MINIMIZING CONSTRUCTION MATERIAL WASTE BY MODELLING ORDER QUANTITY AND ON-SITE REJECTION PARAMETERS

Submitted in partial fulfilment of the requirements

for the degree of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(With specialization in Construction Engineering and Management)

by

Shivendra Tiwari

(Registration Number: Anjuman-47)

Under the guidance of

Dr. R. B. Magar

Department of Civil Engineering

School of Engineering and Technology

Anjuman-I-Islam's Kalsekar Technical Campus

New Panvel, Navi Mumbai-410206

2018

A Dissertation Report on

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CERTIFICATE

This is to certify that the project entitled **“Minimizing Construction Material Waste by Modelling Order Quantity and On-Site Rejection Parameters”** is a bonafide work of **Mr. Shivendra Tiwari (16CEM13)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of “Master of Engineering” in “Civil Engineering (With Specialization in Construction Engineering and Management)”.

Dr. R. B. Magar
(Guide and Head of Department)

Dr. Abdul Razak Honnutagi
(Director, AIKTC)

APPROVAL SHEET

This dissertation report entitled "Minimizing Construction Material Waste by Modelling Order Quantity and On-Site Rejection Parameters" by Shivendra Tiwari is approved for the degree of "Civil Engineering with Specialization in Construction Engineering and Management"

Examiners

1. …………………………
2. …………………………

Supervisors:

1. …………………………
2. …………………………

Date:

Place: New Panvel

DECLARATION

I declare that this written submission represents my ideas in our 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 idea/data/fact/source in our 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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ABSTRACT

Construction material wastages are one of the biggest problems associated with waste management in developing countries like India. This work aims to study the occurrence, causes and degree of construction material resource wastage during the course of a residential construction project in India. Different causes of material wastage and top materials being wasted are identified and ranked using experience-based data from the construction industry personnel. Further, correlation analysis between causes and degree of wastages revealed a highly positive relationship. Regression analysis is used to model the daily production quantities and on-site wastage parameters to obtain standard equations for prediction of material wastages. The models developed are limited to work accurately only for the RMC plant from where data is collected during the course of this study. Similar models can be developed for different RMC plants with other techniques. Wastages can be reduced by optimizing the work processes in construction industry and recycling the unused materials wherever needed. In this study, similar kind of practice was adopted for minimizing concrete wastages associated with RMC and construction site just by optimizing the daily order quantities. A simple and standard tool namely, Economic order quantity (EOQ) were computed for the daily production of RMC plant as per site demand on daily basis. The differences in waste reduction in usual production quantity and as per EOQ practice were significant to reveal that the tools can be effectively utilized to reduce huge degree of wastages, diverting construction practices towards sustainability.

Keywords— EOQ; Concrete waste; correlation analysis; material wastages; prediction modelling; resource optimization; regression analysis.

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ABBREVIATION NOTATION AND NOMENCLATURE

CPM	Critical Path Method
GA	Genetic Algorithm
NCAER	National Council of Applied Economics Research
GDP	Gross Domestic Product
ISWA	International Solid Waste Association
NSCC	National Specialist Contractors Council
UK	United Kingdom
MSWM	Municipal Solid Waste Management rules
C&D	Construction and Demolition
3R's	Reduce, Recycle and Reuse
MRA	Multiple Regression Analysis
RMC	Ready Mix Concrete
F.I.	Frequency Index
S.I.	Severity Index
I.I.	Importance Index
NCBISD	National Centre for Biotechnology Information Search database
DSR	District Scheduled Rates
MS	Microsoft
ANN	Artificial Neural Network
MARCOS	Multi-objective Automated Construction Resource Optimization System
ANN	Artificial Neural Network
EOQ	Economic Order Quantity

Chapter 1

Introduction

1.1 General

There are few things certain in life such as death, transition and waste. Either of the three cannot be avoided from happening but, we can make our lives better with proper management of the same, (Agarwal *et al.*, 2015). World has witnessed significant population explosion, technological advancement and is equally increasing the use of its resources following the industrial revolution. It is acknowledged that technological advances have impacted the utilisation of resources and cause ozone depletion, deforestation, global warming, flooding etc particularly in the developing nations. These factors are affecting the sustainability of the earth in terms of the resources ability to meet the needs of current and future generations, (Cartlidge 2004). Lack of concern by the majority of governments and developers globally and in India, in particular, is continuously affecting the use of construction material resources. Population eruption, along with demand of improving life style results in increasing demand of infrastructure for basic needs such as housing, transportation, business, education etc.

Since, the Industrial revolution, the globe has noticed a compelling development in advancement of technology, population and growth. Thus, the use of resource is also increasing simultaneously. In other words, the technological advancements achieved, resulting in excessive use and extraction of any kind of resources and directly or indirectly has a hand in global warming related issues like ozone depletion, thinning of the ice layers on the poles, flooding etc. Sustainability is affected by such activities which also, raises a question on the availability of resources for the future generations, (Cartlidge, 2004). Therefore, the engineers should find solutions for the optimum utilization and waste reduction techniques of the construction resources.

The resource planning and management is one of the most important aspects for competitiveness and profitability in today's construction industry which can be used to provide sustainable construction. Initially, which could be used for estimating multi-project resource planning and sharing done with making models base on Critical Path Method (CPM) time analysis (Karaal and Nasr, 1986).

The use of material resources in the construction industry is related to finance, human resource and equipment. The optimum use of these resources collectively leads to preservation of the base material resources and more affordable construction. Hence, the aim is to examine ways by which construction material resources can be optimised. This can be achieved through specific objectives such as identifying the major sources of material wastage, challenges of resource optimization and lastly the means of material resources optimization.

Studies done outside India also state similar facts, National Specialist Contractors Council (NSCC), UK says - that the 10% of construction material ordered on site is never used and directly goes to the construction wastage lists. If these wastages on construction sites are neglected, it may lead to project cost overrun and time overruns unnecessarily. Therefore, there is an immediate need to increase the material wastage management activities at construction site is to obtain more benefits in less time with minimum cost of constructions.

1.2 Construction industry in India

According to the economic times and 13th five-year plan states that the growth rate in the first year of the five-year plan (2018 - 2022) is 8.2 percent with an unstoppable growing population of 1.36 billion people need lands to grow crops to feed, fresh water to drink and in a civil engineer’s aspect, “space to live and public facilities” to survive. Also, National Council of

Applied Economics Research (NCAER) says, India's middle-class population was 267 million in 2016. Further ahead, by 2025-26 the number of middle class households in India is likely to be more than double from the 2015-16 levels to 113.8 million households or 547 million individuals. It is estimated that average real wages will quadruple between 2013 and 2030 (NCAER). With one of the fastest growing economies in the world, clocked at a growth rate of 8.2% in 2018, India. Which makes increasing middle class population of India capable of buying expensive properties with their increasing needs of better lifestyle and improved living quality. On the other hand, construction industry being second just after agriculture in India is an 7.74% of approximate contributor to its total GDP growth and development (13^{th} five-year plan 2018-2022). As the industry is growing big with rising demand in housing sector with quality construction, it will come at cost of multiple design changes, raw material quality issues (as multiple options are available in market) and finished product quality issues, which in result required huge amount of raw materials to produce a good quality product with generation of waste of used construction materials.

1.3 Material waste in Indian Construction industry

Waste can be defined as, loss of material during usage or decay of unused or unattended material on construction site can be stated as construction material wastage. Alternatively, "It is something that never gives a process of increase in value to the work of construction at any phase". The dominant crisis in the construction sector is the material waste with its evident associations with causes of wastages. Knowing that construction industry is the second largest industry in India being a rapidly developing nation & generate waste beyond bearing and manageable quantities (Shrivastava and Chini, 2009).

In 2013, International Solid Waste Association (ISWA) reported that, the total garbage generation in 2013 was 1.84 billion tonnes per year around the world and the countries creating the highest amounts of waste were China, followed by the United States and India. Each year, India produces 62 million tonnes (2013) of total solid waste of which 24 million tonnes (2010) of construction waste which is increasing every year (Shrivastava and Chini, 2009). Globally, the production of building material waste estimates to 2 to 3 billion tonnes every year, of which 30-40% is only concrete (Shrivastava and Chini, 2009).

Shrivastava and Chini, 2009) shows, approximately 39% of total solid waste generation in India is attributed to the construction industry alone. Let it be any type of construction project, the material cost associated with it is between 40-60% of total project cost, as indicated in Table 1.1 (modified from Shrivastava and Chini, 2009), supporting the same, which is a very high capital investment. Garba, *et al.*, (2016) estimates approximately 30-40% of the total amount of materials at different stages of construction as waste generated.

Table 1.1: Percentage of Material cost in different types of projects

Sectors of Construction Industry	Material (%)
Commercial & Residential Buildings	58-60
Roads & Highways	42-45
Bridges & Viaducts	46-48
Dams & canals	42-46
Power	41-43
Railways	51-53
Mineral Plants	41-44
Transmission units & structures	49-51

Table 1.1 (modified from Shrivastava and Chini, 2009) shows the distribution of cost among various modes of expense in Indian construction industry. The importance of materials cost in construction industry can be seen from the fact that the component of materials cost comprises nearly 40%–60% of the project cost. This percentage is higher for projects such as building, railway and transmission; and lower but still a critical part of other projects such as power and mineral plant. In addition, the Indian construction industry is the largest consumer of material resources of both natural (such as stone, clay, lime) and the processed (synthetic) resources.

The 13th five-year plan highlighted that, in terms of magnitude construction industry is second largest after agriculture and is growing at a very rapid pace with huge demands of people in search of better lifestyle and quality products. This leads to increase in demand of various infrastructures to be constructed around the country (Shrivastava and Chini, 2009). It was found that an approximate of 24 most common reasons were found for the wastages out of 48 direct/indirect causes for material waste generation during different stages of construction such as Designing stage, Operational stage, Procurement stage and Material handling stage.

1.4 Motivation of the Present Study

In India, the Municipal Solid Waste Management rules, 2000 (MSWM), is the regulatory body to control and dispose or recycle the daily waste collection from the cities. But is a flop system, as it is a general collection and dumping kind of a linear system, which does not solve and provides effective solutions for minimizing the waste production. Whereas, the waste generated during the construction period is tremendous due to non-implementation of rules to check and reduce the wastages effectively. Hence there is a need to chalk out different methods and techniques to minimize the wastages which will reduces extra overheads for transportation in dumping, labour for cleaning and time. Hence the study aimed is at minimizing the construction material wastes that are produced during the construction processes.

1.5 Scope of the study

Today given the problem above as specified, following scope is outlined for the present experimental investigation.

a) It is expected that this study will determine the solutions to the problem stated as above in Indian construction industry, such as construction material wastages during different stages of construction, lack of sustainability in construction processes, cost overrun and time overrun.

b) Bestowed (derived) results from this study will help construction practitioners to be aware, understand and identify the problems associated to material wastage on their construction projects.

c) The study will generate ranked lists in descending order (maximum to minimum) of materials and causes of their wastages along with its magnitude to show the clear picture of the Indian construction projects.

d) In addition to the above, a prediction model will be developed between "production – wastage due to top identified causes" and "production – overall wastage" which will help the construction practitioners project the upcoming wastages depending upon available production quantities.

e) This study will also suggest some measure to reduce the waste incurred at regular intervals due to different causes.

f) Finally, the study is a continuation to the previous research works done up till now and will also serve as a base for upcoming researchers for future studies in similar fields.

1.6 Aim and Objective of the study

The primary aim of this study is to optimize the wastages of construction material. More specifically, the work has the following objectives:

a) To identify the materials being wasted and their causes (parameters).

b) To obtain correlation coefficients between material wastage parameters to its degree of production.

c) To perform a regression analysis between material production and wastage parameters to obtain linear regression models for wastage prediction purposes.

d) To obtain and compare the EOQ production with the actual production quantities. Also compare the difference in material wastages with usual production quantities and EOQ production.

Chapter 2

Literature Review

2.1 General

The work done by the various investigators is referred and summarized here in this chapter. The referred journal and conference papers and reports are presented in the following three phases;

- Phase-I Study of wastage scenario around the world and in India
- Phase-II Resource Optimization
- Phase-III Application of Correlation, Linear Regression analysis and Economic ordering quantity

At the end, the research gaps have been reviewed from each of the above three phases.

2.2 Phase-I Study of wastage scenario around world and in India

A simple definition to waste can be loss of material during usage or decay of unused or unattended material on construction site or something that never gives a process of increase in value to the work of construction at any phase is termed as waste, (Tiwari *et al.*, 2018).

