CHAPTER 4 RESEARCH METHODOLOGY

4.0 INTRODUCTION

The methodology followed in this research is a primary survey where the data was collected from commercial batching plants of Ahmedabad and Gandhinagar, India. The primary data was collected during the visits to the RMC batching plants. The details of the RMC batching plants relating to the model type, production capacity, type and grades of concrete produced, mix-design of the available grades and the test results of the available grades of concrete were collected. Data pertaining to the types of equipment and raw materials used were also collected. Further, the detailed study was carried out for the storage of raw materials, testing, cycle time for production of one batch and capacity of the truck mixers.

SPC tools like CUSUM with V-mask and EWMA control charts were then designed to monitor the quality parameters like 7 day and 28 day cube compressive strength. The analysis were carried out to detect whether the results obtained were accurate as well as precise. If the results passed these tests, further qualitative testing could then be applied but if unexpectedly the results failed, then a root cause analysis could be performed to improve the quality characteristics. Also, a model to achieve consistency could be framed.

Based on the results obtained, it was observed that the results were neither precise nor accurate and therefore a root cause analysis with a remedial action plan to improve or modify the mix-design, workmanship, has been recommended.

The basic methodology for the CUSUM technique is that it measures the deviations of the observed strength from the target mean strength (TMS). Then a CUSUM plot of the sample number versus the obtained CUSUM value of the respective quality characteristic is plotted in an excel spread sheet. A standard V-mask is then designed according to the standard deviation. The control limits for the V-mask are pre-calculated with the decision interval at 8.5σ and σ/6 is the gradient.

The primary data collection was made through the personal site visits of the authors. This data consists of the tests that are conducted on fresh and hardened concrete. These test results were evaluated within the system and SPC optimization techniques were run.
For scheduled dispatching and route optimization real time data was opted for. The inward-outward register being maintained by the RMC batching plant authority was studied and documented. This registered was then followed to develop a new heuristic mixed integer programming algorithm.

4.1 METHOD OF DATA ANALYSIS

4.1.1 Method of Data Analysis for CUSUM with V-Mask

The basic equation for the CUSUM technique is as follows (Dewar and Anderson, 1992):

\[ C_i = \sum_{j=1}^{i} (\bar{x}_j - \mu_0) \]  

(1)

Where, \( C_i \) is the cumulative sum up to and including the \( i^{th} \) sample; \( \bar{x}_j \) is the average of the \( j^{th} \) sample and \( \mu_0 \) is the target for the process mean.

4.1.2 Method of Data Analysis for EWMA

EWMA charts can smoothen a series of data based on a moving average with weights that decay exponentially. EWMA charts have two smoothening factors lambda (\( \lambda \)) and L. The EWMA chart displays data geometrically. The points in the EWMA chart represent a shift in the expected course of the process, relative to its past behaviour. In EWMA, the control limits are based on an exponentially smoothened prediction error for past observations. So the larger the prior drifts, the more insensitive the chart will be in detecting the amount of drift. EWMA is used to detect the shifts of the magnitude from 0.5 to 2 sigma. The exponentially weighted moving averages are calculated based on the following equation:

\[ Z_i = \lambda X_i + (1-\lambda) Z_{i-1} \]  

(2)

Where, \( Z_i \) is the moving average of the \( i^{th} \) sample; \( X_i \) is the average 28 day compressive strength of 3 cubes of the \( i^{th} \) sample. \( \lambda \) is a constant with values \( 0 < \lambda \leq 1 \) and the mean of the set of samples (\( \mu_0 \)) is considered as the centre line (CL) of the control chart. The starting value (required with the first sample at \( i=1 \)) is the process target with upper control limits (UCL) and lower control limits (LCL) calculated with the following formula:
UCL= \mu_0 + L\sigma \left[ \frac{\lambda}{(2-\lambda)} [1 - (1 - \lambda)^2] \right] \quad (3)

CL = \mu_0 \quad (4)

LCL = \mu_0 - L\sigma \left[ \frac{\lambda}{(2-\lambda)} [1 - (1 - \lambda)^2] \right] \quad (5)

4.1.3 Method of Data Analysis for Change in Cement Content and Water Cement Ratio

After identifying the out of control points and carrying out a root cause analysis, changes in cement content can be proposed as per Dewar and Anderson (1992). The equation is as follows:

d_c = 0.75 \times r \times [(DI/n) + G] \quad (6)

Where, \(d_c\), is the change in cement content (kg/m\(^3\)); 0.75 is the reduction factor; \(r\) is the cement equivalent of 1 N/mm\(^2\) strength, typically 5 kg/m\(^3\); DI is the decision interval of the mask; G is the gradient of the mask and \(n\) is the number of results from lead point to action point.

