CHAPTER 6 CONCLUSION

6.1 CONCLUSIONS FOR SPC

6.1.1 Conclusion for Normality

1. It was observed that the data is normally distributed. This also means that all the parametric tests can be applied on this kind of data.
2. Mean, median and mode can also be effectively used for the statistical processing. The bell-curves and chi-square tests show that the data does not have multicollinearity, equal variance and autocorrelation.
3. The average p-value is greater than 0.05 implying that there is a strong evidence of the data being normally distributed.
4. As the data is normally distributed, the interpretation of probability can be taken to account and a forecast model is formulated with appropriate statistical tools.

6.1.2 Conclusion for CUSUM with V-MASK

1. From the CUSUM with V-mask tool, it was revealed that this tool is highly sensitive. Because of this sensitivity, it can be very effective in monitoring the characteristic cube compressive strength of concrete.
2. The smallest of the variations were captured in the data with the CUSUM values. CUSUM with V-mask can be a potential solution for the daily and weekly monitoring of the concrete compressive strength.
3. The formulae of \( D_c \) and \( \Delta f_m \) provide high amounts of saving and judicious use of the raw materials. With nearly 1 bag of cement being saved per truck mixer of 6m³ of concrete, the savings are very high.

6.1.3 Conclusion for EWMA

1. From the CUSUM with V-mask tool, it was revealed that this tool is highly sensitive. Because of this sensitivity, it can be very effective in monitoring the characteristic cube compressive strength of concrete but it may also trigger false alarms.
2. To doubly verify the data, EWMA was used for this verification as an alternative tool.
3. EWMA is also highly robust as compared to the CUSUM with V-mask control chart.
4. EWMA effectively avoids the false alarms that might be observed in CUSUM with V-mask control charts.
5. Also, EWMA tool can be effectively used as a forecasting tool.
6. This proves to be highly beneficial as EWMA charts perform both the functions that is to check the validity of the CUSUM with V-Mask and to forecast the strength criteria.
7. EWMA as recommended by many authors can also be used with the stable values $\lambda=0.10$ and $L=2.814$ for the monitoring of the compressive strengths.

6.1.4 General Conclusion for SPC

1. It has been observed that both the plants, particularly the plant referred to as case 1, follow an over-conservative mix design. Even after having a high design margin of $2\sigma$, the commercial RMC batching plants are using more cement than that stipulated in the design mix.
2. Investigations revealed that the use of cement higher than recommended is primarily to reduce the producers’ risk of producing a concrete which may be rejected by the consumer.
3. For case 1, the mean strength for 30 samples for mix M20P1, mix M25P1 and mix M30P1 was observed to be 27.64 N/mm$^2$, 31.91 N/mm$^2$ and 39.54 N/mm$^2$ against the required minimum specified strength of 20 N/mm$^2$, 25 N/mm$^2$ and 30 N/mm$^2$.
4. For case 2, the mean strength for 30 samples for mix M20P2, M25P2 and M30P2 was observed to be 25.17 N/mm$^2$, 34.76 N/mm$^2$ and 41.98 N/mm$^2$ against the required minimum specified strength of 20 N/mm$^2$, 25 N/mm$^2$ and 30 N/mm$^2$.
5. This indicates that more cement has been used during the production than that stipulated in the mix-design. By using more cement, resources are wasted and further, the use of more cement has adverse side effects like generation of more heat of hydration which may cause more shrinkage cracks in the concrete.
6. According to the estimation carried out it has been observed that for the M20 grade concrete produced by the commercial RMC batching plant referred to as case 1, the recommended average change in cement content is about 11.21 kg/m$^3$. The approximate cost of M20 grade is INR 3200 per m$^3$ and the approximate cost of OPC 53 grade cement is about INR 250 per 50 kg. Assuming a tentative sale
of about 3500 m$^3$ of concrete per month, the approximate savings in cement cost would be INR 56.05 per m$^3$ x 3500 m$^3$ = INR 196175.

7. For M25 grade concrete for case 1, the cost of concrete is about INR 3900 per m$^3$ and the average sale is about 1250 m$^3$ per month. Thus, the potential savings in the cost of cement would be INR 64375 per month.

8. For M30 grade concrete for case 1, the cost of the concrete is about INR 4100 per m$^3$ and the potential savings in the cost of cement would be INR 65600. For case 2, the approximate savings in cement cost per month would be INR 106750, INR 37950 and INR 33725 for M20, M25 and M30 grade concrete respectively.