Shrivastava and Chini (2009), not only studied about the construction waste production but also considered demolition waste production scenario in India as a considerable issue and challenge to suggest measures for minimization, along with its generation handling and disposal status on Indian sites keeping it with the aim of sustainability. Here author's study was an overview to Indian construction industry providing volumetric statistics of C&D waste generation along with suggestion of Indian government and construction practitioners about 3R's i.e. Reduce, Reuse and Recycle.

Agarwal *et al.* (2015) linked population eruption, along with demand of cultivating life style of results in increasing demand of infrastructure for basic needs such as housing, transportation, business and education etc to be the main reasons for straining and extraction of limited resources avoiding the part of sustainability in construction industries around the world. Tiwari *et al.* (2018) reviewed that resource optimization is necessary at its sector because nature has enough for the need but never enough for greed.

2.3 Phase-II Resource Optimization

Different number of causes for material waste generation during construction are identified in different studies based on the area and country where study was conducted with the different ways of ranking. In Nigeria, a minimum of twenty-six (26) different causes of material wastage were identified in a study by Garba et al. (2016) and Ghanim (2014) studied sixty (60) causes of wastages out of a hundred (100) identified causes on construction sites in Jordan. Karaal and Nasr (1986) stated that resource planning and management is one of the most important ingredients for competitiveness and profitability in today's construction industry which can be achieved by minimizing the total cost of leased resources under the constraint of maximum and most efficient use of owned equipment and contracted labour force using a mixed integer linear programming model for the management of resources throughout the project life which is based on the Critical Path Method time analysis, the model derives the schedule for equipment rentals and transient resources, as well as the utilization scheme for owned equipment and other available resources.

Bell et al. (1992) studied the In-situ materials for construction and found seven potential lunar construction materials which were analysed with respect to their physical properties, processes, energy requirements, and resource efficiency. He concludes that there is significant potential for the use of basalt as a low-cost alternative to Earth-based materials. AbouRizk et al. (1994) discusses the basis for automating system optimization through simulation-feedback analysis. Starting with an arbitrary resource combination, a pilot-simulation run was performed. Depending on the specified objectives, resource performance was analysed and a new combination was recommended to get closer to the desired optimum allocation.

Feng et al. (1997) and Hegazy (1998) used Genetic algorithms as a technique for optimization, machine learning, automatic programming, transportation problems, adaptive control etc. for his resource optimization problems in his study. Hegazy (1999) did a significant amount of study on resource allocation and levelling. Which were solved mainly using heuristic procedures that cannot guarantee optimum solutions. Improvements were proposed to resource allocation and levelling heuristics, and the Genetic Algorithm (GA) technique was used to search for near-optimum solution, considering both aspects simultaneously.

Optimizing resource utilization can lead to significant reduction in the duration and cost of repetitive construction projects such as highways, high-rise buildings and housing projects as concluded by Rayes et al. (2001), also developed model that utilize dynamic programming formulation and incorporates a scheduling algorithm and an interruption algorithm so as to automate the generation of interruptions during scheduling. Further in area of optimization Hegazy (2003) developed optimization-based simulation models, which are integrated with commonly used project management software in which the bestowed approach determines the least cost and most productive amount of resources that achieve the highest benefit by cost ratio. Peralta and Kalwij (2004) proposed in their study that different combinations of use of optimizer and simulator software were best for optimizing the groundwater supply, groundwater plume management and conjunctive use. With their study the updated the previously used technique in which have been a range of classical and heuristic optimization methods, and of simulator and surrogate simulator techniques. The heuristic model developed by Peralta and Kalwij (2004) were used for speeding up the optimization process include linking of a heuristic optimizer to ‘Tabu search’ or artificial neural networks. The basic tool used in their study was "Simulation/Optimization Modelling System" (SOMOS) software (SSOL, 2004).

Peralta and Wu (2004) again studied the SOMOS based optimization technique to optimize and manage the use of water resource. As stated by the authors SOMOA module is best for field groundwater and conjunctive water management situations as it employs several analytical simulation models and several optimization methods. In their study they emphasized on SOMOA and its applications for common field-level water management problems.

Cartlidge (2004) bestowed that sustainability is affected by such activities of resource wastages which also, puts a question for the availability of resources for the future generations concluding that we as engineers should find solutions for the optimum utilization and waste reduction techniques of the resources. Ellis and Kim (2005) solved case examples to illustrate the presentation and efficiency of the resource allocation model by presenting an optimal algorithm for a resource allocation model, which would be implemented into a framework for the development of an integration model. In which model determines the shortest duration by allocating available resources to a set of activities simultaneously.

As resource management is necessary in today's construction industry, Kandil et al. (2006) emphasis upon the automated system for the resource optimization using Spreadsheet software, database application and project planning software. Kandil et al. (2006) also presented the progress of a parallel multi-objective genetic algorithm framework to empower an efficient and effective optimization of resource usage in extensive construction projects.

Sadi and Al-Hejji (2006) and Ghanim (2014), performed an investigation in their study on time performance for different types of construction in Eastern Province of Saudi Arabia to test the causes of delay in construction projects. The type of data collection was in the form of field investigation conduction with Owners, Contractors and Consultants with a decent response rate to their survey. Ghanim (2014) studied the related reasons of material resource wastage accompanied by its magnitude on construction sites of Jordan. Author obtained the estimated magnitude of material wastage in percentage form along with probable causes for the same with the help of a questionnaire form-based survey. Survey was aimed to get responses from Client linked to construction industry, Contractors and Consultants. As a result, the survey bestowed 60 different causes linked to material wastage distributed under 6 different categories. From the data collected by the survey in the study author has defined some sources of material waste being; Recurrent client and design change during construction, retool the work due to error of labour, contract document with poor clauses, absence of material storage space, unplanned action for minimizing waste during construction, labour with less or zero experience of work being performed, nonexistence of properly skilled labour, unfavourable site conditions, transportation loss and damage to raw material causing waste, errors in survey calculations with higher/lower ratio of allowances, burglary and mischief were the most commonly active causes on any construction sites and concludes with the percentage of waste construction material identified in his study being from 15% to 21% on construction projects in Jordan along with his recommendations towards waste minimization. Sonmez and Gürel (2016) opted for a new hybrid optimization method to achieve an improvement in optimal planning and scheduling of large-scale construction projects with multiple duration or resource execution modes and resource constraints which allows significant savings by optimum planning and scheduling of medium and large-scale construction projects with numerous duration or resource execution modes and resource constraints.

2.4 Phase-III Application of Soft Computing Tool

Wang and Linker (2008) studied the mid-Atlantic region of the United States, sediment loads from stream runoff using regression simulation and developed three regression models for eight rivers and recommended regression equations for better results of sediment deposits over previously existing models.

Ahmed and Aziz (2009) developed the time prediction models with the application of general multiple regression analysis, ridge regression analysis, and nonlinear partial least-square regression analysis to a project data from Washington State Department of Transportation. The developed models were validated against an actual project data proving to be significantly accurate.

Hwang (2009) developed two models to predict construction cost index during the planning phase, studied the fluctuations in the price of different construction materials in the market and along with its trendline behaviour which helped the author using regression analysis in developing construction cost index prediction model.

Yin (2011) utilised the EOQ (Economic Order Quantity) as a tool to coordinate and encourage the retailers and manufacturers in fashion industry for demand forecasting and inventory control. Use of EOQ certainly helps in optimizing the demand and supply errors made by the purchaser.

MacKenzie1 and Barker (2013) used regression modelling and quantified the flexibility of a critical infrastructure sector through the dynamic inoperability input-output model, which describes how inoperability spreads through a set of interdependent industry and infrastructure sectors following a disruptive event, includes a flexibility parameter that has not yet been adequately evaluated. Regression models were demonstrated with electric power outage data and a regional disruption in Oklahoma, US.

Siu *et al.* (2013) uses regression techniques for addressing complicated prediction and classification problems with fundamental algorithms of "least square error" and "least mean square" in order to facilitate the prediction and classification of cycle times of construction operations in a viaduct bridge construction in which the installation was done by launching precast girders with a mobile gantry sitting on two piers. Author demonstrated input factors in connection with operations, logistics and resources using effectiveness of regression techniques in classifying and forecasting.

Wei *et al.* (2015) utilised regression analysis for selection of accurate path with minimum traffic and distance between Shenyang and Shanhaiguan. Also compared the results of associative regression prediction has higher accuracy than separate regression prediction, in result developing a new theoretical calculation results in traffic demand prediction area.
Espino et al. (2018) developed a methodology created on Multiple Regression Analysis (MRA) to assess flood risk in urban catchment areas by replacing storm water models which were replaced resulting in identifying parameters of runoff rates found in urban catchment area.

2.5 Summary

From literature survey following summary is extracted from Phase-I, II and III are as follows:

Phase-I: The findings of the above literature review, may serve as a useful guideline for judiciously applying the concept of resource wastages, which is not new to the research field in civil engineering. Significant studies have been done to understand and study different kinds of wastages linked to construction industry in India by multiple authors.

Phase-II: It is observed from the above reporting that multiple attempts have been done by researchers to optimize resources by different optimizing techniques such as: Genetic algorithm, Critical Path Method time analysis, use of In-situ materials, machine learning, automatic programming, transportation problems, adaptive control, resource allocation and levelling, dynamic programming formulation with the use of scheduling and interruption algorithm and optimization using Spreadsheet software. Also, multiple different methods exist as optimization tools for similar works. Some researchers have tried optimizing resource use to reduce wastage by optimizing the resource allocation methods.

Phase-III: The previous research has been done on identifying causes of wastages and ranking the same. Similar work has been done to identify the materials being wasted on sites in different cities of the world except in India. Findings also cleared that the studies done previously did not continued to optimise the top-ranking material wastages or its prediction with Simple linear Regression analysis. Whereas regression analysis is being used multiple times to predict the traffic flow, prediction of perfect route for the traffic flow and prediction of cost index of construction. Hence there is a need to prepare a prediction model using predicting tools like Correlation and Simple Linear Regression analysis to predict the wastages on upcoming day in relation with wastage parameters for time saving and minimization of unnecessary wastages. Similarly, minimum works have been done with EOQ as a tool of minimizing waste in construction industry.

Chapter 3

Methodology

3.1 General

This study demonstrates the applicability of correlation analysis and simple linear regression analysis for the prediction of degree of wastage depending on wastage parameters of concrete. An Experimental work will be carried out to model onsite material rejection parameters with the daily production from an RMC plant. The results generated through experimental work can be used to find out the future material wastage through the models generated. Thus, the models generated through software would be helpful for effective utilization of materials with respect to production quantity of concrete.

3.2 Methodology

Some parts of the methodology were learned and adopted as from literature survey in previous studies done to identify and understand the most important parameters of wastages and the materials being wasted the most on Indian construction sites. Further after identification of the important parameters of material wastages and top wasted materials a cost analysis was done as on market prices of materials around Mumbai region to select costliest material for further work. In the next step of the work, it was resolved to find a correlation coefficient index to understand the degree of association between material and its on-site wastage parameters. Depending on the results obtained, models were developed using a Simple Linear regression analysis for prediction of wastages. Further, EOQ for each 20-day demand from sites was calculated to optimize the production rate to produce minimum wastages.

3.2.1 Questionnaire Based Survey

Part I of the study consists of questionnaire design for the survey to be floated for gathering experienced based data from construction practitioners and industry personals including personal interviews along with the surveys. The questionnaire was designed in four parts for data collection. Part I of the questionnaire survey consisted simple questions for the response's personal details as follow:

a) Name
b) Company
c) Post in the company
d) Experience in total
e) Responder being a client, contractor or a consultant
f) Whether he agrees for material wastage on his site?

Part II of the questionnaire consisted questions about material wastage of 12 most commonly used materials on Indian construction sites, as shown in Figure 3.1 below.

In Part III, 24 most commonly found causes of 48 of overall direct and indirect causes of material waste were selected for the questionnaire survey, as shown in Figure 3.2 below:

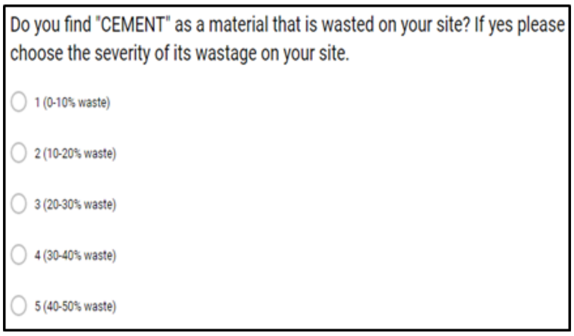

Figure 3.1: Sample question from part 2 of questionnaire

Figure 3.2: Sample question from part 3 of questionnaire

Figure 3.1 shows, sample questions from the survey, attached to each material contained a weightage meter (1 - waste up to 10%, 2 - waste between 10% to 20%, 3 - waste between 20% to 30%, 4 - waste between 30% to 40% and 5 - waste between 40% to 50%) for the responder to allot for that particular material wastage on his site based on the percentage of material wastage. Based on the data gathered for the degree of material wastage on construction sites, a cumulative percentile average was calculated for each of the 12 commonly used materials. Figure 3.2 shows, a sample question from the survey attached to each cause for material wastage contained two weightage meters one for frequency of occurrence (1 – rarely up to 5 – very frequent) and the other for severity of waste (1 – less severe to 5 – highly severe) for the responder to allot for that particular material wastage on his site.

