	0.8	0.55	0.8
X5	1	0.75	0.6	0.6	0.6
X6	0.85	0.7	0.45	0.5	0.45
X7	1	0.95	0.35	0.85	0.35
X8	0.95	0.65	0.9	0.7	0.95
X9	0.9	0.6	0.25	0.15	0.65
X10	0.8	0.55	0.8	0.55	0.6

Table 4- Position Matrix of an expert no.4 for Material Hoist

Criteria	Expert 4				
	MH1	MH2	MH3	MH4	MH5
X1	0.95	0.9	0.4	0.9	0.4
X2	0.95	0.55	0.8	0.85	0.8
X3	0.9	0.6	0.3	0.1	0.3
X4	0.85	0.55	0.75	0.6	0.75
X5	1	0.75	0.65	0.55	0.65
X6	0.8	0.7	0.5	0.45	0.5
X7	0.95	0.9	0.4	0.9	0.9
X8	0.95	0.55	0.8	0.85	0.55
X9	0.9	0.6	0.3	0.1	0.6
X10	0.85	0.55	0.75	0.6	0.55

Table 5- Position Matrix of an expert no.5 for Material Hoist

Criteria	Expert 5				
	MH1	MH2	MH3	MH4	MH5
X1	1	0.9	0.3	0.9	0.9
X2	0.9	0.6	0.85	0.8	0.8
X3	0.9	0.6	0.3	0.15	0.15
X4	0.85	0.55	0.85	0.65	0.65
X5	0.95	0.8	0.65	0.5	0.5

Table 6- Position Matrix of an expert no.6 for Material Hoist

Criteria	Expert 6				
	MH1	MH2	MH3	MH4	MH5
X1	0.9	0.95	0.35	0.95	0.35
X2	0.9	0.65	0.9	0.85	0.9
X3	0.9	0.6	0.3	0.1	0.3
X4	0.8	0.5	0.8	0.7	0.8
X5	0.95	0.75	0.7	0.55	0.7

X6	0.8	0.75	0.5	0.5	0.5
X7	1	0.9	0.3	0.9	0.9
X8	0.9	0.6	0.85	0.8	1
X9	0.9	0.6	0.3	0.15	0.9
X10	0.85	0.55	0.85	0.65	0.9

X6	0.85	0.75	0.55	0.5	0.55
X7	0.9	0.95	0.35	0.95	0.95
X8	0.9	0.65	0.9	0.85	0.65
X9	0.9	0.6	0.3	0.1	0.6
X10	0.8	0.5	0.8	0.7	0.5

Table 7- Position Matrix of an expert no.7 for Material Hoist

Criteria	Expert 7				
	MH1	MH2	MH3	MH4	MH5
X1	0.95	0.85	0.35	0.95	0.95
X2	0.9	0.5	0.9	0.8	0.9
X3	0.9	0.65	0.25	0.05	0.9
X4	0.8	0.55	0.8	0.6	0.8
X5	0.9	0.7	0.65	0.6	0.9
X6	0.85	0.75	0.5	0.55	0.95
X7	0.95	0.85	0.35	0.95	0.8
X8	0.9	0.5	0.9	0.8	0.05
X9	0.9	0.65	0.25	0.05	0.6
X10	0.8	0.55	0.8	0.6	0.6

Table 8- Position Matrix of an expert no.8 for Material Hoist

Criteria	Expert 8				
	MH1	MH2	MH3	MH4	MH5
X1	1	0.8	0.4	0.9	0.4
X2	0.9	0.55	0.95	0.85	0.95
X3	0.9	0.6	0.3	0.05	0.3
X4	0.85	0.5	0.75	0.65	0.75
X5	0.95	0.75	0.6	0.6	0.6
X6	0.8	0.75	0.55	0.6	0.55
X7	0.8	0.55	0.8	0.6	0.8
X8	0.9	0.7	0.65	0.6	0.9
X9	0.85	0.75	0.5	0.55	0.95
X10	0.95	0.85	0.35	0.95	0.8

Table 9- Position Matrix of an expert no.9 for Material Hoist

Criteria	Expert 9				
	MH1	MH2	MH3	MH4	MH5
X1	1	0.9	0.3	0.95	0.6
X2	0.95	0.65	0.9	0.85	0.55
X3	0.95	0.6	0.25	0.15	0.8
X4	0.85	0.55	0.75	0.65	0.65
X5	0.95	0.75	0.6	0.55	0.5
X6	0.8	0.7	0.5	0.45	0.35
X7	0.85	0.5	0.75	0.65	0.75
X8	0.95	0.75	0.6	0.6	0.6
X9	0.8	0.75	0.55	0.6	0.55
X10	0.8	0.55	0.8	0.6	0.8

