Course
Number:
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Course Title:

Total Quality Methodologies in Engineering

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1. Introduction

India is the second-largest country with an extensive road network. It covers more than 5,000,000 kilometers across the country, thus making roads an important mode of transportation in the country. The length of national highways in India has increased from 70,934 km (44,076 mi) in 2010–11 to 142,126 km (88,313 mi) in 2018–19(1). As it gets applauded for its massive employment efforts and its wide distribution of network, it is also criticized for congestion, construction issues, and fatalities. According to the study conducted by Transport Corporation India, "the cost of delay was $6.6 billion per year and the cost of additional fuel consumption due to delay was $14.7 billion per year"(2). In a highly populated country with the highest number of road transports, it becomes the need of the hour to address this problem of long waits so that the citizens can be saved from incurring losses. Through our project we have tried to solve the problem of delay on Indian roads using the Six Sigma approach. After defining the problem in the define phase, we identified Critical to Quality parameters and the major causes leading to the problem. Delay times in major metropolitan cities with worst performance were noted to understand the current situation. The measurements helped to calculate DPMO, Sigma level, and process capability. We further analyzed the problem using R&R Analysis, Cause and Effects Diagram, and Root Cause Analysis.

1.1 Purpose

The main purpose of this project is to solve the problem of Traffic Delays mainly caused by Traffic Congestion in India by applying the DMAIC approach of Six Sigma. This project examines and analyzes the factors that are causing the problem of long waiting times that a citizen encounters during peak/rush hours. The project also focuses on methods for enhancing the quality of service that is determined by the passenger's experience at the time of travel.

1.2 Objective

Our main objectives are to identify the Critical to Quality parameters, which contribute to the overall quality of traffic on roads, to measure and improve the identified CTQs using six sigma techniques, and to ensure that the problems identified are solved after successful implementation of the DMAIC approach.

1.3 Importance

Efficient transportation is essential for getting to work, obtaining health care, education, training, recreation, culture, and ensuring the community's economic prosperity. However, other equally essential issues must now be taken into account when making our personal and collective travel choices. These issues include protecting the environment, air quality, quality of life, the peace, quiet and character of neighborhoods; the health and safety of residents; the quality, comfort, and urban development design; social inclusion, and the cost of investment.

A greater waiting time proves to be counter-productive both on the transportation organization as well as the passenger. Most people living in these metropolitan cities work 24*7, which gets affected by the improper facilities causing delays on the roads. In the define phase, we would be recognizing significant areas of problems using various techniques of six sigma and then applying analytical tools in the following phases to resolve the identified issues.

2. Data Collection

Critical to quality parameters (Customer's Voice)

1. Long waiting time
2. Construction hours
3. Proper maintenance/Congestion
4. Skilled drivers
5. Ride-sharing
6. Enforce existing road traffic laws
7. A large number of private vehicles
8. Violence/Accidents
9. Widen roads
10. Build tunnels
11. Smart parking
12. Use CCTV to monitor road conditions
13. Public cycling system

2.1 Procedure for Collection

After online surveying the real data from Transport Corporation of India, we observed that most of the roadways are connected via four major cities which contribute to increasing the average traffic delays all around the country. The data shows the congestion levels on highway and non-highway roads during the rush hours.

We took into account the four major metropolitan cities of India namely Delhi, Mumbai, Bangalore, and Pune. After analyzing the reports from Transport Corporation of India, we noticed different problems leading to the delays on roads. The major of them were poor road maintenance, narrow roads, and infrastructure for both highways as well as highways. We took the average of highway data and non-highway data for the four cities and applied the six sigma methodology on the same.

3. Initial DPMO

A defect is defined as an imperfection that impairs quality, function, or utility. DPMO is stated in opportunities per million. Processes considered highly capable are those that are produced experiencing only a handful of defects per million units. DPMO is used to precisely describe the price. This value is 3.4 defects per million incentives, for six sigma ventures.

Sigma level = NORMSINV (1-dpmo/1000000) + SHIFT

= NORMSINV (1-number of defects/number of opportunities) + SHIFT

Highways		Non-Highways	
Number of Opportunities	90853	Number of Opportunities	105135
Defects	9968	Defects	17531
DPMO	109715.69	DPMO	166747.52
Sigma Level	2.73	Sigma Level	2.47

4. DMAIC

DMAIC is a Six Sigma quality improvement technique for improving the processes. DMAIC stands for five phases: Defining, Measuring, Analyzing, Improving, and Control.

Define: This step defines the problem of traffic delays and critical to quality parameters

Measure: In the measure phase we will measure the data which is collected in the form of a number of vehicles arriving and waiting on highways and non-highways.

Analyze: In this step, we analyzed the collected data to identify the main reasons behind the problem of traffic delays.

Improve: This step identifies the solution and implements it to eliminate the root cause behind the problem.

Control: In this step of the DMAIC process we will ensure that the techniques used to reduce the traffic delays are performing as expected.