Part IV of the survey consisted questions asking for suggestions to improve the data collection method for the study.

3.2.2 Distribution of Survey and personal Interview

Survey made was distributed as a Google form questionnaire and personal interviews from the construction practitioners and industry personals, which included clients, consultants and contractors. The questionnaire was distributed online and was made available with personal meetings to seventy-one (71) individuals, as shown on Figure 3.3 below:

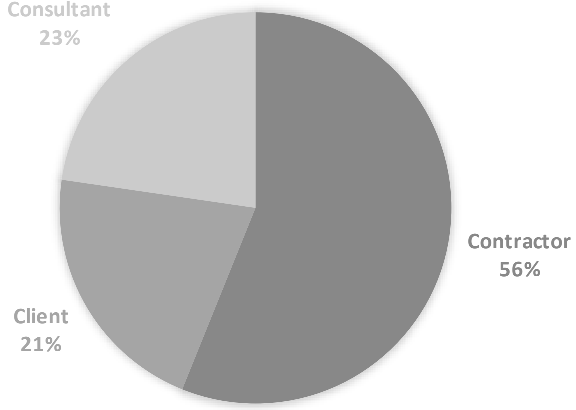

Figure 3.3: Pi-chart showing responses from targeted responders

The above Figure 3.3, illustrates that 56.1% of the responders were contractors highlighted in yellow portion being the highest of all, 22.7% were consultants highlighted in red portion of the pi-chart and 21.2% of rest were client out of all respondent as highlighted in blue portion. Similar is explained in the below Table 3.1:

Table 3.1: Response rate for questionnaire survey

Description	Consultants	Contractors	Clients	Total
Distributed	16	40	15	71
Respondents	15	37	14	66
Percentage of Response	93.75	92.5	93.3	93.2

The above Table 3.1 show, the response rate for the questionnaire distributed to the construction practitioners having experience up to 30 years. Total of seventy-one (71) questionnaires were distributed to sixteen (16) consultants, forty (40) contractors and fifteen (15) clients. The total number of responses received was sixty-six (66). Giving a response rate of 93.2%.

The data gathered from the responses of the survey, itself cleared the major question raised before the start of this study, "If there are any wastages of construction materials on Indian site?" The results for the same are displayed in Figure 3.4 below:

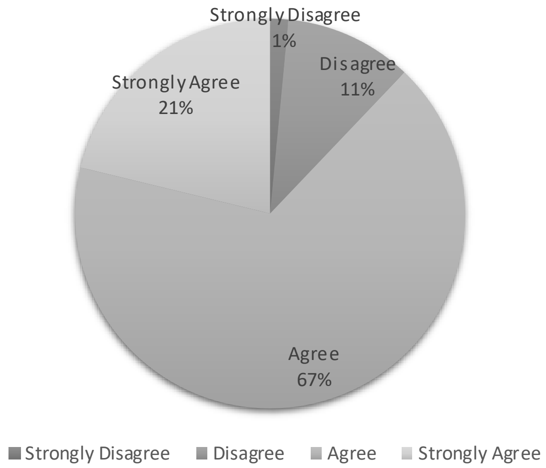

Figure 3.4: Result showing presence of material waste in Indian construction industry

The above Figure 3.4 shows the agreement of responders for material wastage on their sites in India. 21.2% of them strongly agreed and 66.7% agreed to material waste incurred, whereas, 10.6% disagreed for material wastage and approximately 1.5% of the responders strongly disagreed to material wastages on their construction sites.

3.2.3 Descriptive Statistical & Frequency Analysis

Based on the data collected from the responders of the survey, a descriptive and frequency & statistical analysis was done to get the three indices. All indices can be calculated as below:

1. Frequency Index: A formula is shown below which consist the rank component depending on the summation of the weightage allotted to one particular data depending upon its frequency of occurrence on site [Modified from Sadi (2006) and Ghanim (2014)].

   $$\text{Frequency Index} = (\sum a(n/N)*100)/5 \quad (1)$$

   In equation 1, 'a' is the constant expressing weightage given to each response (ranges from 1 for rarely up to 5 for always), 'n' is the frequency of the responses, and 'N' is total number of responses.

2. Severity index: Depends upon the severity of any particular event (how severely the event occurs), on basis of which the responder needs to allots a weightage to that particular event [Modified from Sadi (2006) and Ghanim (2014)].

   $$\text{Severity Index} = (\sum a(n/N)*100)/5 \quad (2)$$

   In equation 2, 'a' is the constant expressing weightage given to each response (ranges from 1 for less severe to 5 for highly severe), 'n' is the frequency of the responses, and 'N' is total number of responses.

3. In equation 3, Importance index: Based on the values of the above two indices the final values are obtained namely, Importance index which can be derived as below [Modified from Sadi (2006) and Ghanim (2014)]:

$$\text{Importance Index (IMP.I.) \%} = [(\text{F.I.\%} * \text{S.I.\%})/100] \tag{3}$$

Where, 'F.I' and 'S.I' used as obtained from above equation 1 & equation 2.

3.2.4 Cost comparison

For the results achieved from the survey, top three materials being wasted were selected for a practical cost comparison, which was carried out to understand the costliest material. Further after the cost comparison work, data collection for the production as raw material or finished product along with its magnitude of waste was to be collected of the costliest material for further study.

3.2.5 Correlation Analysis

A numerical measure, that means a statistical relationship between two variables with some correlation. The variables may be two columns of a given data set of observations made for one single individual, thing, or a process, which is often called a sample sets, or two components of a multivariate random variable with a known distribution. Correlation coefficient can be calculated by the below mentioned equation. The coefficient of correlation is denoted with 'r'. The value of correlation will always stay between $-1 \leq r \leq +1$. As the value of 'r' moves above zero (0) towards '+1' it denotes that for every positive increase in one variable, there is a positive increase of a fixed proportion in the other which is directly proportional. Similarly, if 'r' moves below zero (0) towards '-1' means that for every positive increase in one variable, there is a negative drop of a fixed proportion in the other which denotes inversely proportionality. When value of 'r' is equal to zero (0), that means for every increase, there is not a positive or negative increase or decrease respectively. The value of 'r' can be calculated with the below mentioned equation 4 National Centre for Biotechnology Information Search database (NCBISD).

$$r = \frac{\sum(XY) - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{\left[\sum X^2 - \frac{\sum(X)^2}{N}\right]}\sqrt{\left[\sum Y^2 - \frac{\sum(Y)^2}{N}\right]}} \tag{4}$$

In the above equation 4, 'X' and 'Y' are the variables associated with the correlation requirements. A correlation analysis is carried out to understand the relationship between the daily production quantity of concrete in RMC plant with the daily waste incurred due to the causes of its wastage, namely (1) Ordering error/excess quantity production or limitation to order small quantity and (2) Rejection of transit mixer due to concrete quality issues. From the magnitude of correlation coefficients obtained it can be said using Table 3.2 if the correlation formed is positive or a negative correlation.

Table 3.2: Interpretation from degree of correlation (NCBISD)

Size of Correlation coefficient	Interpretation
0.90 to 1.00 (−0.90 to −1.00)	Very high positive (negative) correlation
0.70 to 0.90 (−0.70 to −0.90)	High positive (negative) correlation
0.50 to 0.70 (−0.50 to −0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (−0.30 to −0.50)	Low positive (negative) correlation
0.00 to 0.30 (0.00 to −0.30)	Negligible correlation

The above Table 3.2, can be utilised to interpret the meaning of correlations formed between production and waste incurred. The above Table 3.2 was referred from NCBISD (National Centre for Biotechnology Information Search Database) website.

3.2.6 Simple Linear Regression

Regression techniques are frequently used for addressing complex prediction and organization problems in civil engineering thanks to its effortlessness and simplicity (Siu *et al.*, 2013). Regression analysis was used to make a model for prediction of concrete wastage due to the two main parameters being: (1) Ordering error/excess quantity production or limitation to order small quantity and (2) Rejection of concrete due to its poor quality.

The term regression arrived from genetics and was popularized by Sir Francis Galton during the late 19^{th} century with his publication of Regression towards mediocrity in hereditary stature. It is a statistical tool for modelling in statistical analysis and includes different techniques for modelling and analyzing multiple variables, while it establishes relationship between a dependent variable and one or more independent variables or also known to be 'predictors'. More specifically, regression analysis helps one understand how the value of the dependent variable or 'criterion variable' changes when any one of the independent variables gets changed.

Regression analysis is used worldwide for predicting and forecasting purposes, while its use has overlapped with the field of machine learning techniques. However, this can lead to illusions or false relationships, so caution is advisable, correlation does not prove causation as stated by Armstrong (2012). In the study done for the prediction of concrete wastages three models ware developed after finding the value of constants associated with the models, as in below equation 5:

$$(\mathrm{Y} - \bar{\mathrm{y}}) = \mathrm{byx}(\mathrm{X} - \bar{x}) \quad (5)$$

In the above equation 5, Y is the independent variable which in this study's case be the daily production quantity, $\bar{y}$ is the mean of the daily production of concrete for a total of 'N = 455' days of data, b_{yx} can be derived from below mentioned standard equation 6, while X is the dependent variables being daily wastage incurred and $\bar{x}$ is mean of total waste incurred for 455 days (Appendix IV) of production respectively.

$$b_{yx} = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sum X^2 - \frac{(\sum Y)^2}{N}} \quad (6)$$

Where in above equation 6, b_{yx} is known as coefficient of regression of Y on X and N is the total number of values i.e. 455 as stated above. The model to be developed is a simple regression line equation which consists of two constants namely 'a' and 'b'. thus, the value for constant 'b' can be obtained from above equation 6 and value of constant 'a' can be obtained from below mentioned equation 7.

$$a = \bar{y} - b\bar{x} \quad (7)$$

Where in above equation 7, 'a' is the constant from the standard straight-line equation 8, mentioned below, $\bar{y}$ is the mean of the production and $\bar{x}$ is the mean of wastage on daily basis.

$$Y = a + b\,(X) \quad (8)$$

Where in the above equation 8, 'a' and 'b' are the constants of standard straight-line equation. Hence to develop models using regression analysis the constants 'a' and 'b' can be derived from above mentioned equation 6 and equation 7.

3.2.7 EOQ – Economic Order Quantity

For further minimization of wastages of concrete, the total demand of the site for 455 days was divided into equal sections of 10, 20 and 30 days separately. Economic Order Quantity was obtained for every 10, 20 and 30 days of demand by site. EOQ for only a select grade M40 was obtained as it had maximum demand from sites during the study period. Initially EOQ was performed to get the best slot of demand of sites out of everyday demand, 10 days of demand, 20 days demand and 30 days demand.

EOQ obtained for every day, 10 days 20 days and 30 days of demand was then compared with the daily actual demand to find difference in daily production. This calculated difference in production was considered as losses, as site is unable to fulfil the demand of site if huge quantities are ordered on some days. Correlation and regression analysis were done between the EOQ production and losses as well to compare the reduction in wastages with the usually practiced form of concrete production in RMC plants. Below mentioned Equation (9) below is the simple model to derive the Economic Order Quantity.

$$EOQ = \sqrt{\frac{2*S*Co}{Cu*\, i}} \tag{9}$$

In the above equation (9), 'S' is the total demand or supply of the material, 'Co' stands for the ordering cost of the product (Amount payable during placing an order of the material), 'Cu' stands for the unit cost of the material and 'i' denotes the inventory cost of the material.