Table 10- Position Matrix of an expert no.10 for Material Hoist

Criteria	Expert 10				
	MH1	MH2	MH3	MH4	MH5
X1	1	0.9	0.35	0.9	0.9
X2	0.95	0.65	0.95	0.85	0.85
X3	0.9	0.6	0.35	0.15	0.15
X4	0.85	0.55	0.75	0.65	0.65
X5	0.9	0.75	0.6	0.55	0.55
X6	0.8	0.7	0.55	0.4	0.4
X7	0.85	0.55	0.75	0.65	0.65
X8	0.95	0.75	0.6	0.55	0.5
X9	0.8	0.7	0.5	0.45	0.35
X10	0.85	0.5	0.75	0.65	0.75

APPENDIX-III

Table 1 - Position Matrix of an expert no.1 for Concrete Pump

Criteria	Expert 1				
	CP1	CP2	CP3	CP4	CP5
X1	0.35	0.9	0.35	0.9	0.9
X2	0.9	0.8	0.9	0.6	0.9
X3	0.3	0.1	0.3	0.6	0.9
X4	0.7	0.6	0.7	0.5	0.8
X5	0.6	0.5	0.6	0.7	0.9
X6	0.5	0.4	0.5	0.7	0.8
X7	0.9	0.9	0.35	0.9	0.9
X8	0.6	0.8	0.9	0.6	0.9
X9	0.6	0.1	0.3	0.6	0.9
X10	0.5	0.6	0.7	0.5	0.8
X11	0.7	0.5	0.6	0.7	0.9
X12	0.7	0.4	0.5	0.7	0.8
X13	0.7	0.4	0.5	0.7	0.8

Table 2- Position Matrix of an expert no.2 for Concrete Pump

Criteria	Expert 2				
	CP1	CP2	CP3	CP4	CP5
X1	0.4	0.85	0.4	0.85	0.9
X2	0.8	0.75	0.8	0.65	0.9
X3	0.25	0.1	0.25	0.55	0.9
X4	0.75	0.55	0.75	0.5	0.75
X5	0.55	0.5	0.55	0.75	0.85
X6	0.45	0.45	0.45	0.65	0.85
X7	0.4	0.85	0.4	0.85	0.9
X8	0.85	0.75	0.7	0.65	0.9
X9	0.75	0.1	0.25	0.55	0.9
X10	0.1	0.55	0.75	0.5	0.75
X11	0.55	0.5	0.55	0.75	0.85
X12	0.5	0.45	0.45	0.65	0.85
X13	0.45	0.1	0.25	0.55	0.9

Table 3- Position Matrix of an expert no.3 for Concrete Pump

Criteria	Expert 3				
	CP1	CP2	CP3	CP4	CP5
X1	0.35	0.85	0.35	0.95	1
X2	0.9	0.7	0.9	0.65	0.95
X3	0.25	0.15	0.25	0.6	0.9
X4	0.8	0.55	0.8	0.55	0.8
X5	0.6	0.6	0.6	0.75	1
X6	0.45	0.5	0.45	0.7	0.85
X7	0.35	0.85	0.35	0.95	1
X8	0.95	0.7	0.9	0.65	0.95
X9	0.65	0.15	0.25	0.6	0.9
X10	0.6	0.55	0.8	0.55	0.8
X11	0.55	0.6	0.6	0.75	1
X12	0.75	0.5	0.45	0.7	0.85
X13	0.7	0.15	0.25	0.6	0.9

Table 4- Position Matrix of an expert no.4 for Concrete Pump

Criteria	Expert 4				
	CP1	CP2	CP3	CP4	CP5
X1	0.4	0.9	0.4	0.9	0.95
X2	0.8	0.85	0.8	0.55	0.95
X3	0.3	0.1	0.3	0.6	0.9
X4	0.75	0.6	0.75	0.55	0.85
X5	0.65	0.55	0.65	0.75	1
X6	0.5	0.45	0.5	0.7	0.8
X7	0.9	0.9	0.4	0.9	0.95
X8	0.55	0.85	0.8	0.55	0.95
X9	0.6	0.1	0.3	0.6	0.9
X10	0.55	0.6	0.75	0.55	0.85
X11	0.75	0.55	0.65	0.75	1
X12	0.7	0.45	0.5	0.7	0.8
X13	0.9	0.9	0.4	0.9	0.95

Table 5- Position Matrix of an expert no.5 for Concrete Pump

Criteria	Expert 5				
	CP1	CP2	CP3	CP4	CP5
X1	0.9	0.9	0.3	0.9	1

Table 6- Position Matrix of an expert no.6 for Concrete Pump

Criteria	Expert 6				
	CP1	CP2	CP3	CP4	CP5
X1	0.35	0.95	0.35	0.95	0.9

X2	0.8	0.8	0.85	0.6	0.9
X3	0.15	0.15	0.3	0.6	0.9
X4	0.65	0.65	0.85	0.55	0.85
X5	0.5	0.5	0.65	0.8	0.95
X6	0.5	0.5	0.5	0.75	0.8
X7	0.9	0.9	0.3	0.9	1
X8	1	0.8	0.85	0.6	0.9
X9	0.9	0.15	0.3	0.6	0.9
X10	0.9	0.65	0.85	0.55	0.85
X11	0.85	0.5	0.65	0.8	0.95
X12	0.95	0.5	0.5	0.75	0.8
X13	0.8	0.5	0.5	0.75	0.8