4.1 Techniques used to implement each phase of DMAIC

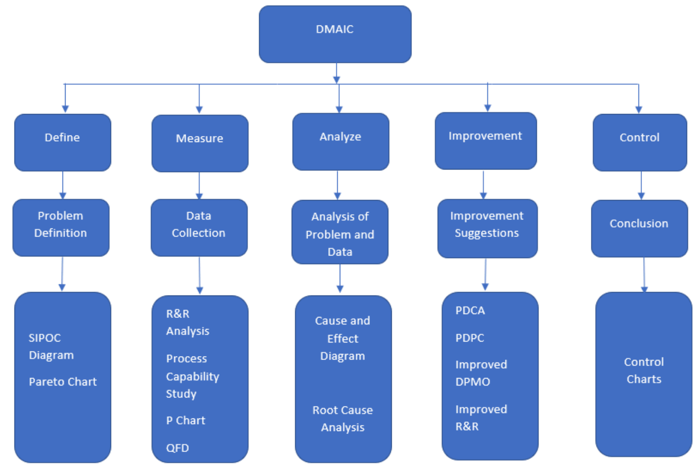

Figure 1: Techniques used to implement each phase of DMAIC

5. Define Phase

The first phase of the DMAIC process is to define phase. In this phase, the problem of traffic delay is stated. Traffic delays are mainly caused by traffic congestion. Traffic congestion occurs when there is a large number of vehicles on the road when traffic completely stops or the speed of vehicles is lower than their normal speeds. The main reasons behind this problem are the increasing number of vehicles, road blockages because of accidents or constructions which make it difficult for the traffic to move freely. The critical to quality parameters are specified in this phase in which we discuss how the project scope and deliverables meet the requirements of people suffering from this problem. Moreover, the available data is used to do the Pareto analysis.

5.1 Critical to Quality Parameters

Critical to Quality Parameters describes the characteristics of a service or a product required by the customers. To reduce the problem of traffic delays, we have identified the following CTQs.

1. Long waiting time: People waste countless hours of their precious lives in traffic delays. The capital of India Delhi has the highest accident rate in India and the third-highest in the world. Moreover, accidents are one of the major reasons for waiting as they cause road blockage. Therefore, waiting time on roads should be reduced so that people can travel without wasting their time.

2. Construction hours: Construction of roads, bridges, and other utility work also lead to traffic delays. The main reason behind this is commuters are not well informed about the beginning of the construction work. So the delays due to construction work should be minimized to ensure that people can reach their destinations on time.

3. Proper maintenance/Congestion:

- **Skilled Drivers:** Unskilled and drunk drivers are one of the most dangerous causes of road accidents in India. To avoid needless accidents caused by simple carelessness, drivers must know the proper traffic rules and they should remain calm while driving.

- **Ride-Sharing:** Ride-sharing services have enormous potential for solving the problem of traffic congestion as it reduces the number of private vehicles on the road. It helps the public use fewer cars and reduces car congestion.

- **Public cycling System:** For short distances, people should use the public cycling system. Reducing the number of cars on road cycles is a good alternative because it will not only reduce traffic jams but will also lower the air and noise pollution.

- **Smart parking:** Drivers looking for parking spend more time on roads and drive slower than the other drivers. They do not pay much attention to what is in front of them or behind them, which can lead to accidents. A smart parking system can reduce the risk of distracted drivers by giving them indications whether parking is available or not.

- **Smart traffic management system:** Smart traffic management systems address the root of the problem by regulating traffic patterns, improving public transport and effectively balancing private and public transportation. It can reduce, and contain the traffic problem.[17]

- **Build tunnels:** Tunnels building is another solution for reducing the traffic congestion by allowing some types of vehicles like heavy trucks or cars to pass through tunnels.

- **Widen Roads:** The majority of Indian roads are not wide enough to handle the large traffic flow. So roads should be wider and multilane as they ensure safe and congestion-free traffic flow and provide more space for the traffic.

- **Use CCTVs to monitor road conditions:** With the help of CCTVs at junctions traffic can be managed by monitoring breakdowns, collisions, and other causes of congestion.

- **Enforce existing road Traffic Laws:** Traffic rules must be followed by everyone to make the traffic move smoothly. Illegal parking, waiting, loading/unloading obstructs traffic flows.

5.2 SIPOC

SIPOC is a Six Sigma tool that gives information about the input and output of a process along with suppliers and customers. Before the beginning of the work, SIPOC defines the complete business process. This provides a high-level overview of the process and helps in defining a new process. Inputs or outputs can be in the form of materials, information, energy, manpower, or services.

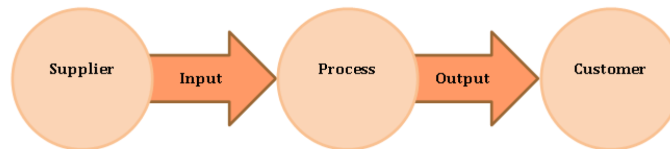

Figure 2 – SIPOC Structure

Supplier	Input	Process	Output	Customer
Government	Traffic Lights	Control the movement of traffic by providing equal waiting time to each vehicle.	Control, regulate and guide the traffic	People, passengers, travellers, drivers, pedestrians, vehicles
	Public Transport	Take people from one place to another.	Passenger reaches their destination	
	CCTV Cameras	Monitor the road.	Reduction in number of accidents	
	Tunnels	Divert traffic from roads to tunnels.	Less number of vehicles on roads	
	Smart Parking System	Provide appropriate place for parking in	Lower the risk of driver distraction	

		a systematic process.		