Minor modifications in the mix design can be carried out according to the equation proposed by Sarkar and Bhattacharjee (2014):

\[ \Delta f_m = \frac{(DI+nG)}{n} = \{8.1\sigma/n + \sigma/6\} \quad (7) \]

Where, \(\Delta f_m\) is the average change in mean strength; DI is the decision interval of the V-mask (8.1\(\sigma\) for monitoring mean strength and 8.5\(\sigma\) for monitoring range), G is the gradient of the V-mask (\(\sigma/6\) for monitoring mean strength and \(\sigma/10\) for monitoring range); n is the average run length or the number of results from the lead point to the action point backwards and \(\sigma\) is the plant standard deviation.

4.1.4 Method of Data Analysis for \(\bar{x}\)-S Chart

Here the standard deviation of the subgroup is plotted using the \(\bar{x}\)-S chart. One advantage of using the standard deviation is that all data are taken into account by the standard deviation, not just the maximum and the minimum. In the \(\bar{x}\) chart, the \(\bar{x}\) values are plotted. The chart shows three lines. The middle line is the average overall process; the upper line
is the upper limit of control; and the lower line is the lower limit of control. \( \bar{x} \)-S charts are used to analyze a process operating over time. Like all control charts, this chart also sends a signal when a special cause of variation is present. One can use \( \bar{x} \)-S charts for any subgroup size greater than 1.

The UCL and LCL for \( \bar{x} \) are calculated from the following equation:

\[
\bar{x} \pm A3 \times \bar{s}
\]  
(8)

And, consequently UCL for S chart is calculated by

\[
B4 \times \bar{s}
\]  
(9)

And LCL by

\[
B3 \times \bar{s}
\]  
(10)

Where:

\( \bar{x} \) = the average of each individual subgroup;
\( \bar{x} \) = the grand average
\( \bar{s} \) = the average of all the standard deviations

A3, B3 & B4 are constants

\( \bar{x} \)-S charts are analyzed with the help of run chart rules also that indicate the consistency of the process.
4.1.5 Run Chart Rules

1. One point beyond three standard errors.

Figure 15: Figure of “One point beyond three standard errors”

2. Nine consecutive points on the same side of the center line within one standard error of the centerline.

Figure 16: Figure of “Nine consecutive points on the same side of the center line within one standard error of the centerline”

3. Six consecutive points increasing or decreasing order.

Figure 17: Figure of “Six consecutive points increasing or decreasing order”
4. Fourteen consecutive points alternating, increasing and decreasing.

![Figure 18: Figure of “Fourteen consecutive points alternating, increasing and decreasing order”](image)

5. Two of three consecutive points between two and three standard errors on either side of the centerline.

![Figure 19: Figure of “Two of three consecutive points between two and three standard errors on either side of the centerline”](image)

6. Four of five consecutive points on either side of the center line beyond one standard error from the centerline.

![Figure 20: Figure of “Four of five consecutive points on either side of the center line beyond one standard error from the centreline”](image)
7. Fifteen consecutive points within one standard error of the centerline.

Figure 21: Figure of “Fifteen consecutive points within one standard error of the centerline”

8. Eight consecutive points on either or both sides of the center line—with none within one standard error of the centerline.

Figure 22: Figure of “Eight consecutive points on either or both sides of the center line with none within one standard error of the centerline”

9. Also, the graphs that are obtained are many times classified in accordance to the trend observed.

Figure 23: Figure of “Clustered” Plot
Figure 24: Figure of "Mixture" Plot

Figure 25: Figure of "Oscillating" Plot

Figure 26: Figure of "Same Value" Plot
4.1.6 Method of Data Analysis for Scheduled Dispatching and Route Optimization