This work is organized into following five stages and as shown in flowchart and Figure 3.5

Stage-I: Literature review

- Phase-I: Study of wastage scenario around world and in India
- Phase-II: Resource Optimization
- Phase-III: Application of Correlation and Linear Regression analysis
- Phase-IV: Review of Research Gaps or Summary

Stage-II: Concept formulation

- Statement of the Problem
- Research Objectives
- Expected Outcomes

Stage-III: Data collection

- Survey through Google form and Personal Interviews
- RMC Plant Data

Stage-IV: Data analysis techniques

- Descriptive Statistical and Frequency analysis
- Microsoft Excel 2016
- Correlation analysis
- Simple Linear Regression
- Modeling Production and On-site Parameters

Stage-V: Research outcomes/results

- Regression model
- EOQ model

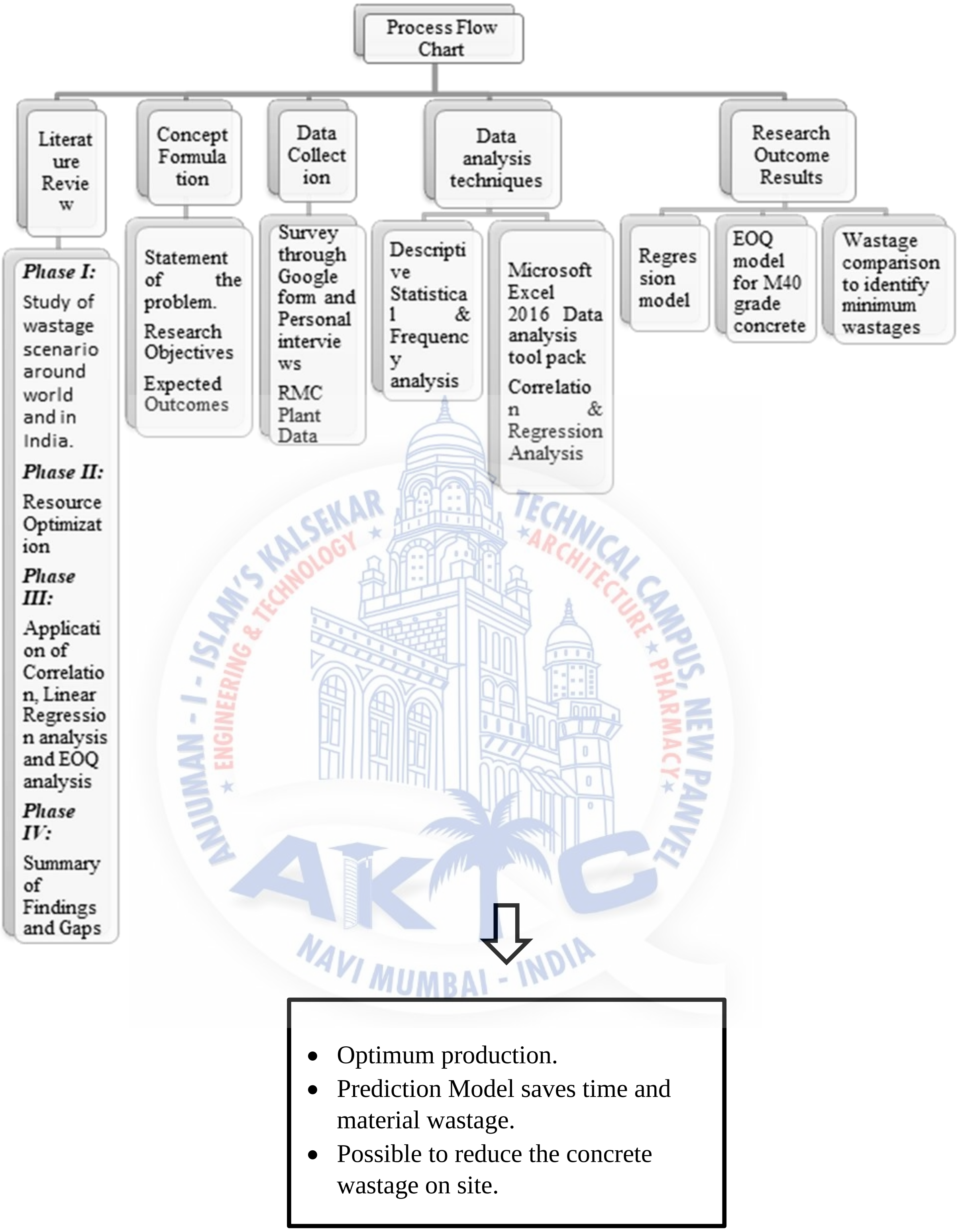

Figure 3.5 Methodology adopted in the present work

Chapter 4

Results and Discussions

4.1 General

Data was collected from an RMC plant located in Mumbai suburban region which does production for three Residential sites at different locations. Below Figure 4.1 and Figure 4.2 show some photos of the waste concrete from site and RMC plant.

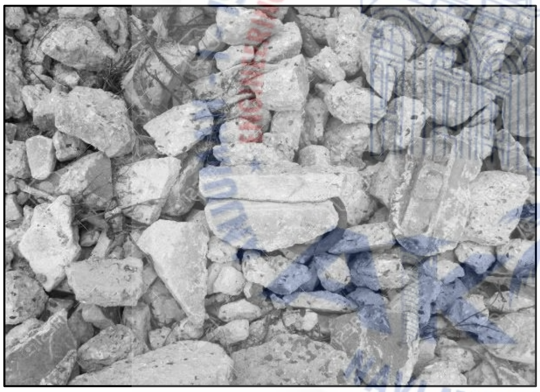

Figure 4.1: Pile of waste concrete 1

Figure 4.2: Pile of waste C&D concrete 2

The above Figure 4.1 shows the pile of waste concrete from the site where concrete was delivered and Figure 4.2 show the pile of waste concrete from construction and demolition works from a site in Dahanu. Concrete wastage, as learned from the analysis of data gathered from RMC plant gave the results of wastages incurred over fifteen (15) months as shown in a graphical format in Figure 4.3 below:

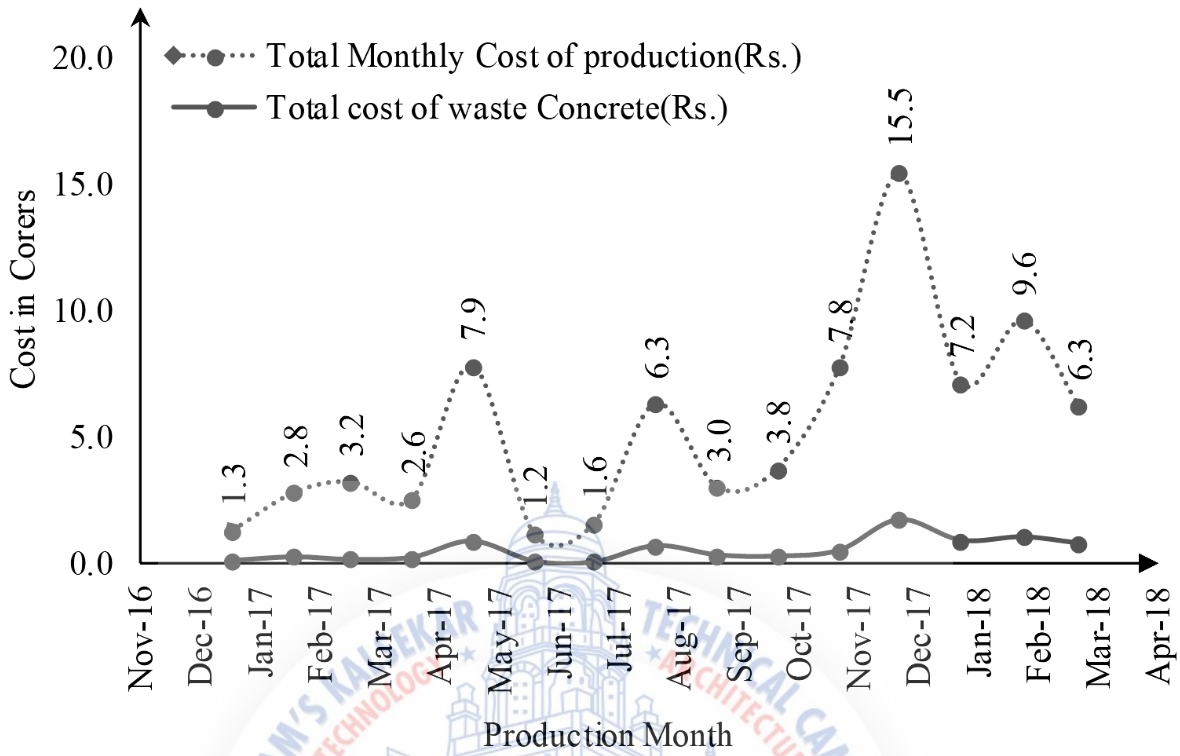

Figure 4.3: Production Vs Wastage concrete

From the Figure 4.3, it can be understood that there is a subsequent degree of losses in production of concrete. As the rainy season strikes around the months of June – July the production of concrete decreases with decrease in wastage rates. Similar kind of uphill can be traced from the above graph near the end of the year demand and supply of concrete increases with the increase of wastages associated with them. Further analysis of the data brings it to notice that there was an approximate of 10.24% of concrete being wasted on an average monthly basis, similar can be collected from the below Table 4.1:

Table 4.1: Percent waste in monthly concrete production

Sr. No.	Month	Percent wastage of concrete (%)
1.	January 2017	11.198
2.	February 2017	10.248
3.	March 2017	5.735
4.	April 2017	10.667
5.	May 2017	11.659
6.	June 2017	10.281
7.	July 2017	5.719
8.	August 2017	11.531

9.	September 2017	12.063
10.	October 2017	8.481
11.	November 2017	7.099
12.	December 2017	11.391
13.	January 2018	13.183
14.	February 2018	11.185
15.	March 2018	13.305

It can be understood from the above Table 4.1, that there is high variation in wastage of concrete, ranging from 5.719% to as high as 13.305%. Appendix I shows a detailed calculation in tabular form for the results obtained in above Table 4.1. Where minimum wastages were observed in the months of March, July, October and November (5% to 9% approximately) and maximum wastages in rest of the months (9% to 13.5% approximately). The reason for such high wastages during the period of Dec 2017 to March 2018 were the varying quality of the fly-ash used from random sources due to political pressures.

4.2 Cumulative Percentile Average analysis

A cumulative percentile analysis was done on the data received from the google survey to rank the twelve commonly used materials in construction for being most wasted on site. Analysis done for the calculating degree of wastages and ranking based on those results from data collected by questionnaire survey and personal interviews. As shown in Table 4.2 below, we can identify that, frequency statistical analysis revealed, on Indian construction sites the most wasted material (from rank one and below) are Water, Sand and Concrete.

Table 4.2: Results of the survey, showing percentages of wastage of materials

Materials	**Percentages of wastage of materials**					**Average**	**Rank**
	0-10%	**11-20%**	**21-30%**	**31-40%**	**41-50%**		
Water	19	12	16	12	7	21.72	1
Sand	19	17	21	9	0	18.39	2
Concrete	22	20	13	9	2	17.61	3
Bricks	29	12	12	13	0	16.64	4
Mortar	31	9	14	12	0	16.33	5
Timber/Formwork	30	15	13	6	2	15.42	6
Ceramic tiles	31	18	9	6	2	14.66	7

Steel	32	16	11	6	1	14.35	8
Aggregate	32	17	11	5	1	14.05	9
Cement	35	14	13	4	0	13.11	10
Fuel	31	14	6	3	2	12.90	11
Pipes	34	22	7	2	1	12.21	12

In the above Table 4.2, it shows various frequency scattered in different percentile range of material waste in. Sand, Bricks, Mortar and Cement show minimum wastage in 41-50% of waste range. Water, Sand and Concrete show the highest percentage magnitude of wastage among all responses. For further study a cost comparison of top three materials needs to be done in order to understand the costliest of them which needs immediate attention for waste minimization. The top three material waste incurred from the above Table 4.2, are compared on their cost in Indian market scenario to move the experimental analysis ahead with concrete being the costliest among the top three.

4.3 Cost Comparison

For the results achieved from the survey, top three materials being wasted were selected for a practical cost comparison, which was carried out to understand the costliest material. Further after the cost comparison work, data collection for the production as raw material or finished product along with its magnitude of waste was to be collected of the costliest material for further study.

Cost comparison was done between water, sand and concrete. Material cost for each material was compared based on per cubic meter unit. Upon market analysis in Mumbai region it was found that from water for construction purpose fluctuates somewhere between free of cost to ₹ 43.20 per cubic meter as per Water Charges Rules (2015-16) clause 1.5, point 21. Similarly, the sand in market varied from ₹ 353.35 – ₹ 400 per cubic meter as per DSR (2017). Whereas concrete being the costliest varied from ₹ 3000 to ₹ 8000 and above (Rates are as from RMC plant and may vary depending upon the ingredients and admixtures used in production process). This clears that, concrete needs much attention for optimization in construction industry achieve sustainability to some extent, as concrete is a mix of multiple raw materials as its ingredients are directly extracted from the nature.