5.3 Pareto Chart

Analyzing Pareto is an innovative way to look at the causes of problems as it helps stimulate thought and coordinate thought. This technique helps to identify the top portion of causes that need to be addressed to resolve the majority of problems.[(18)] A Pareto diagram is a histogram of the data from the largest frequency to the smallest. Pareto diagrams are used to analyze the cost of quality data. It follows 80:20 rules, i.e., 20% of causes determine 80% of problems. A **Pareto Chart** is a type of chart comprising both bars and line graphs, where the individual values are represented by bars in descending order, and the line represents the total cumulative.

To apply the Pareto chart we have taken account of the major CTQs that cause 80% of the delays on Indian roads.

CTQ	Frequency	Cumulative	Cumulative %
Poor road maintenance	10500	10500	65.625
Large number of private vehicles	3150	13650	85.3125
Infrastructure	900	14550	90.9375
Unskilled drivers	500	15050	94.0625
Accidents	450	15500	96.875
Narrow roads	300	15800	98.75
Illegal parking	200	16000	100

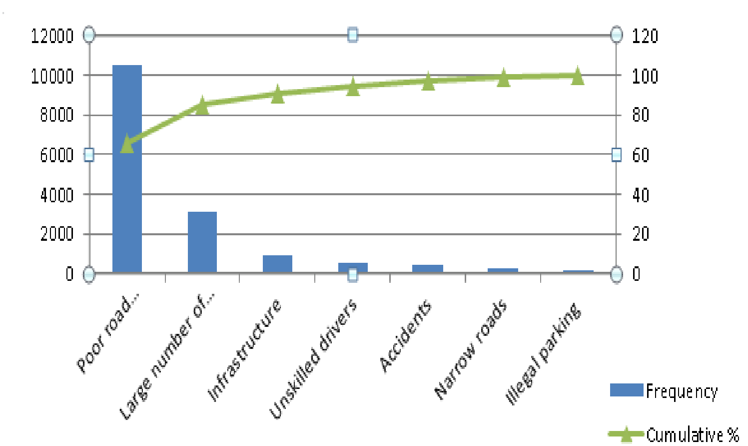

Figure 3 – Pareto chart

5.4 Process Map

Process mapping is a technique in Six Sigma that visualizes step by step flow of events or operations in a process. This helps to identify the value-added activities in the process as well as reduce the cycle time and defects in the process.

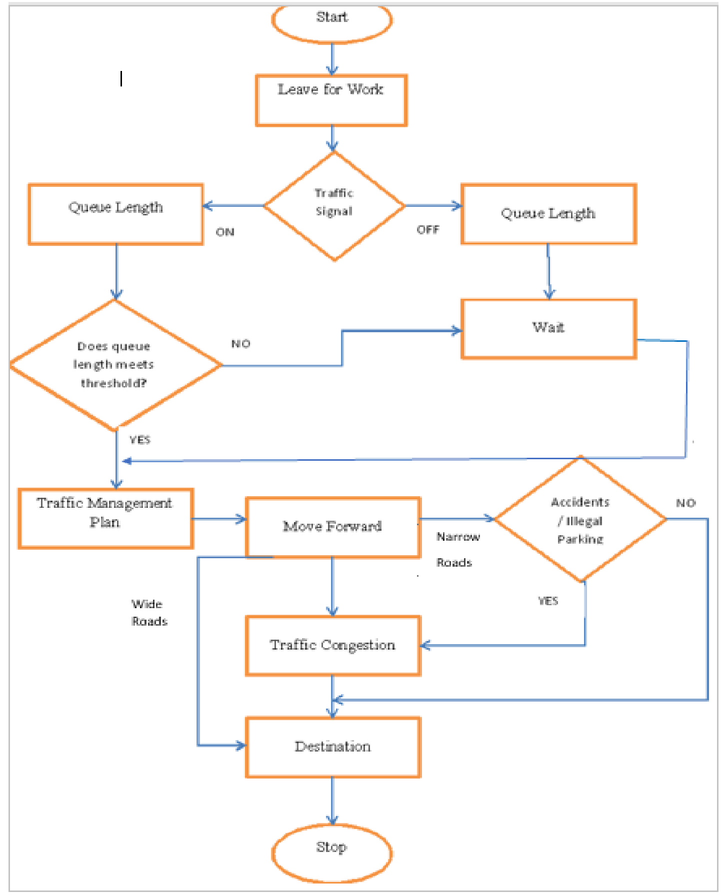

Figure 4-Process Map

6. Measure phase

The measure is the second phase of DMAIC. This phase involves the collection of data on the problem areas for analysis. It focuses on the measurement of internal processes that impact the CTQs. In this phase, we used tools like R&R analysis to analyze and identify the areas of concern.

6.1 R&R Analysis

It is the amount of measurement variation introduced by a measurement system, which consists of the measuring instrument itself and the individuals using the instrument. It is a critical step in manufacturing Six Sigma projects, and it quantifies three things:

1. Repeatability or Equipment Variation - It is the variation from the multiple measurements by the individual using the same instrument.
2. Reproducibility or Operator Variation – It is the variation in the same measuring instrument from different individuals using it to measure the same

parts.
3. Overall R&R, which is the combined effect of Repeatability and Reproducibility.

The overall Gage R&R is normally expressed as a percentage of the tolerance for the CTQ being studied, and a value of 30% Gage R&R or less is considered acceptable in most.[8]

In this project, R&R analysis was performed on the total number of vehicles for the collective datasets from all four cities including highways and non-highways. Four trials were conducted in four different cities by three operators. Using the tolerance limit to be 15 minutes, EV and AV were calculated. The EV was calculated to be 96.87% and AV was calculated to be 17.65%. Both these results showed that there was a need to investigate the causes for such high levels of equipment variation. Also, the overall R&R was calculated to be 98.47%, which is also intolerable.