9. Thus, considering all the grades of concrete produced by the RMC batching plant referred to as case 1, there is a potential of savings of the order of INR 600000 per month. For case 2, the potential savings would be about INR 400000 per month. It is also recommended that the mix of the different grades of the concrete should be re-designed according to the revised water-cement ratio.

10. For most of the time we think of procuring hardware and hardware based items to increase the productivity. But in this research, all the soft computing techniques have been explored and an optimized result without any hard investment has been achieved.

**6.2 CONCLUSION FOR ROUTE OPTIMIZATION**

**6.2.1 Model Validation**

1. It was observed that considering the formulated equations, the positive waiting time i.e. the site waiting for the truck mixer for delivering the concrete was on an average reduced from 20 to 13 minutes.

2. This was achieved with the help of a heuristic algorithm with mixed integer programming. The approach was novel considering the all the time and travel duration functions as continuous functions and, the number of deliveries required, number of sites handled and number of truck owned and operated by the RMC batching plant authorities as a discrete function.

3. As recommended that the plant needs to have 7 truck mixers instead of 5. This would lead to lesser waiting times as compared to the present practice. Also, for most of the times the plant operates on expert based decision making systems that may be conservative in nature. But with the help of real-time primary data
integrated with mixed integer programming with heuristic approach has led to drastic time savings.

4. In the entire dispatching sequence 1, 2, 2, 1, 1, 3, 2, 3, 2, 3, 3, 3 obtained from iteration number 40, after validating the model it has been observed that the waiting time of the RMC truck mixer was within the assumed allowable buffer time of the respective sites, but the waiting time of site 3 was about 48 minutes due to the late arrival of the RMC truck mixer.

5. Also the waiting time for the above dispatch sequence after validating the model is 1+ 28+ 11+ 28+ 10+ 10 = 93 minutes. Further, the total waiting time after addition of penalty time for one obstruction is 93 + 60 = 153 minutes. This matches with the results obtained after 101 iterations in MATLAB.

6. It is recommended that the RMC batching plant authorities should increase the number of RMC trucks from five to seven. This would certainly reduce the waiting interval of the respective project sites for arrival of RMC trucks to start their casting of concrete and also for the RMC trucks for placing the concrete at the respective project sites.

7. As this model is based on real-time data, the geographical scope of this model is not limited to Ahmedabad and Gandhinagar only. This model can be run at most of the locations throughout the globe in nearly all of the RMC batching plant organizations.

8. At most of the geographical locations, the stated characteristic obstructions may be observed and only the multiplication factor of the route optimization equation needs to be changed according to the nature and kind of the obstruction. For example, if this model is run in any other city of plane terrain, most of the obstruction may have the similar nature viz. speed-breakers, signalled intersection, non-signalled intersection, merging and diverging traffic and U-turns, all of which are stated in the equation. Therefore it can be concluded that this model has a universal applicability and the geographical scope is not only limited to cities of Ahmedabad and Gandhinagar only.

9. The limitation of this model is that it cannot be run in hill terrain. For example, in hill terrain, this model may not work as the average speed and the type and nature of obstructions may be different as compared to the traffic characteristics of plane and paved terrain. In hill terrain more of special causes of variations like land slide and crashes are reported as compared to traffic of plane terrain.
6.3 SCOPE FOR FUTURE RESEARCH

As the concept of SPC is versatile enough, it can be applied to a variety of line-production units of civil engineering like pre-cast and pre-fabricated housing, manufacturing of modular components, etc. Software can be developed to manage the quality of RMC. User-friendly software can be developed for the route optimization and delivery sequencing of RMC truck mixers. Formula for change in strength with respect to EWMA control charts can be developed as $D_c$ and $\Delta f_m$ are for CUSUM with V-mask.

This study of route optimization and delivery scheduling can be extended by integrating global positioning systems (GPS) with the existing logic used for this study for scheduling the dispatching sequence based on real time data. Further, a route optimization model can be developed through the application of genetic algorithm as well as bee algorithm. The use of Information and Communication Technologies (ICT) can be integrated and an automated navigation system can be developed. This type of research requires extensive usage of real-time primary data and once this real-time primary data is captured for any location, the above generated equations with the feed of real-time data of any city could produce highly desirable results.