4.4 Descriptive & Frequency Statistical analysis

Descriptive and frequency statistical analysis has been discussed and explained in methodology chapter of this study, which includes calculating frequency index for the causes of material waste by giving options to the individual to select a weightage from 1 – rarely up to 5 – very frequent for every cause or event identified during the study. Similar options were provided for severity of waste, 1 – less severe to 5 – highly severe for every cause or event identified during the study. The results from the survey data is tabulated in Table 4.3 below:

Table 4.3: Ranked causes of resource wastages on construction sites

Sr. No.	Cause of waste	FI	SI	II	Rank
1	Poor strategy for waste minimization	52.73	55.45	29.24	1
2	Ordering errors/Limitations to order small quantities	50.61	51.52	26.07	2
3	Quality constraints of material received	48.79	51.52	25.13	3
4	Frequent design and client’s changes	47.27	49.39	23.35	4
5	Long project duration	45.45	47.27	21.49	5
6	Leftover material on site	45.15	46.97	21.21	6
7	Shortage and lack of experience of skilled workers	44.55	47.27	21.06	7
8	Poor site conditions	42.12	45.76	19.27	8
9	Wrong and lack of storage of materials	41.82	43.33	18.12	9
10	Rework due to workers mistakes	39.70	42.42	16.84	10
11	Damage caused by workers due to lack of experience	39.39	42.12	16.59	11
12	Poor quality and non-availability of equipment	37.27	40.91	15.25	12
13	Change in material prices	36.97	40.30	14.90	13
14	Mistakes in quantity surveying and over allowance	37.58	39.09	14.69	14
15	Weather conditions	35.15	39.09	13.74	15
16	Poor quality of materials	35.15	39.09	13.74	16
17	Unnecessary material handling	34.85	37.88	13.20	17
18	Interaction between various specialists	34.24	38.18	13.07	18
19	Complicated design	34.55	37.58	12.98	19
20	Damage during transportation	30.91	36.06	11.15	20
21	Theft and vandalism	30.61	35.15	10.76	21
22	Poor contract documents	29.09	35.45	10.31	22

23	Purchasing materials not complying with specifications	29.09	34.85	10.14	23
24	Supply in loose form	29.09	33.33	9.70	24

Table 4.3 highlights that, poor strategies for waste minimization, ordering errors, limitations to order small quantities, Quality constraints for rejection of concrete and Long project duration are the major causes for material wastage of material on construction sites in India.

4.5 Correlation Coefficients Between waste incurred and production of concrete

Correlation coefficient analysis was done on the 455 numbers of data collected from the RMC plant (Appendix-IV) in three sub categories:

a) Total quantity of daily concrete production (Y).
b) Total quantity of daily concrete produced/delivered in excess due to limitation of ordering small quantities (X_1).
c) Total quantity of daily concrete rejected from client/site of construction for its poor quality (X_2).
d) Total quantity of daily concrete waste incurred ($X_3 = X_1 + X_2$).
e) The results obtained from the correlation analysis between the production and wastages incurred is as shown in below Table 4.4:

Table 4.4: Correlation coefficients developed between Production and waste incurred

Sr. No.	Correlation between	Denotation	Correlation coefficient
1.	Production and waste incurred due to limitation of ordering small quantities/ordering error.	$Y - X_1$	0.84
2.	Production and waste incurred due to rejection of concrete for its poor quality.	$Y - X_2$	0.93
3.	Production and total wastage incurred.	$Y - X_3$	0.92

From Table 4.4, it can be summarised that the correlation between the daily production (Y) of concrete and waste incurred due to excess concrete (X_1) production is 0.84 which comes out to be a high positive correlation, correlation between the daily production (Y) of concrete and waste incurred due to rejected concrete(X_2)due to its poor quality is 0.93 which is a very high positive correlation and correlation between the daily production (Y) of concrete and total waste (X_3) incurred is 0.92 which is also a very high positive correlation. Thus, it can be incurred from the above results that there is a very high positive correlation between the production and wastage of concrete on Indian sites which needs proper minimization.

4.6 Modelling Production and On-site wastage Parameters

Simple Linear Regression analysis done using Data analysis tool add-in in Microsoft excel 2016 bestowed the following results.

4.6.1 Regression analysis between Y and X_1

The analysis conducted was between the daily production quantity and waste incurred due to excess quantity of concrete production or limitation of ordering small quantities. Below mentioned Figure 4.4, plots the X_1 line fit plot.

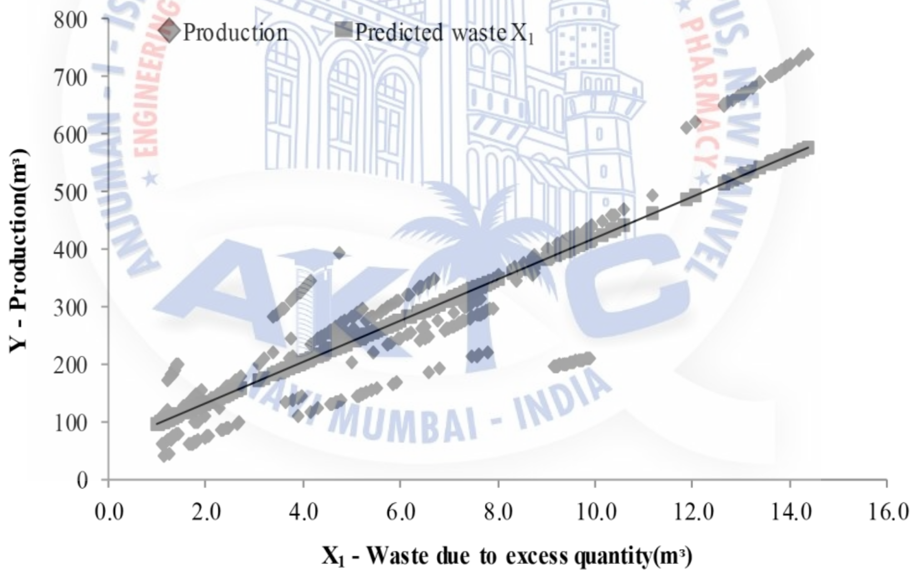

Figure 4.4: Scatter plot for the predicted value of X_1 with the Regression line model

Figure 4.4 show the results of the developed model 10 as mentioned below, for the prediction of daily waste incurred due to excess production and limitations to order small quantities.

$$Y = 0.0196X_1 + 0.3112 \quad (10)$$

Where for the developed model 10, we get the values of constants ‘a’ and ‘b’ to be 0.3112 and 0.0196 respectively. From the above equation if we have the production values for the next day, the values of wastages X_1 can be predicted easily.

4.6.2 Regression analysis between Y and X_2

The analysis conducted was between the daily production quantity and waste incurred due to rejection of concrete due to its quality issues. Below mentioned Figure 4.5, plots the X_2 line fit plot.

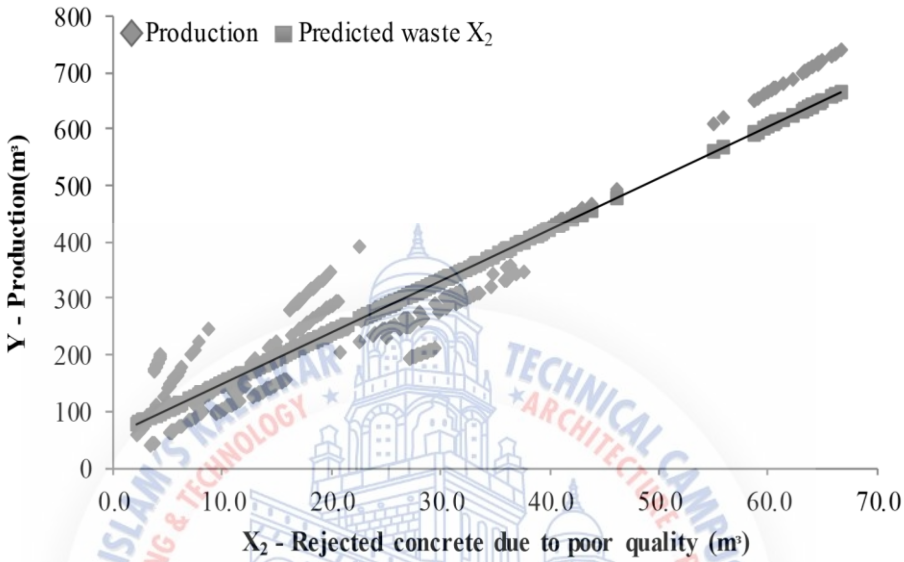

Figure 4.5: Scatter plot for the predicted value of X_2 with the Regression line model

Figure 4.5 show the results of developed model 11 as mentioned below, for the prediction of daily waste incurred due to rejected concrete for its poor quality.

$$Y = 0.0945X_2 - 2.6956 \tag{11}$$

Where for the developed model 11, we get the values of constants 'a' and 'b' to be -2.6956 and 0.0945 respectively. From the above equation if we have the production values for the next day, the values of wastages X_2 can be predicted easily.

4.6.3 Regression analysis between Y and X_3

The analysis conducted was between the daily production quantity and waste incurred due to rejection of concrete due to its quality issues. Below mentioned Figure 4.6, plots the X_3 line fit plot.

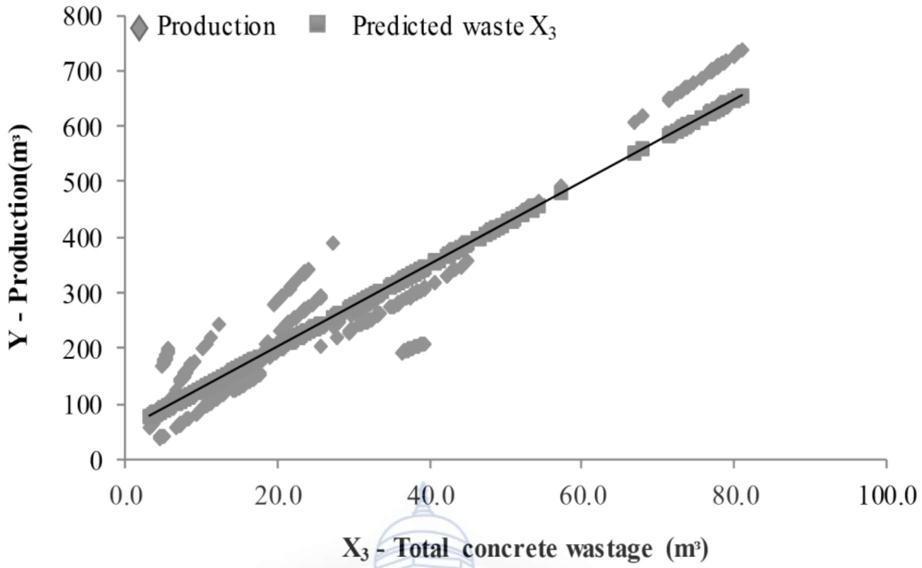

Figure 4.6: Scatter plot for the predicted value of X_3 with the Regression line model

Figure 4.6 show the results of developed model 12 as mentioned below, for the prediction of total waste incurred daily.

$$Y = 0.1141X_3 - 2.3844 \quad (12)$$

Where for the developed model 12, we get the values of constants 'a' and 'b' to be -2.3844 and 0.1141 respectively. From the above equation if we have the production values for the next day, the values of wastages X_3 can be predicted easily.

The line equation developed in model 12, can be used by any of the three (client, contractor and consultant) parties to predict the degree of wastages that can happen during the next day of concrete production, transportation and placing, to be alert for the upcoming situation and be ready with the measure to optimize and minimize the wastage to some extent. The models developed in model 8 and model 9 can be used by the parties to predict the degree of waste due to the specific cause of the wastage. These models are developed to help the construction practitioners on site for reduction of concrete waste production on daily basis. For details of Regression statistics please refer Appendix-III.

4.7 Results from EOQ modelling of the production

Economic Order Quantities were derived of daily production to fulfil each 20-days demand of the site to keep the production and delivery in control. This practice will help to study & compare the difference in wastage incurred. EOQ was derived only for M40 grade of concrete as it was produced in huge quantities based on the demands of the site during the study period.

Below mention Table 4.5 states the difference in total cost of concrete grade M40. Upon EOQ analysis it was found that the economic order quantities for 20 days of demand resulted in lowest overall cost of concrete. Calculation for the above derived results of 20-day EOQ are shown in Appendix-II. Also, upon analysing further it came to picture that 20days economic order quantity gave the minimum differences in daily demand from site and daily production as per EOQ modelling, keeping the loss of RMC plant to minimum.