EV	96.87%
AV	17.65%
R&R	98.47%

6.2 Process Capability Analysis

It is useful to predict quantitatively, how well a process meets the specifications, and to specify equipment requirements and the level of control necessary. It provides information about the performance of the process being analyzed under specified operating conditions. Based on the results obtained, we determine whether the process is capable or not. On highways, a sample of **90853** passengers was monitored for every hour of a day. On non-highways, another sample of **105135** was monitored for every hour of a day as well.

Process Capability Index (C_p) = (UTL-LTL)/6σ

Cpu = (UTL-μ)/3σ
Cpl = (μ-LTL)/3σ
Cpk = min(Cpu,Cpl)

Where:
UTL= upper tolerance limit
LTL= lower tolerance limit
σ = standard deviation of the process
μ = mean of the process

Following table gives the results obtained for the process:-

Highways			**Non-Highways**	
Mean	390		Mean	730
Standard Deviation	130		Standard Deviation	260
UTL	613		UTL	1057
LTL	120		LTL	215
Cp	0.6320		Cp	0.5397
Cpu	0.5717		Cpu	0.4192
Cpl	0.6923		Cpl	0.6602
Cpk	0.5717		Cpk	0.4192

From the above analysis, we deduced that the process is not capable of producing results in the specified control limits, as the process capability indices are less than 1. Therefore, to make the process capable, the process variation needs to be decreased.

6.3 Control Charts

P-chart with **Variable** Sample size is used because the waiting time of passengers on the roads of India is a Defective attribute. Long waiting times on the road is an attribute, not a variable since it assumes only two values: Long or short. This problem is defective (as it has many defects) with variable sample sizes.

Analysis:

6.4 P-Chart of Highways

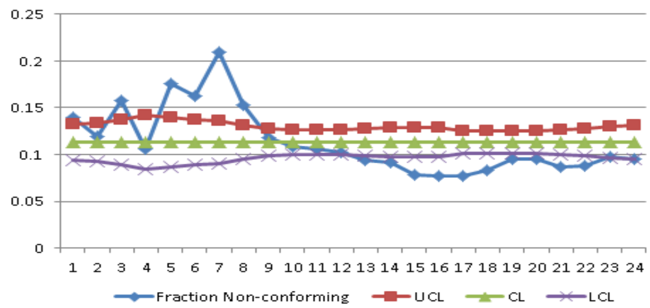

Figure 5- P-chart of Highways

6.5 P-Chart of Non-Highways

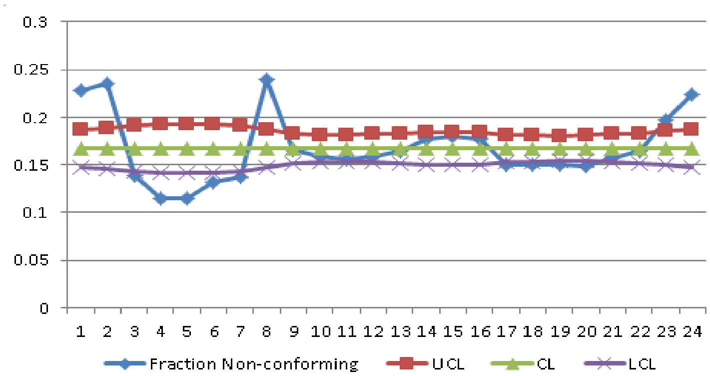

Figure 6- P-chart of Non-Highways

Analysis for both P-Charts:
Using a variable sample size, the process is identified to be out of control as most of the items are out of the control limit.

7. Analyze Phase

Analyze phase is the third phase in the DMAIC Process. This phase focuses on the data gathered in the measure phase. This helps us to identify the root cause of the problem and provides a deep understanding of how to eliminate them.

7.1 Cause and Effect Diagram

The Cause and effect diagram is a graphical tool to indicate a list of causes related to a specific effect. Also known as fishbone or Ishikawa diagram. It identifies the major causes and breaks them down into sub causes. It helps us by immediately sorting ideas into useful categories.

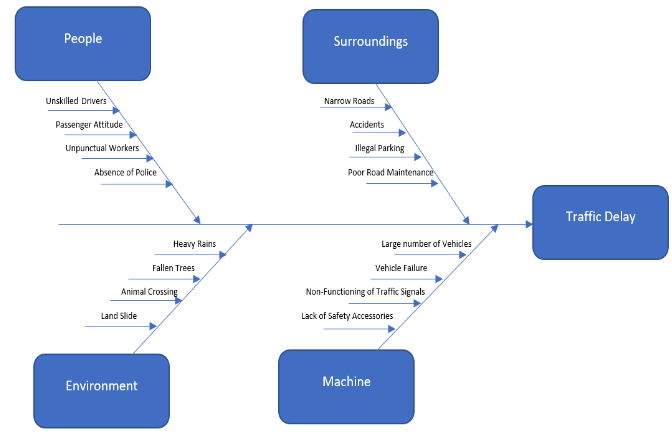

Figure 7 - Cause Effect Diagram-Long Waiting Time

7.2 Root Cause Analysis

Root Cause Analysis is a problem-solving method that is used in the analysis phase of DMAIC methodology. 5 Why Techniques' primary aim is to determine the root cause of the issue by asking the 'Why' question.