X2	0.9	0.85	0.9	0.65	0.9
X3	0.3	0.1	0.3	0.6	0.9
X4	0.8	0.7	0.8	0.5	0.8
X5	0.7	0.55	0.7	0.75	0.95
X6	0.55	0.5	0.55	0.75	0.85
X7	0.95	0.95	0.35	0.95	0.9
X8	0.65	0.85	0.9	0.65	0.9
X9	0.6	0.1	0.3	0.6	0.9
X10	0.5	0.7	0.8	0.5	0.8
X11	0.75	0.55	0.7	0.75	0.95
X12	0.75	0.5	0.55	0.75	0.85
X13	0.95	0.55	0.7	0.75	0.95

Table 7- Position Matrix of an expert no.7 for Concrete Pump

Criteria	Expert 7				
	CP1	CP2	CP3	CP4	CP5
X1	0.95	0.95	0.35	0.85	0.95
X2	0.9	0.8	0.9	0.5	0.9
X3	0.9	0.05	0.25	0.65	0.9
X4	0.8	0.6	0.8	0.55	0.8
X5	0.9	0.6	0.65	0.7	0.9
X6	0.95	0.55	0.5	0.75	0.85
X7	0.8	0.95	0.35	0.85	0.95
X8	0.05	0.8	0.9	0.5	0.9
X9	0.6	0.05	0.25	0.65	0.9
X10	0.6	0.6	0.8	0.55	0.8
X11	0.55	0.6	0.65	0.7	0.9
X12	0.95	0.55	0.5	0.75	0.85
X13	0.8	0.55	0.5	0.75	0.85

Table 8- Position Matrix of an expert no.8 for Concrete Pump

Criteria	Expert 8				
	CP1	CP2	CP3	CP4	CP5
X1	0.4	0.9	0.4	0.8	1
X2	0.95	0.85	0.95	0.55	0.9
X3	0.3	0.05	0.3	0.6	0.9
X4	0.75	0.65	0.75	0.5	0.85
X5	0.6	0.6	0.6	0.75	0.95
X6	0.55	0.6	0.55	0.75	0.8
X7	0.8	0.6	0.8	0.55	0.8
X8	0.9	0.6	0.65	0.7	0.9
X9	0.95	0.55	0.5	0.75	0.85
X10	0.8	0.95	0.35	0.85	0.95
X11	0.05	0.8	0.9	0.5	0.9
X12	0.6	0.05	0.25	0.65	0.9
X13	0.6	0.6	0.8	0.55	0.8

Table 9- Position Matrix of an expert no.9 for Concrete Pump

Criteria	Expert 9				
	CP1	CP2	CP3	CP4	CP5
X1	0.6	0.95	0.3	0.9	1
X2	0.55	0.85	0.9	0.65	0.95
X3	0.8	0.15	0.25	0.6	0.95
X4	0.65	0.65	0.75	0.55	0.85
X5	0.5	0.55	0.6	0.75	0.95
X6	0.35	0.45	0.5	0.7	0.8

Table 10- Position Matrix of an expert no.10 for Concrete Pump

Criteria	Expert 10				
	CP1	CP2	CP3	CP4	CP5
X1	0.9	0.9	0.35	0.9	1
X2	0.85	0.85	0.95	0.65	0.95
X3	0.15	0.15	0.35	0.6	0.9
X4	0.65	0.65	0.75	0.55	0.85
X5	0.55	0.55	0.6	0.75	0.9
X6	0.4	0.4	0.55	0.7	0.8

X7	0.75	0.65	0.75	0.5	0.85
X8	0.6	0.6	0.6	0.75	0.95
X9	0.55	0.6	0.55	0.75	0.8
X10	0.8	0.6	0.8	0.55	0.8
X11	0.9	0.6	0.65	0.7	0.9
X12	0.95	0.55	0.5	0.75	0.85
X13	0.8	0.95	0.35	0.85	0.95

X7	0.65	0.65	0.75	0.55	0.85
X8	0.5	0.55	0.6	0.75	0.95
X9	0.35	0.45	0.5	0.7	0.8
X10	0.75	0.65	0.75	0.5	0.85
X11	0.6	0.6	0.6	0.75	0.95
X12	0.55	0.6	0.55	0.75	0.8
X13	0.8	0.6	0.8	0.55	0.8

LIST OF PUBLICATION AND CONFERENCES

Publication

[1] "Optimum selection of machinery in construction project using Artificial Intelligence technique", International Journal of Recent Advances in Engineering & Technology (IJRAET) ISSN: 2347-2812, 1st April 2016.

[2] "Decision Making for Selection of Optimum Machinery in Mega Construction Project Using Artificial Intelligence Techniques" by NICMARC, Pune

Conferences

[1] "Optimum selection of machinery in construction project using Artificial Intelligence technique", International Conference on Advances in Civil Engineering (IC-ACE 2016), TCET, Mumbai, 26th – 27th February 2016.