Table 4.5: Cost comparison of waste incurred before and after EOQ.

Sr. No.	Description	Waste		Difference
		Before EOQ	After EOQ	
1.	Quantity (m^3)	6384	1152	5232
2.	Cost (Rs.)	4,10,96,553.12	74,17,979	3,36,78,554.12

The above Table. 4.5 shows the obvious and a huge difference in quantity and cost of M40 grade concrete wastage of 5232m^3 valued at Rs. 3.37 crores approximately. Also, a correlation was derived between the new economic order quantity (denoted as p) and the difference in previous order quantities to the economic order quantity (denoted as q), which came out to be a strong downhill (negative linear relationship) at -0.911 (very high negative correlation). Regression analysis results between 'p' and 'q' for 20day economic order quantity are shown below Fig. 4.7 and EOQ prediction model.

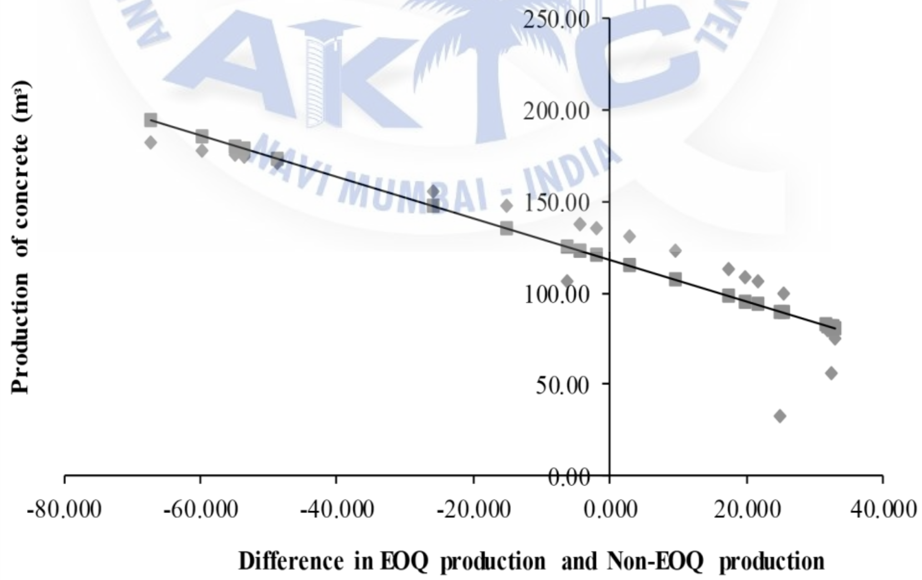

Figure 4.7: Predicted Production as per EOQ

Figure 4.7 show the results of developed model (13) as mentioned below, for the prediction EOQ Production of M40 concrete on daily basis.

$$Y = -1.132X + 118.034 \quad (13)$$

Where for the developed model (13), we get the values of constants ‘a’ and ‘b’ to be 118.034 and -1.132 respectively. From the above equation if we have the production values for the next day, the values of wastages X can be predicted too. The regression statistics for above Eq. (13) can be viewed as in Appendix-III. From Appendix-III it can be understood that, the value of R^2 signifies that linear model fits the set of observations by 83%, which is quite accurate for prediction purpose of wastages in RMC plant. The models developed in this study are subjected to only one particular RMC plant from where data was collected for the study purpose. Similar studies can be done to develop models for prediction of wastage associated to their pattern of production and wastage parameters.

Chapter 5

Summary and Conclusions

5.1 Summary

The entire study depends on the three main objectives.

1. To identify and determine the magnitude of causes and materials being wasted during the construction stages of any project and optimizing the same for a sustainable construction process.
2. Finding correlation coefficients between the Production and waste incurred on daily basis of construction materials.
3. To develop a waste prediction model using Simple Regression analysis with the help of Data analysis tool pack add-in in Microsoft Excel 2016 taking in account the causes and magnitude of waste obtained from the first part of the study.

Data collected from a single RMC plant was done between January 2017 to March 2018 with one rainy season during which the production rate was low. The limitations of models developed in this study is that they will be applicable only to one RMC plant, as this study was done using their data only. Similar kind of study can be done to develop models for wastage prediction and EOQ model for wastage minimization for different RMC plants and materials. The flexibility of this study was that the techniques and tools used in this study are simple to easily understood by any engineer, manager or skilled leman on construction sites to personally develop and minimize the material wastages by their own.

Reconciliation is a process practiced by the construction practitioners at the end of project to estimate and quantify the excess cost incurred for the project, where as a remedial suggestion, this practice can be introduces on monthly to weekly basis to track excess cost incurred which will allow taking measures to regulate wastages, overheads, cost-overrun and time-overrun. This change in practice can help in forming measures to minimize wastages and lift up the lacking areas in construction which cause wastages while saving the environment and keeping the construction processes sustainable.

Use of Recycling bins on construction sites is one of the best methods to recycle the construction material waste instantly without any transportation or extra labour cost included in it. These bins are set up on construction sites and assigned with different colours for specific materials. As shown in Figure 5.1 below:

Figure 5.1: Recycle bins for construction material recycling purpose (Aravind, 2018).

The above Figure 5.1 shows an example: Green bins are used to dump and recycle unused steel bars. The unused steel bars of different lengths are dumped in steel recycle bin, during the course of construction if a spare steel bar is needed for overlapping works or other such small reinforcement works, appropriate size of steel bar from the bin can be collected for the purpose. This process can be done for other materials too, such as: Bricks, Wood, PVC pipes, Blocks etc.

5.2 Conclusions

Wastages can not be made zero at any phase of construction hence the only way to achieve sustainability in construction processes is by minimizing the existing wastages in the industry. Identification of forty-eight (48) causes of material wastages were done from the literature survey of which, twenty-four (24) most common and directly relatable to Indian sites were selected for the questionnaire survey. A descriptive and frequency statistical analysis was done with the data collected from the questionnaire survey to identify and rank the most important causes of construction material wastage. The list of twelve (12) most commonly used materials on Indian sites were also distributed along the questionnaire survey to gather the degree of waste observed and select the top three materials with maximum wastage. A cost comparison of the top three materials with high waste in industry was done to select the most costly of them for the further study. Concrete being the costliest of all was selected for further study.

Data collection was done from a RMC plant for a fifteen (15) months of time which included data of (1) Daily concrete production, (2) Daily waste due to excess production because of limitation in ordering small quantities and (3) Daily waste incurred due to rejection of poor quality of concrete. The data of waste incurred were analysed on the basis of correlation with daily production quantity giving results up to 0.92 degree of correlation which is a very high correlation. Further developing model keeping production of concrete as independent variable and wastage as dependent variables was done. Regression analysis was used for modelling the prediction model on MS Office Excel with the use of Data analysis tool pack add-in which can be used by any construction practitioner for waste prediction if he has the production quantity for the next day. Use of EOQ analysis done to minimize the wastages of M40 grade concrete by 5232 m^3 costing Rs. 3.37 crores approximately.

In this study, further work needs to be done for validation of results in comparison with regression analysis and its accuracy by modelling the prediction models using soft computing techniques as well.

5.3 Scope for future work

1. The above developed statistical model proved to be reasonable and optimum with fair amount of accuracy between 71% to 89%, showed a satisfactory performance to predict the wastage of concrete as a construction material.
2. Further study can be done using ANN (Artificial Neural Networks) and other soft computing techniques to develop better model for the prediction purpose with much better accuracy. ANN have proved to be highly accurate in predicting and forecasting of expected data.
3. The study only covered concrete wastages, further studies can be done to minimize other resources of the construction industry such as cement, sand, steel, wood formwork, etc.
4. Also, different programming languages like Python, etc. can also be used for machine learning in developing expected models.

5. It was also observed during the study that use of EOQ on sites in India is very minimum to the knowledge of contractors, reducing the material wastage.

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APPENDIX I

Spreadsheet showing Production and wastage rate with its cost analysis on monthly basis.

Month	Sr. No.	Grade of Concrete	Quantity(m^3)	Total quantity(m^3)	Rate(Rs/m^3)	Monthly cost(Rs.)	Total Monthly Cost(Rs.)	Unused Concrete(m^3)	Rejected Concrete(m^3)	Total wastage(m^3)	Grand total of concrete waste(m^3)	Individual cost of Waste concrete(Rs.)	Total cost of waste Concrete(Rs.)
January, 2017	1	M10	720	2400	5193.78	3739521.6	13947593	24	42	66	265	342789.48	1548470.46
	2	M30	90		6082.2	547398		4	9	13		79068.6	
	3	M40	1200		6437.43	7724916		18	120	138		888365.34	
	4	M5	390		4963.48	1935757.2		20	28	48		238247.04	
February,2017	5	M30	4500	4680	6082.2	27369900	28528637	150	300	450	478	2736990	2917238.04
	6	M40	180		6437.43	1158737.4		15	13	28		180248.04	
March, 2017	7	M30	2700	4980	6082.2	16421940	30391289	59	16	75	262	456165	1630468.91
	8	M40	1620		6437.43	10428636.6		15	146	161		1036426.23	
	9	M50	150		6728.92	1009338		2	3	5		33644.6	
	10	M5	510		4963.48	2531374.8		5	16	21		104233.08	
April, 2017	11	M30	210	3240	6082.2	1277262	20826398	3	15	18	346	109479.6	2223871.54
	12	M40	2880		6437.43	18539798.4		29	289	318		2047102.74	
	13	M50	150		6728.92	1009338		1	9	10		67289.2	
May, 2017	14	M10	270	10050	5193.78	1402320.6	64219118	11	4	15	1167	77906.7	7473423.26
	15	M30	570		6082.2	3466854		12	52	64		389260.8	
	16	M40	9000		6437.43	57936870		270	810	1080		6952424.4	
	17	M50	210		6728.92	1413073.2		1	7	8		53831.36	
June, 2017	18	M10	120	1590	5193.78	623253.6	10057313	2	5	7	160	36356.46	1019898.86
	19	M30	180		6082.2	1094796		2	6	8		48657.6	
	20	M40	1170		6437.43	7531793.1		35	105	140		901240.2	
	21	M50	120		6728.92	807470.4		1	4	5		33644.6	
July, 2017	22	M25	720	2290	5947.96	4282531.2	14365734	11	22	33	128	196282.68	806424.81
	23	M35	300		6358.89	1907667		6	12	18		114460.02	
	24	M40	1270		6437.43	8175536.1		26	51	77		495682.11	

August, 2017	25	M10	570	8460	5193.78	2960454.6	53463902	6	46	52	962	270076.56	6102504.49
	26	M25	540		5947.96	3211898.4		11	38	49		291450.04	
	27	M35	300		6358.89	1907667		3	18	21		133536.69	
	28	M40	7050		6437.43	45383881.5		205	635	840		5407441.2	
September, 2017	29	M10	480	4215	5193.78	2493014.4	26084028	15	19	34	483	176588.52	3045888.05
	30	M35	135		6358.89	858450.15		3	3	6		38153.34	
	31	M40	3300		6437.43	21243519		33	396	429		2761657.47	
	32	M5	300		4963.48	1489044		2	12	14		69488.72	
October, 2017	33	M10	1650	7920	5193.78	8569737	49708812	25	99	124	713	644028.72	4525674.59
	34	M30	990		6082.2	6021378		18	70	88		535233.6	
	35	M40	1410		6437.43	9076776.3		28	57	85		547181.55	
	36	M50	3870		6728.92	26040920.4		74	342	416		2799230.72	
November, 2017	37	M30	2700	9420	6082.2	16421940	60809536	24	109	133	655	808932.6	4248264.85
	38	M40	2850		6437.43	18346675.5		51	200	251		1615794.93	
	39	M50	3870		6728.92	26040920.4		39	232	271		1823537.32	
December, 2017	40	M10	120	20700	5193.78	623253.6	131016778	1	4	5	2385	25968.9	15061167.12
	41	M25	210		5947.96	1249071.6		2	4	6		35687.76	
	42	M30	8700		6082.2	52915140		292	881	1173		7134420.6	
	43	M35	300		6358.89	1907667		5	18	23		146254.47	
	44	M40	7500		6437.43	48280725		38	675	713		4589887.59	
	45	M50	3870		6728.92	26040920.4		78	387	465		3128947.8	
January, 2018	46	M25	105	8685	5947.96	624535.8	56259577	2	6	8	1143	47583.68	7404492.89
	47	M35	450		6358.89	2861500.5		8	18	26		165331.14	
	48	M40	6630		6437.43	42680160.9		133	796	929		5980372.47	
	49	M50	1500		6728.92	10093380		30	150	180		1211205.6	
February, 2018	50	M30	2760	12240	6082.2	16786872	78423797	83	193	276	1350	1678687.2	8672969.85
	51	M35	360		6358.89	2289200.4		4	29	33		209843.37	
	52	M40	6930		6437.43	44611389.9		132	624	756		4866697.08	
	53	M50	2190		6728.92	14736334.8		44	241	285		1917742.2	
March, 2018	54	M30	2850	8070	6082.2	17334270	51488571	80	342	422	1090	2566688.4	6933642.85
	55	M40	3330		6437.43	21436641.9		73	366	439		2826031.77	
	56	M50	1890		6728.92	12717658.8		59	170	229		1540922.68	
Grand Total			108940			689591082.5		2323	9264	11587		73614400.57	