A heuristic mixed integer programming algorithm has been developed for the scheduled dispatching and route optimization of the RMC truck mixers. This algorithm has a novel and original approach. The operations are considered to be operational only when required and not continuous and therefore discrete. Therefore the problem is addressed in a way where the operations may be continuous or discrete depending upon the demand that arises. The truck mixers are considered to be always available i.e. the plant never runs out of a truck mixer. This is assumed to find out the optimum number of truck mixers required at the plant and also if what could be the maximum number of truck mixers the RMC batching plant can handle. There are different types of time considerations that are taken into the account. Initially, the starting time of the construction site is taken in consideration. The starting time of the construction site works as a benchmark for the starting time of the batching plant. The RMC batching plant has to start on such a time that there is adequate time for travelling a fully loaded truck mixer from the RMC.
batching plant to the respective construction site. This can be achieved by deducting the travel time of a fully loaded RMC truck mixer from the batching plant to the site considering the mixing time as an addition to the time taken to travel. The time taken to unload the concrete also adds to the time taken to complete the concreting operation. The whole of the concreting operation has to be completed within the time limit of 120 minutes as in accordance to IS: 4926 (2003). So, four operations namely mixing of concrete at the batching plant, travel time of the truck mixer from the batching plant to the respective construction site, waiting time if any and unloading of the concrete should be finished within the time limit of 120 minutes. Generally, when the construction sites are more than 5 and the truck mixers are limited to 8 in numbers, a waiting time for delivery sequencing and concrete dispatching at the respective site is observed. Waiting times are of two types. First kind of waiting time is when the truck mixer is waiting at the construction side to unload the concrete, this is the negative waiting time. The second kind of waiting time is when the construction site is waiting for the truck mixer to arrive and unload the concrete, this is the positive waiting time and in time operations, this positive waiting time delays the operations. Therefore a penalty function has been added to the positive waiting time. Generally each of the construction site is allowed a buffer time of twelve to fifteen minutes is allowed for the truck mixer to arrive at the site. This design buffer time gives some relaxation and a range to the batching plant manager and the truck mixer driver. This time range also enables the batching plant authority to prioritize and plan the trip. For the delivery sequence on a particular day, the orders are taken based on the first come first serve basis i.e. if there is any clash detected while planning the dispatch sequence, the construction site that had ordered relatively earlier than the other site is given the priority. After the simulated trip is planned, a schedule is prepared and the minimum time difference between two consecutive truck mixers is kept to be about ten to twelve minutes. This time difference of ten to twelve minutes is kept considering the CP-60 fully automated batching plant and all the truck mixers having the capacity of 6m$^3$. Once the truck mixers’ depart, the returning time of the truck mixer is calculated by adding the mixing time, travel time from the batching plant to the construction site, travel time from the construction site to the batching plant, unloading time of the concrete at the construction site and the positive or negative waiting times if any. The calculated return time gives us the timing at which the truck mixer arrives back at the batching plant and this returned truck mixer can be re-used as a resource to deliver
the concrete at any of the construction sites if the orders are pending. This completes the operation of the batching plant.

The equations that are developed are:

Objective function 

\[ \text{min}(\text{Total Waiting Time}) \]  

\[ =\text{min}(TDG+WT+CD+P1+P2+P3+P4+P5+P6+P7) \]  

(11)

Constraint:  

\[ TDG+WT+CD+P1+P2+P3+P4+P5+P6+P7 \leq 120 \]  

(12)

Departure time for 1st RMC truck mixer 

\[ =\text{min}(\text{starting time of site} - \text{travel time from plant to site}) \]  

(13)

Ideal departure time of \( i^{th} \) truck mixer 

\[ =\text{Departure time of 1st RMC truck mixer} + \text{Concrete mix time}, \text{ for } i=1 \]  

\[ \text{Ideal departure of } i^{th} \text{ truck mixer} + \\text{Concrete mix time, for } i=2<N \]  

(14)

Simulated departure time (SDT) 

\[ =\text{Ideal departure time, if } i \leq c \]  

(15)

Simulated departure time (SDT) 

\[ =\text{min (returning time of } i^{th} \text{ truck mixer} + \text{concrete mix time), if } c<i \leq N \]  

(16)

Arrival time if \( i^{th} \) truck mixer to site \( j \)  

\[ =\text{SDT} + \text{travel time from plant to site} \]  

(17)

Start time of casting at site \( j \)  

\[ =\text{starting of casting at site } j \text{ OR leaving time of } i^{th} \text{ truck mixer at site } j + \text{travel time of the truck mixer from batching plant to the site} \]  

(18)

Waiting time of \( i^{th} \) dispatched truck mixer 

\[ =\text{The start time of casting at site } j - \text{Arrival time of } i^{th} \text{ truck mixer at site } j \]  

(19)