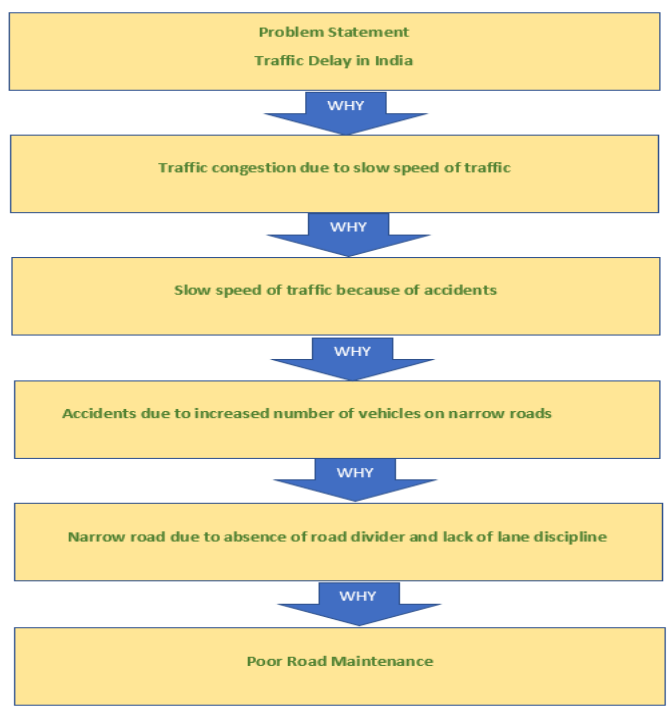

Figure 8-Root Cause Analysis of delays

8. Improve Phase

The fourth phase in the Six Sigma DMAIC cycle is the Improve Phase. The main focus of this phase is to improve the process by removing the defects and errors from the process. The results of the measure and analysis phase were used to suggest organizational or technical changes to propose a new design structure, which will be implemented on a trial basis and the results will be analyzed. If successful, the changes are made permanent and institutionalized throughout the organization. In this phase, solutions are implemented and results are analyzed. The approaches used in this phase are:

1. PDCA Cycle

2. Affinity Diagram

8.1 PDCA Cycle

PDCA involves 4 basic steps (Plan, Do, Check, Act) for carrying out continuous improvement in the process. Sometimes called the Deming Process. It presents an efficient approach for solving the problem and managing changes.

PLAN: Our main aim is to reduce traffic delays. After defining the problem, relevant data is collected and analyzed to find the solution.

The following are suggested solutions for solving the problem of traffic delay:

- Widen the roads
- Smart parking
- Build tunnels
- Smart traffic management system
- Enforce existing traffic laws

DO: The solution is executed and results are measured to ensure that the changes are correctly implemented.

CHECK: The results are analyzed and compared with the planned results. If a deviation occurs an improved plan is proposed to achieve goals.

ACT: In this last step the solution is implemented to remove the problem.

8.2 Affinity Diagram

It is an analytical method used to coordinate several ideas with similar themes or similar relationships within a subgroup. Also known as the K-J form. With the help of the affinity diagram, we will provide a solution for 4 major problems that we found during Cause and Effect analysis.

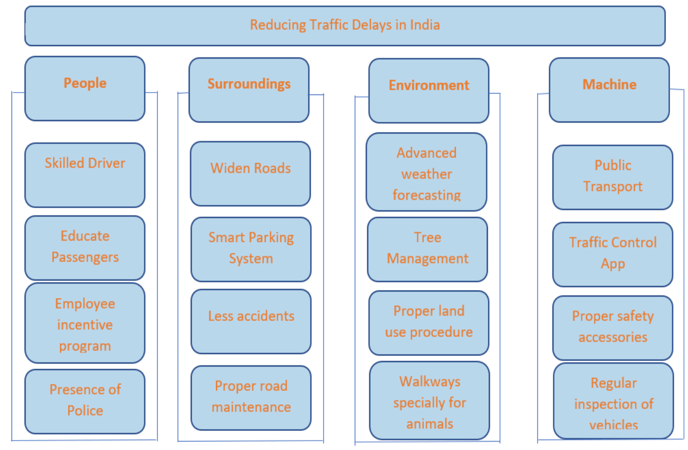

Figure 9-Affinity Diagram

8.3 Improved DPMO

Sigma level = NORMSINV (1-dpmo/1000000) + SHIFT

= NORMSINV (1-number of defects/number of opportunities) + SHIFT

Highways		Non-Highways	
Number of Opportunities	99854	Number of Opportunities	116035
Defects	2572	Defects	4280
DPMO	25757.6061	DPMO	36885.4225
Sigma Level	3.45	Sigma Level	3.25

8.4 Improved Process Capability Study

Highways			Non-Highways	
Mean	107.366		Mean	178.33
Standard Deviation	6.098		Standard Deviation	12.09
UTL	129		UTL	229
LTL	99		LTL	130
Cp	0.8199		Cp	1.3647

Cpu	1.3891		Cpu	1.3632
Cpl	1.3388		Cpl	1.3325
Cpk	1.3388		Cpk	1.3325

From the above analysis, we conclude that the process is now capable of producing results in the specified control limits, as the process capability indices are greater than 1. Hence, it meets the specifications and is under control.