APPENDIX II

Results from EOQ analysis of 10, 20 and 30 days

Sr.no.	Description	Unit	Daily	5Days	10Day	20Days	30Day
1	No. of Order	No.	455	91	46	23	16
2	Qty Per order	m³	124	618	1223	2446	3516
3	Unit Rate per m³ (M40)	₹	6437.43	6437.43	6437.43	6437.43	6437.43
4	Basic Cost Per Order	₹	795963	3979817	7873117	15746234	22635211
5	Discount	%	0%	0%	0%	0%	0%
6	Discounted Cost	₹	795963	3979817	7873117	15746234	22635211
7	Average Annual Inventory	₹	397982	1989909	3936558	7873117	11317605
8	ICC Percentage	%	20%	20%	20%	20%	20%
9	Inventory Carrying Cost	₹	79596	397982	787312	1574623	2263521
10	Ordering Cost	₹	50000	50000	50000	50000	50000
11	Total Ordering Cost	₹	22750000	4550000	2300000	1150000	800000
12	Total Concrete (M40) Cost	₹	362163374	362163374	362163374	362163374	362163374
13	Overall Cost	₹	384992971	367111356	365250686	364887998	365226895

In the above table it can be understood easily that the overall cost for the 20days economic order quantity of M40 grade concrete is the minimum of all with slight to huge difference in cost. Note that the above-mentioned discount applicable and percent inventory cost were used as from the data collected from the sites.

*The above-mentioned cost of concrete obtained does not contains transportation and GST.

APPENDIX III

Regression statistics for the above developed models

Regression Statistics for X_1 Line fit plot	
Multiple R	0.84
R Square	0.71
Adjusted R Square	0.71
Standard Error	83.24
Observations	455

Regression Statistics for X_2 Line fit plot	
Multiple R	0.93
R Square	0.86
Adjusted R Square	0.86
Standard Error	57.48
Observations	455

Regression Statistics for X_3 Line fit plot	
Multiple R	0.92
R Square	0.85
Adjusted R Square	0.85
Standard Error	59.45
Observations	455

Regression Statistics for EOQ & Difference in production fit plot	
Multiple R	0.910845215
R Square	0.829639006
Adjusted R Square	0.821526578
Standard Error	17.68361236
Observations	455

APPENDIX IV

Day	Total concrete Production	Total	Mean	Waste Due to Ordering Errors/Excess Concrete	Waste caused due to Rejection for quality of concrete	Total Wastage
	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
	X			Y_1	Y_2	Y_3
Sunday	138	2488	80	3.8	11.4	15.2
Monday	75			2.1	6.2	8.3
Tuesday	86			2.4	7.1	9.5
Wednesday	90			2.5	7.5	9.9
Thursday	74			2.0	6.1	8.2
Friday	74			2.0	6.1	8.2
Saturday	63			1.7	5.2	7.0
Sunday	142			3.9	11.8	15.7
Monday	66			1.8	5.5	7.3
Tuesday	63			1.7	5.2	7.0
Wednesday	97			2.7	8.0	10.7
Thursday	84			2.3	7.0	9.3
Friday	73			2.0	6.1	8.1
Saturday	89			2.4	7.4	9.8
Sunday	138			3.8	11.4	15.2
Monday	67			1.8	5.6	7.4
Tuesday	65			1.8	5.4	7.2
Wednesday	63			1.7	5.2	7.0
Thursday	61			1.7	5.1	6.7
Friday	62			1.7	5.1	6.8
Saturday	42			1.2	3.5	4.6
Sunday	145			4.0	12.0	16.0
Monday	65			1.8	5.4	7.2
Tuesday	75			2.1	6.2	8.3
Wednesday	43			1.2	3.6	4.7
Thursday	65			1.8	5.4	7.2
Friday	41			1.1	3.4	4.5
Saturday	98			2.7	8.1	10.8
Sunday	133			3.7	11.0	14.7
Monday	45			1.2	3.7	5.0
Tuesday	66			1.8	5.5	7.3
Wednesday	154	4368	156	5.4	10.3	15.7
Thursday	147			5.2	9.8	15.0

Friday	168			5.9	11.2	17.1
Saturday	111			3.9	7.4	11.3
Sunday	212			7.5	14.2	21.6
Monday	154			5.4	10.3	15.7
Tuesday	147			5.2	9.8	15.0
Wednesday	168			5.9	11.2	17.1
Thursday	111			3.9	7.4	11.3
Friday	133			4.7	8.9	13.6
Saturday	146			5.1	9.8	14.9
Sunday	216			7.6	14.4	22.0
Monday	147			5.2	9.8	15.0
Tuesday	122			4.3	8.1	12.4
Wednesday	136			4.8	9.1	13.9
Thursday	145			5.1	9.7	14.8
Friday	148			5.2	9.9	15.1
Saturday	187			6.6	12.5	19.1
Sunday	215			7.6	14.4	21.9
Monday	130			4.6	8.7	13.3
Tuesday	157			5.5	10.5	16.0
Wednesday	131			4.6	8.8	13.4
Thursday	150			5.3	10.0	15.3
Friday	134			4.7	9.0	13.7
Saturday	118			4.2	7.9	12.0
Sunday	222			7.8	14.8	22.6
Monday	193			6.8	12.9	19.7
Tuesday	166			5.8	11.1	16.9
Wednesday	145	5146	166	2.2	5.1	7.3
Thursday	155			2.4	5.4	7.8
Friday	165			2.5	5.8	8.3
Saturday	172			2.6	6.0	8.7
Sunday	201			3.1	7.1	10.1
Monday	158			2.4	5.5	8.0
Tuesday	160			2.4	5.6	8.1
Wednesday	157			2.4	5.5	7.9
Thursday	153			2.3	5.4	7.7
Friday	152			2.3	5.3	7.7
Saturday	158			2.4	5.5	8.0
Sunday	222			3.4	7.8	11.2
Monday	170			2.6	6.0	8.6
Tuesday	152			2.3	5.3	7.7
Wednesday	171			2.6	6.0	8.6
Thursday	165			2.5	5.8	8.3

Friday	141			2.2	4.9	7.1
Saturday	170			2.6	6.0	8.6
Sunday	210			3.2	7.4	10.6
Monday	161			2.5	5.7	8.1
Tuesday	157			2.4	5.5	7.9
Wednesday	156			2.4	5.5	7.9
Thursday	148			2.3	5.2	7.5
Friday	146			2.2	5.1	7.4
Saturday	169			2.6	5.9	8.5
Sunday	245			3.7	8.6	12.3
Monday	155			2.4	5.4	7.8
Tuesday	147			2.2	5.2	7.4
Wednesday	153			2.3	5.4	7.7
Thursday	178			2.7	6.2	9.0
Friday	154			2.4	5.4	7.8
Saturday	111	3240	108	1.1	10.7	11.9
Sunday	119			1.2	11.5	12.7
Monday	109			1.1	10.5	11.6
Tuesday	112			1.1	10.8	12.0
Wednesday	110			1.1	10.6	11.7
Thursday	118			1.2	11.4	12.6
Friday	100			1.0	9.7	10.7
Saturday	99			1.0	9.6	10.6
Sunday	112			1.1	10.8	12.0
Monday	111			1.1	10.7	11.9
Tuesday	116			1.2	11.2	12.4
Wednesday	109			1.1	10.5	11.6
Thursday	97			1.0	9.4	10.4
Friday	102			1.0	9.9	10.9
Saturday	105			1.1	10.1	11.2
Sunday	107			1.1	10.3	11.4
Monday	104			1.1	10.0	11.1
Tuesday	119			1.2	11.5	12.7
Wednesday	104			1.1	10.0	11.1
Thursday	102			1.0	9.9	10.9
Friday	100			1.0	9.7	10.7
Saturday	98			1.0	9.5	10.5
Sunday	111			1.1	10.7	11.9
Monday	112			1.1	10.8	12.0
Tuesday	116			1.2	11.2	12.4
Wednesday	105			1.1	10.1	11.2
Thursday	99			1.0	9.6	10.6

Friday	120			1.2	11.6	12.8
Saturday	112			1.1	10.8	12.0
Sunday	101			1.0	9.8	10.8
Monday	196	6262	202	9.2	27.3	37
Tuesday	204			9.6	28.4	38
Wednesday	200			9.4	27.9	37
Thursday	201			9.4	28.0	37
Friday	197			9.2	27.5	37
Saturday	196			9.2	27.3	37
Sunday	210			9.8	29.3	39
Monday	203			9.5	28.3	38
Tuesday	207			9.7	28.9	39
Wednesday	200			9.4	27.9	37
Thursday	195			9.1	27.2	36
Friday	200			9.4	27.9	37
Saturday	198			9.3	27.6	37
Sunday	211			9.9	29.4	39
Monday	205			9.6	28.6	38
Tuesday	208			9.8	29.0	39
Wednesday	206			9.7	28.7	38
Thursday	197			9.2	27.5	37
Friday	207			9.7	28.9	39
Saturday	195			9.1	27.2	36
Sunday	203			9.5	28.3	38
Monday	209			9.8	29.1	39
Tuesday	197			9.2	27.5	37
Wednesday	206			9.7	28.7	38
Thursday	207			9.7	28.9	39
Friday	202			9.5	28.2	38
Saturday	199			9.3	27.7	37
Sunday	201			9.4	28.0	37
Monday	208			9.8	29.0	39
Tuesday	198			9.3	27.6	37
Wednesday	196			9.2	27.3	37
Thursday	177	5580	186	1.3	3.8	5.1
Friday	191			1.4	4.1	5.5
Saturday	179			1.3	3.9	5.1
Sunday	200			1.4	4.3	5.7
Monday	180			1.3	3.9	5.2
Tuesday	193			1.4	4.2	5.5
Wednesday	183			1.3	3.9	5.2
Thursday	189			1.4	4.1	5.4

Friday	190			1.4	4.1	5.4
Saturday	182			1.3	3.9	5.2
Sunday	196			1.4	4.2	5.6
Monday	178			1.3	3.8	5.1
Tuesday	179			1.3	3.9	5.1
Wednesday	171			1.2	3.7	4.9
Thursday	196			1.4	4.2	5.6
Friday	176			1.3	3.8	5.0
Saturday	185			1.3	4.0	5.3
Sunday	183			1.3	3.9	5.2
Monday	191			1.4	4.1	5.5
Tuesday	181			1.3	3.9	5.2
Wednesday	186			1.3	4.0	5.3
Thursday	193			1.4	4.2	5.5
Friday	191			1.4	4.1	5.5
Saturday	190			1.4	4.1	5.4
Sunday	198			1.4	4.3	5.7
Monday	187			1.3	4.0	5.4
Tuesday	183			1.3	3.9	5.2
Wednesday	175			1.3	3.8	5.0
Thursday	189			1.4	4.1	5.4
Friday	188			1.3	4.0	5.4
Saturday	62	2356	76	1.1	2.2	3.4
Sunday	125			2.3	4.5	6.8
Monday	80			1.5	2.9	4.3
Tuesday	76			1.4	2.7	4.1
Wednesday	62			1.1	2.2	3.4
Thursday	78			1.4	2.8	4.2
Friday	65			1.2	2.3	3.5
Saturday	79			1.4	2.9	4.3
Sunday	109			2.0	3.9	5.9
Monday	80			1.5	2.9	4.3
Tuesday	70			1.3	2.5	3.8
Wednesday	62			1.1	2.2	3.4
Thursday	70			1.3	2.5	3.8
Friday	64			1.2	2.3	3.5
Saturday	78			1.4	2.8	4.2
Sunday	99			1.8	3.6	5.4
Monday	73			1.3	2.6	4.0
Tuesday	75			1.4	2.7	4.1
Wednesday	71			1.3	2.6	3.9
Thursday	74			1.3	2.7	4.0