Leaving time of \( i^{th} \) truck mixer 

\[ =\text{Arrival time of } i^{th} \text{ truck mixer at site } j + \text{Waiting time} + \text{Pouring time, if Waiting time } \geq 0 \]  

(20)

Leaving time of \( i^{th} \) truck mixer 

\[ =\text{Arrival time of } i^{th} \text{ truck mixer at site } j + \text{Pouring time, if Waiting time } < 0 \]  

(21)
Returning time of $i^{th}$ truck mixer =Leaving of $i^{th}$ truck mixer + Travel time from site to plant

\[ P = \text{total delay in minutes} \]  
\[ = \text{penalty function} \]
\[ = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 \]

Where,

$P_1$ = Delay due to traffic signals
\[ = n \times 2, \text{ where } n \text{ is the number of signals in transit and 2 minutes is the maximum waiting time due to red-light} \]

$P_2$ = Delay due traffic congestions in non-signalled cross-roads
\[ = q \times 3, \text{ where } q \text{ is the number of non-signalled traffic junctions and 3 minutes is the maximum delay due to traffic congestion} \]

$P_3$ = Delay due to traffic roundabouts
\[ = r \times 3, \text{ where } r \text{ is the number of roundabouts and 3 minutes is the maximum waiting time due to traffic observed at the roundabout} \]

$P_4$ = Delay due turns of more than 90°
\[ = s \times 1.5, \text{ where } s \text{ is the number of turns and 1.5 minutes is the maximum waiting time due to the turns} \]

$P_5$ = Delay due toll queues
\[ = t \times 4, \text{ where } t \text{ is the number off toll booths on the way and 4 minutes is the maximum delay due to toll booth} \]

$P_6$ = Delay due to improper merging and changing of lanes
\[ = u \times 3, \text{ where } u \text{ is the number of occurrences and 3 minutes is the maximum waiting time due each occurrence} \]
P7 = Delay due speed breakers

\[ P7 = v \times 0.75, \text{ where; } v \text{ is the number of speed breakers and 0.75 minutes is the maximum waiting time due each speed breaker} \]

where;

TDG = Travel time from plant to site;

TDB = Travel time from site to plant;

ABD = Allowable buffer time of site;

K = Required deliveries to each site;

FDT = Departure time of 1st RMC truck mixer;

CD = Pouring time at site;

LT = Leaving time of ith truck mixer

i = dispatched order of an RMC truck mixer

N = the required RMC truck deliveries for the construction site j

IDT = Ideal departure time of ith truck mixer;

MD = Concrete mix time;

SDT = Simulated departure time;

TAC = Arrival of ith truck mixer at site j;

PTF = Start time of casting at site j;

WC = Waiting time;

TBB = Returning time of ith truck mixer;

c = Number of RMC truck mixers stationed at the batch plant
WT= Waiting time for the RMC truck mixer at the site

\( j \) = the total number of sites being handled by the plant on a typical day

### 4.2 CONCLUDING REMARKS

After the data collection, data processing as stated in chapter 5 was performed on the fresh as well as the hardened concrete. The statistical tools applied were \( \bar{x} \)-S charts with run chart rules as mentioned in section 4.1.5, CUSUM with V-Mask and EWMA control charts. The results indicated that the formulated equations prove to be highly effective in optimizing the quantity of cement. The optimized quantity of cement leads to a new water cement ratio and this also proves to be highly effective. Thus the cube compressive strength of concrete is optimized. These statistical techniques helped in time, cost and material and savings. This also proves to be the judicial use of raw materials. It also helps in less internal failures leading higher productivity and cost savings. The repeatability and reproducibility is optimized. The consistency of the results achieved is also higher than the previously observed results. The algorithm based on mixed integer programming developed for the simulation of the scheduling and route optimization model to optimize the delivery schedule and dispatch sequence of RMC truck mixers greatly reduced the waiting time of the truck mixers at the site.

The developed algorithm takes in to account the typical work pattern of a RMC batching plant. This algorithm has been specifically designed to simulate the truck mixers’ operations. It delivers the output in the sequence of the truck mixers that are to be dispatched. This algorithm also works on the clash detection and identifies the probable clashes in timings of departure of the truck mixers. This helps in identifying whether or not to opt for a typical site RMC delivery or not. This identification of RMC delivering to a typical site also shows with which other site the clash in timings is possible.

Thus, this approach of research methodology contributes to higher probability of better quality and consistent production.