8.6 Improved R&R

EV and AV were calculated after implementing the improvements. For Highways and Non-Highways R&R was found to be **20.03%**.

EV	24.91%
AV	14.85%
R&R	20.03%

8.6 Improved P-Chart

P-Chart of Highways

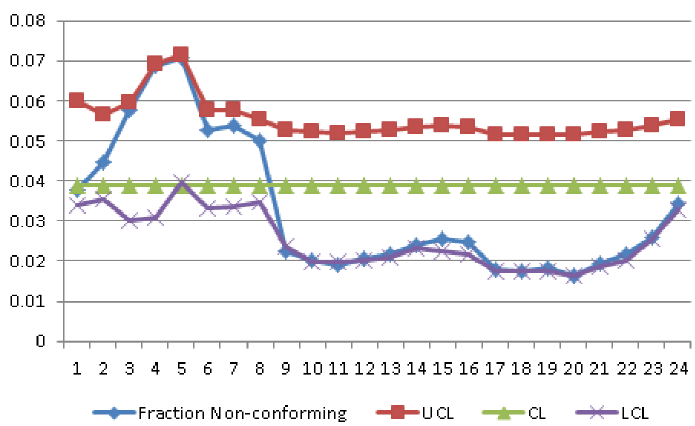

Figure 10- Improved P-chart of Highways

P-Chart of Non-Highways

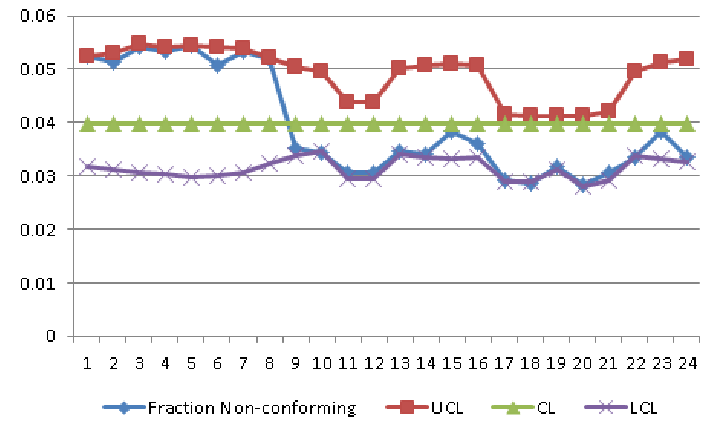

Figure 11- Improved P-chart of Non-Highways

From the above P charts, we conclude that the process is completely under control as all the items fall within the control limits.

9. Conclusion

The project proved to be a successful undertaking. By employing an effective methodology of DMAIC to improve the six sigma level of our system especially for the waiting time of passengers during daily work and non-work hours on the roads in India has been improved. Our main objective was to identify significant Critical to Quality parameters which contribute to the overall quality of delays on Indian roads. These CTQ's were defined during the define phase using Pareto analysis. We ensured that the problems identified are solved after the successful implementation of the DMAIC approach. We collected the data from Transport Corporation of India which included the study of four major metropolitan cities of India namely Pune, Bengaluru, Delhi, and Mumbai for the highway as well as non-highways traffic in all the respective cities. The key issue was road infrastructure was scrutinized and resolved in the subsequent phases by recommending various technical and organizational changes. These changes included ride-sharing, public cycling system, installation of CTV's, and many more. After the changes were made a new improved plan was proposed, applied and the successful results of the new plan led us to execute the plan as a standard throughout the organization which led us to create new random data. The DMAIC approach was a huge success which was reflected by the increase in the number of daily commuters using the roadways. We were able to raise the sigma level of operation from 2.73 to 3.45 for highways and 2.47 to 3.25 for non-highways. Thus, the various techniques learned in the class like Pareto analysis, QFD, control charts, root cause analysis, R&R analysis, and many others were used hands-on in our project which further complimented our knowledge, skill, and ability.

10. Future Scope

Working on this project was an amazing experience, which led to successful results! The project was quite promising, successful and further work can be done in the project. The reasons behind our suggestions are to further improve the quality of the delays on roads. A few examples of future improvements may include:

1. Increasing Traffic Services during peak hours
2. Promoting the usage of Public transportation
3. Introduction of new separate lanes for buses
4. Providing 24-hour service on busy routes
5. Provision for e-ticketing

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12. Appendices

Appendix 1

Data before applying DMAIC

Highways				Non-Highways	
Hour	**Vehicles arriving (hourly basis)**	**Vehicles Waiting (>15 min)**		**Vehicles arriving (hourly basis)**	**Vehicles Waiting (>15 min)**
1	2548	355		3098	708
2	2280	271		2869	674
3	1537	243		2145	299
4	1129	120		1867	215
5	1240	218		1920	220
6	1566	254		2019	267
7	1779	372		2198	301
8	2785	427		3281	785
9	4359	513		4875	809
10	5247	569		5833	923
11	5200	553		5777	902
12	5091	522		5665	896
13	4536	425		5124	843
14	3988	367		4638	819
15	3672	289		4289	771
16	3883	301		4452	787
17	5912	459		6590	989
18	5998	498		6719	1012
19	6451	613		7054	1057
20	6259	599		6877	1028