Friday	71			1.3	2.6	3.9
Saturday	63			1.1	2.3	3.4
Sunday	98			1.8	3.5	5.3
Monday	63			1.1	2.3	3.4
Tuesday	61			1.1	2.2	3.3
Wednesday	67			1.2	2.4	3.6
Thursday	60			1.1	2.2	3.3
Friday	75			1.4	2.7	4.1
Saturday	71			1.3	2.6	3.9
Sunday	101			1.8	3.6	5.5
Monday	74			1.3	2.7	4.0
Tuesday	281	8460	273	7.5	24.5	31.9
Wednesday	279			7.4	24.3	31.7
Thursday	245			6.5	21.3	27.9
Friday	281			7.5	24.5	31.9
Saturday	261			6.9	22.7	29.7
Sunday	267			7.1	23.3	30.4
Monday	263			7.0	22.9	29.9
Tuesday	271			7.2	23.6	30.8
Wednesday	285			7.6	24.8	32.4
Thursday	260			6.9	22.6	29.6
Friday	289			7.7	25.2	32.9
Saturday	261			6.9	22.7	29.7
Sunday	260			6.9	22.6	29.6
Monday	240			6.4	20.9	27.3
Tuesday	266			7.1	23.2	30.2
Wednesday	265			7.0	23.1	30.1
Thursday	261			6.9	22.7	29.7
Friday	297			7.9	25.9	33.8
Saturday	279			7.4	24.3	31.7
Sunday	287			7.6	25.0	32.6
Monday	286			7.6	24.9	32.5
Tuesday	287			7.6	25.0	32.6
Wednesday	290			7.7	25.3	33.0
Thursday	295			7.8	25.7	33.5
Friday	247			6.6	21.5	28.1
Saturday	292			7.8	25.4	33.2
Sunday	274			7.3	23.9	31.2
Monday	272			7.2	23.7	30.9
Tuesday	270			7.2	23.5	30.7
Wednesday	275			7.3	24.0	31.3
Thursday	274			7.3	23.9	31.2

Friday	148	4262	142	1.8	14.9	16.8
Saturday	130			1.6	13.1	14.7
Sunday	155			1.9	15.7	17.6
Monday	132			1.6	13.3	15.0
Tuesday	141			1.7	14.2	16.0
Wednesday	140			1.7	14.1	15.9
Thursday	143			1.8	14.4	16.2
Friday	152			1.9	15.4	17.2
Saturday	139			1.7	14.0	15.8
Sunday	155			1.9	15.7	17.6
Monday	127			1.6	12.8	14.4
Tuesday	131			1.6	13.2	14.9
Wednesday	134			1.7	13.5	15.2
Thursday	136			1.7	13.7	15.4
Friday	126			1.6	12.7	14.3
Saturday	151			1.9	15.3	17.1
Sunday	155			1.9	15.7	17.6
Monday	128			1.6	12.9	14.5
Tuesday	148			1.8	14.9	16.8
Wednesday	145			1.8	14.6	16.4
Thursday	151			1.9	15.3	17.1
Friday	142			1.8	14.3	16.1
Saturday	135			1.7	13.6	15.3
Sunday	156			1.9	15.8	17.7
Monday	147			1.8	14.8	16.7
Tuesday	152			1.9	15.4	17.2
Wednesday	143			1.8	14.4	16.2
Thursday	153			1.9	15.5	17.4
Friday	126			1.6	12.7	14.3
Saturday	141			1.7	14.2	16.0
Sunday	295	8184	264	5.2	20.5	25.7
Monday	271			4.8	18.8	23.6
Tuesday	255			4.5	17.7	22.2
Wednesday	249			4.4	17.3	21.7
Thursday	258			4.6	17.9	22.5
Friday	291			5.2	20.2	25.3
Saturday	284			5.0	19.7	24.7
Sunday	294			5.2	20.4	25.6
Monday	273			4.8	18.9	23.8
Tuesday	255			4.5	17.7	22.2
Wednesday	258			4.6	17.9	22.5
Thursday	211			3.7	14.6	18.4

Friday	214			3.8	14.9	18.6
Saturday	244			4.3	16.9	21.3
Sunday	291			5.2	20.2	25.3
Monday	234			4.1	16.2	20.4
Tuesday	244			4.3	16.9	21.3
Wednesday	267			4.7	18.5	23.3
Thursday	275			4.9	19.1	24.0
Friday	247			4.4	17.1	21.5
Saturday	246			4.4	17.1	21.4
Sunday	288			5.1	20.0	25.1
Monday	247			4.4	17.1	21.5
Tuesday	264			4.7	18.3	23.0
Wednesday	294			5.2	20.4	25.6
Thursday	282			5.0	19.6	24.6
Friday	270			4.8	18.7	23.5
Saturday	252			4.5	17.5	21.9
Sunday	263			4.7	18.3	22.9
Monday	286			5.1	19.8	24.9
Tuesday	282			5.0	19.6	24.6
Wednesday	298	9420	314	3.6	17.1	20.7
Thursday	288			3.5	16.5	20.0
Friday	325			3.9	18.7	22.6
Saturday	337			4.1	19.3	23.4
Sunday	345			4.2	19.8	24.0
Monday	317			3.8	18.2	22.0
Tuesday	286			3.5	16.4	19.9
Wednesday	340			4.1	19.5	23.6
Thursday	328			4.0	18.8	22.8
Friday	290			3.5	16.6	20.2
Saturday	337			4.1	19.3	23.4
Sunday	292			3.5	16.8	20.3
Monday	332			4.0	19.1	23.1
Tuesday	281			3.4	16.1	19.5
Wednesday	297			3.6	17.0	20.6
Thursday	290			3.5	16.6	20.2
Friday	298			3.6	17.1	20.7
Saturday	290			3.5	16.6	20.2
Sunday	340			4.1	19.5	23.6
Monday	312			3.8	17.9	21.7
Tuesday	296			3.6	17.0	20.6
Wednesday	336			4.1	19.3	23.4
Thursday	286			3.5	16.4	19.9

Friday	316			3.8	18.1	22.0
Saturday	320			3.9	18.4	22.2
Sunday	393			4.8	22.6	27.3
Monday	324			3.9	18.6	22.5
Tuesday	310			3.8	17.8	21.5
Wednesday	296			3.6	17.0	20.6
Thursday	320			3.9	18.4	22.2
Friday	620	21389	690	12.1	55.9	68.0
Saturday	700			13.6	63.1	76.8
Sunday	720			14.0	64.9	78.9
Monday	665			12.9	60.0	72.9
Tuesday	715			13.9	64.5	78.4
Wednesday	701			13.6	63.2	76.9
Thursday	651			12.7	58.7	71.4
Friday	729			14.2	65.8	79.9
Saturday	709			13.8	64.0	77.7
Sunday	673			13.1	60.7	73.8
Monday	705			13.7	63.6	77.3
Tuesday	689			13.4	62.1	75.5
Wednesday	734			14.3	66.2	80.5
Thursday	703			13.7	63.4	77.1
Friday	703			13.7	63.4	77.1
Saturday	680			13.2	61.3	74.6
Sunday	710			13.8	64.0	77.9
Monday	710			13.8	64.0	77.9
Tuesday	703			13.7	63.4	77.1
Wednesday	716			13.9	64.6	78.5
Thursday	717			13.9	64.7	78.6
Friday	700			13.6	63.1	76.8
Saturday	650			12.6	58.6	71.3
Sunday	654			12.7	59.0	71.7
Monday	610			11.9	55.0	66.9
Tuesday	660			12.8	59.5	72.4
Wednesday	671			13.1	60.5	73.6
Thursday	739			14.4	66.7	81.0
Friday	669			13.0	60.3	73.4
Saturday	710			13.8	64.0	77.9
Sunday	673			13.1	60.7	73.8
Monday	333	8990	290	6.4	35.9	42.3
Tuesday	342			6.6	36.9	43.4
Wednesday	291			5.6	31.4	37.0
Thursday	231			4.4	24.9	29.3

Friday	332			6.4	35.8	42.2
Saturday	306			5.9	33.0	38.9
Sunday	250			4.8	27.0	31.8
Monday	244			4.7	26.3	31.0
Tuesday	321			6.2	34.6	40.8
Wednesday	291			5.6	31.4	37.0
Thursday	254			4.9	27.4	32.3
Friday	283			5.4	30.5	35.9
Saturday	263			5.0	28.4	33.4
Sunday	310			6.0	33.4	39.4
Monday	335			6.4	36.1	42.5
Tuesday	302			5.8	32.6	38.4
Wednesday	348			6.7	37.5	44.2
Thursday	320			6.1	34.5	40.6
Friday	299			5.7	32.2	38.0
Saturday	253			4.9	27.3	32.1
Sunday	282			5.4	30.4	35.8
Monday	309			5.9	33.3	39.2
Tuesday	294			5.6	31.7	37.3
Wednesday	251			4.8	27.1	31.9
Thursday	333			6.4	35.9	42.3
Friday	276			5.3	29.8	35.1
Saturday	248			4.8	26.7	31.5
Sunday	297			5.7	32.0	37.7
Monday	252			4.8	27.2	32.0
Tuesday	262			5.0	28.2	33.3
Wednesday	278			5.3	30.0	35.3
Thursday	385	11640	416	8.7	36.0	44.7
Friday	367			8.3	34.3	42.6
Saturday	355			8.0	33.1	41.2
Sunday	459			10.4	42.9	53.2
Monday	449			10.1	41.9	52.1
Tuesday	437			9.9	40.8	50.7
Wednesday	457			10.3	42.7	53.0
Thursday	354			8.0	33.1	41.1
Friday	416			9.4	38.8	48.2
Saturday	427			9.7	39.9	49.5
Sunday	460			10.4	43.0	53.4
Monday	422			9.5	39.4	48.9
Tuesday	434			9.8	40.5	50.3
Wednesday	367			8.3	34.3	42.6
Thursday	399			9.0	37.3	46.3

Friday	409			9.2	38.2	47.4
Saturday	401			9.1	37.4	46.5
Sunday	494			11.2	46.1	57.3
Monday	377			8.5	35.2	43.7
Tuesday	416			9.4	38.8	48.2
Wednesday	413			9.3	38.6	47.9
Thursday	439			9.9	41.0	50.9
Friday	388			8.8	36.2	45.0
Saturday	440			9.9	41.1	51.0
Sunday	468			10.6	43.7	54.3
Monday	417			9.4	38.9	48.4
Tuesday	420			9.5	39.2	48.7
Wednesday	370			8.4	34.6	42.9
Thursday	356	8664	279	8.7	36.1	44.8
Friday	300			7.3	30.4	37.7
Saturday	304			7.4	30.8	38.2
Sunday	343			8.4	34.7	43.1
Monday	245			6.0	24.8	30.8
Tuesday	276			6.8	28.0	34.7
Wednesday	235			5.7	23.8	29.6
Thursday	237			5.8	24.0	29.8
Friday	244			6.0	24.7	30.7
Saturday	266			6.5	26.9	33.5
Sunday	358			8.8	36.3	45.0
Monday	290			7.1	29.4	36.5
Tuesday	222			5.4	22.5	27.9
Wednesday	305			7.5	30.9	38.4
Thursday	300			7.3	30.4	37.7
Friday	302			7.4	30.6	38.0
Saturday	313			7.7	31.7	39.4
Sunday	265			6.5	26.8	33.3
Monday	204			5.0	20.7	25.7
Tuesday	222			5.4	22.5	27.9
Wednesday	301			7.4	30.5	37.9
Thursday	300			7.3	30.4	37.7
Friday	254			6.2	25.7	31.9
Saturday	251			6.1	25.4	31.6
Sunday	245			6.0	24.8	30.8
Monday	234			5.7	23.7	29.4
Tuesday	263			6.4	26.6	33.1
Wednesday	306			7.5	31.0	38.5
Thursday	303			7.4	30.7	38.1

Friday	310			7.6	31.4	39.0
Saturday	310			7.6	31.4	39.0

LIST OF PUBLICATIONS

1. Tiwari, S., Magar, R. B. and Honnutagi, A. (2018), "Resource Optimization for Sustainable Construction: A State of Art", International Advanced Research Journal in Science, Engineering and Technology, Vol. 5, Special Issue 3, pp. 69-73.
2. Tiwari, S., Magar, R. B. and Honnutagi, A. (2018), "Resource Optimization for Sustainable Construction: A State of Art", Conference on Advances in Civil Engineering 2018 (CACE-2018), Thakur College of Engineering and Technology, February 2018.
3. Tiwari, S., Magar, R. B. and Srivastava, A. S. (2018), "Minimizing Construction Material Waste by Modelling Order Quantity and On-Site Rejection Parameters", ASMMCE 2018, NIT Jalandhar, November 3rd – 4th, 2018.

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