21	5033	437		5663	891
22	4266	375		4835	798
23	3378	329		3969	783
24	2716	259		3378	755
Total	**90853**	**9368**		**105135**	**17531**

Appendix 2

Data after applying DMAIC

Highways				**Non-Highways**	
Hour	**Vehicles arriving (hourly basis)**	**Vehicles Waiting (>15 min)**		**Vehicles arriving (hourly basis)**	**Vehicles Waiting (>15 min)**
1	2670	101		3398	178
2	2391	107		3082	177
3	1748	101		2776	181
4	1456	100		2579	179
5	1397	99		2410	173
6	1971	104		2511	171
7	2043	102		2673	165
8	2979	107		3781	162
9	4855	109		5375	188
10	5534	112		6447	192
11	5733	110		6245	181
12	5427	111		6165	179
13	4947	107		5674	180
14	4299	104		5012	182
15	3983	102		4681	180
16	4378	109		4926	178
17	6413	115		6993	182
18	6576	116		7120	191
19	6981	129		7392	229
20	6746	110		7264	181
21	5623	109		6013	179
22	4837	105		5233	173
23	3922	102		4409	169
24	2945	101		3876	130
Total	**99854**	**2572**		**116035**	**4280**

Appendix 3

P-Chart-Highways-Data Calculations

Highways						
Hour	**Vehicles arriving(hourly basis)**	**Vehicles Waiting(>15 min)**	**Fraction Non-conforming**	**UCL**	**CL**	**LCL**
1	2548	355	0.1393	0.13203	0.1132	0.09437
2	2280	271	0.1188	0.133106	0.1132	0.093294
3	1537	243	0.1581	0.137445	0.1132	0.088955
4	1129	120	0.1062	0.141489	0.1132	0.084911
5	1240	218	0.1758	0.140193	0.1132	0.086207
6	1566	254	0.1621	0.137219	0.1132	0.089181
7	1779	372	0.2091	0.13561	0.1132	0.09079
8	2785	427	0.1533	0.131211	0.1132	0.095189
9	4359	513	0.1176	0.127597	0.1132	0.098803
10	5247	569	0.1084	0.126322	0.1132	0.100078
11	5200	553	0.1063	0.126381	0.1132	0.100019
12	5091	522	0.1025	0.126522	0.1132	0.099878
13	4536	425	0.0936	0.127313	0.1132	0.099087
14	3988	367	0.092	0.128251	0.1132	0.098149
15	3672	289	0.0787	0.128886	0.1132	0.097514
16	3883	301	0.0775	0.128454	0.1132	0.097946
17	5912	459	0.0776	0.125562	0.1132	0.100838
18	5998	498	0.083	0.125473	0.1132	0.100927
19	6451	613	0.095	0.125034	0.1132	0.101366
20	6259	599	0.0957	0.125214	0.1132	0.101186
21	5033	437	0.0868	0.126598	0.1132	0.099802
22	4266	375	0.0879	0.127753	0.1132	0.098647
23	3378	329	0.0973	0.129554	0.1132	0.096846
24	2716	259	0.0953	0.131439	0.1132	0.094961
Total	**90853**	**9368**				
		P-Bar	**0.1132**			

P-Chart-Non Highways-Data Calculations

Non-Highways						
Hour	**Vehicles arriving(hourly basis)**	**Vehicles Waiting(>15 min)**	**Fraction Non-conforming**	**UCL**	**CL**	**LCL**
1	3098	708	0.2285	0.187522	0.1674	0.147278
2	2869	674	0.2349	0.18831	0.1674	0.14649
3	2145	299	0.1393	0.191583	0.1674	0.143217
4	1867	215	0.1151	0.193321	0.1674	0.141479
5	1920	220	0.1145	0.19296	0.1674	0.14184
6	2019	267	0.1322	0.192326	0.1674	0.142474
7	2198	301	0.1369	0.191289	0.1674	0.143511
8	3281	785	0.2392	0.186953	0.1674	0.147847
9	4875	809	0.1659	0.183441	0.1674	0.151359
10	5833	923	0.1582	0.182065	0.1674	0.152735

11	5777	902	0.1561	0.182136	0.1674	0.152664
12	5665	896	0.1581	0.18228	0.1674	0.15252
13	5124	843	0.1645	0.183046	0.1674	0.151754
14	4638	819	0.1765	0.183846	0.1674	0.150954
15	4289	771	0.1797	0.184502	0.1674	0.150298
16	4452	787	0.1767	0.184186	0.1674	0.150614
17	6590	989	0.15007	0.181197	0.1674	0.153603
18	6719	1012	0.1506	0.181064	0.1674	0.153736
19	7054	1057	0.1498	0.180735	0.1674	0.154065
20	6877	1028	0.1494	0.180906	0.1674	0.153894
21	5663	891	0.1573	0.182283	0.1674	0.152517
22	4835	798	0.165	0.183507	0.1674	0.151293
23	3969	783	0.1972	0.185178	0.1674	0.149622
24	3378	755	0.2235	0.18667	0.1674	0.14813
	105135	**17531**				
		P-Bar	**0.1674**			

Appendix 4

Improved P-Chart-Highways-Data Calculations

Highways						
Hour	**Vehicles arriving (hourly basis)**	**Vehicles Waiting (>15 min)**	**Fraction Non-conforming**	**UCL**	**CL**	**LCL**
1	2670	101	0.0378	0.059908	0.039	0.034092
2	2391	107	0.0447	0.056583	0.039	0.035417
3	1748	101	0.0577	0.059717	0.039	0.030283
4	1456	100	0.0686	0.069125	0.039	0.030875
5	1397	99	0.0708	0.071622	0.039	0.039538
6	1971	104	0.0527	0.057859	0.039	0.033141
7	2043	102	0.0537	0.057613	0.039	0.033387
8	2979	107	0.0499	0.055273	0.039	0.034727
9	4855	109	0.0224	0.05283	0.039	0.02371
10	5534	112	0.0202	0.052271	0.039	0.019729
11	5733	110	0.0191	0.052126	0.039	0.019874
12	5427	111	0.0204	0.052352	0.039	0.020148
13	4947	107	0.0216	0.052748	0.039	0.020952
14	4299	104	0.0241	0.053384	0.039	0.023216
15	3983	102	0.0256	0.053749	0.039	0.022521
16	4378	109	0.0248	0.053299	0.039	0.021701
17	6413	115	0.0179	0.051683	0.039	0.017317
18	6576	116	0.0176	0.051587	0.039	0.017413
19	6981	129	0.0184	0.051417	0.039	0.017583
20	6746	110	0.0163	0.051491	0.039	0.016201
21	5623	109	0.0193	0.052205	0.039	0.018795
22	4837	105	0.0217	0.052847	0.039	0.020153
23	3922	102	0.0260	0.053825	0.039	0.025715
24	2945	101	0.0342	0.055338	0.039	0.032662

Total	99854	2572				
		P-bar	0.039			

Improved P-Chart-Non-Highways-Data Calculations

Non-Highways						
Hour	**Vehicles arriving(hourly basis)**	**Vehicles Waiting(>15 min)**	**Fraction Non-conforming**	**UCL**	**CL**	**LCL**
1	3398	178	0.0523	0.05254	0.0399	0.0318
2	3082	177	0.0512	0.05306	0.0399	0.0313
3	2776	181	0.0541	0.05464	0.0399	0.0307
4	2579	179	0.0533	0.05407	0.0399	0.0303
5	2410	173	0.0544	0.05448	0.0399	0.0299
6	2511	171	0.0506	0.05423	0.0399	0.0301
7	2673	165	0.0532	0.05386	0.0399	0.0305
8	3781	162	0.0518	0.0521	0.0399	0.0323
9	5375	188	0.0352	0.05042	0.0399	0.0339
10	6447	192	0.0345	0.04971	0.0399	0.0346
11	6245	181	0.0307	0.04383	0.0399	0.0295
12	6165	179	0.0306	0.04388	0.0399	0.0295
13	5674	180	0.0347	0.0502	0.0399	0.0341
14	5012	182	0.0341	0.05071	0.0399	0.0336
15	4681	180	0.0384	0.05101	0.0399	0.0333
16	4926	178	0.0361	0.05079	0.0399	0.0336
17	6993	182	0.0291	0.04141	0.0399	0.0289
18	7120	191	0.0286	0.04134	0.0399	0.0288
19	7392	229	0.0317	0.04121	0.0399	0.0311
20	7264	181	0.0283	0.04127	0.0399	0.0281
21	6013	179	0.0307	0.04197	0.0399	0.0292
22	5233	173	0.0335	0.04953	0.0399	0.0338
23	4409	169	0.0383	0.05128	0.0399	0.0333
24	3876	130	0.0335	0.05188	0.0399	0.0325
	116035	**4280**				
		P-Bar	**0.0399**			

Appendix 5

R&R before the improve phase

m =	4		UTL =	15																
n =	4		LTL =	0																
r =	3																			
	Driver1					Driver2					Driver3					Driver4				
Route	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range
1	17	21	22	17	5	20	19	23	22	4	16	18	21	19	5	17	18	21	16	5
2	20	16	22	18	6	16	20	22	18	6	20	21	18	23	5	16	22	19	18	6

3	22	23	25	18	7	21	24	17	19	7	18	23	17	21	6	23	16	16	19	7
				R1 =	5.75				R2 =	6				R3 =	5.5				R4 =	6
R-double bar =	5.8125																			
K1 =	2.5																			
K2 =	2.7																			
	X1 =	20.083				X2 =	20.083				X3 =	19.916				X4 =	18.416			
Xd =	1.666																			
EV =	14.5312	96.87%																		
AV =	2.64849	17.65%																		
R&R =	14.769	98.47%																		

R&R after the improve phase

m =	4		UTL =	15																
n =	4		LTL =	0																
r =	3																			
	Driver1					Driver2					Driver3					Driver4				
Route	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range	T1	T2	T3	T4	Range
1	10	11	10	11	1	10	8	10	9	2	8	7	9	9	2	10	10	10	9	1
2	11	9	10	11	2	9	11	10	10	2	10	9	10	10	1	8	7	9	8	2
3	9	10	9	10	1	8	9	8	8	1	10	10	8	10	2	11	10	10	11	1
				R1 =	1.33				R2 =	1.66				R3 =	1.66				R4 =	1.33
R-double bar =	1.495																			
K1 =	2.5																			
K2 =	2.7																			
	X1 =	10.083				X2 =	9.166				X3 =	9.166				X4 =	9.416			
Xd =	0.91																			
EV =	3.737	24.91%																		

AV =	2.228	14.85%																		
R&R =	14.769	22.03%																		