Traffic Impact Analysis on the Operational and Functional / Structural Performance of Highway-A Case Study of Motorway M-1

Project report submitted in partial fulfilment of the requirements for the degree of

BE CIVIL ENGINEERING

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(2020)

It is to certify that
the report entitled

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Has been accepted towards partial fulfilment of the requirements for

Bachelor of Engineering

In

Civil Engineering

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بسم الله الرحمن الرحيم

ACKNOWLEDGEMENT

In the name of ALLAH Almighty, the Merciful and the Beneficent, who guided us and provided us the knowledge to complete this Final Year Project. Many people who assisted us in the completion of this research and without their help and support it would not have been possible to complete this FYP. Above all, we would thank our advisor, Brig. Dr. Muhammad Irfan, dean, Military College of engineering Risalpur, who was a beacon of light for us. Without his guidance, support, mentorship, and encouragement, this research project would not have been possible. We are also very grateful towards Brig. Dr Muhammad Irfan, Dean Military College of Engineering Risalpur Cantt, who provided us with an online platform amid the COVID-19 pandemic so that we can continue our research work without delaying the completion of our degree. Last but not least we would like to thank our parents, who provided unlimited support and best wishes and had absolute faith in us. May Allah bless them and bestows His countless blessings and bounties on them.

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ABSTRACT

Urban sprawl and the exponential traffic growth in the developing countries, like Pakistan, affect transportation systems in general and highway infrastructure. Traffic Impact Analysis evaluates the adequacy of a highway facility to serve a proposed/ upcoming development, and its expected effects on the transportation system. Comprehensive and coordinated transportation planning is critical to providing a balanced transportation system. Highway construction and its connectivity with existing motorways can reasonably be expected to generate more vehicle trips. M-1 is the major motorway in Pakistan connecting major cities of Peshawar and Islamabad. In the recent past, traffic growth due to inter-connectivity of M-1 with newly constructed Swat Motorway and E-35/ Hazara Motorway, causes degradation in operational performance in terms of long queues and vehicular delays especially while approaching exit toll plaza near Islamabad. Due to these conditions, the Islamabad bound commuter traffic (southbound traffic) is facing inconvenience and traffic delays on Islamabad Toll plaza. Moreover, manifestation of rutting and fatigue cracking is the evidence of the additional traffic load beyond the pavement's capacity. This study is focused on traffic impact analysis on operational and functional/ structural performance of M-1. Existing and future projected traffic volumes and/or the peak hour toll counts/ queues due to recent development are evaluated to analyze the existing and future operational performance of the transportation system, including levels of service (LOS) and volume/ capacity ratios (v/c) using PTV VISSIM® micro-simulation software within the study area. Physical performance included functional and structural evaluation using distress survey techniques and PaveXpress® tool, respectively. The study results help estimating the remaining design life, future maintenance and Rehabilitation needs and suggest a viable solution to reduce the vehicular delays on toll plaza of Motorway M-1.

Chapter No.1-Introduction

1.1 Background

Transportation systems make a crucial contribution to the economic growth and development of a country. The economy needs a reliable infrastructure to connect supply chains and the efficient movement of goods and services. A broad highway designed for high-speed operations of restricted type motor vehicles, usually divided, and having at least two lanes in each direction and merging lanes instead of cross traffic. Due to exponential growth in population, rise in earnings, and a corresponding increase in passenger cars, aggravated with poor design & planning of transport systems and land-use, traffic congestion has become a menace in urban centers. Also, rapid industrialization has increased the traffic density on the roads, which further triggered the government plans to build roads and highways.

Nowadays, major road networks in developing country like Pakistan is facing traffic congestion and is manifested mainly in periodic delays and long queues which travelers experience especially during rush hours. Due to the above-mentioned situation, most effected places are major road intersection and toll plazas. The traffic arrival rate is alarmingly high on the toll plazas on highways near metropolitan cities in Pakistan. An increase in arrival rate leads to an increase in the waiting time of vehicles in the queue. Longer waiting time results in losses in terms of increased fuel costs, pollution, and an increase in opportunity cost in the form of wastage of valuable time of commuters.

1.1.1 Introduction of M-1 Motorway

M-1 is one of the main strategic routes of Pakistan which carries heavy traffic of Pakistan as well as connects all motorways of Pakistan with Afghanistan and Central Asian. This is the East-west motorway of Pakistan connecting two major cities, Islamabad, and Peshawar. M-1 started its operation and inaugurated by President Pervez Musharraf, in2007. The total length of M-1 is 155 km, 67 kilometers in Punjab, and 88 kilometers in KPK. Major interchanges are 14 including two recently added interchanges for Hazara and Swat motorways. (Duhan, Arya et al. 2014)

Table 1 M-1 Motorway Configuration

West bound exits	Junction	East bound exits
Peshawar Ring Road	Exit 1	Start of motorway
Charsadda & KP highways S1	Peshawar Nothern Bypass	Chamkiani & N-5 National highway
Peshawar-Charsadda Road	Nowshera Interchange	Nowshera
Mardan, Rashakai & N-95 National Highway	Rashakai Interchange	Risalpur
Mardan ring road	Jehangera Interchange	Jehangera
Swat Expressway	**Karnal Sher Khan interchange**	
Sawabi	Sawabi Interchange	Jahangera
Ghor Ghushti	Chach Interchange	Hazro Hattian
Ghor Ghushti	Ghazi Interchange	Lawrencpur
Hazara Expressway	**Hazara expressway interchange**	
Hassan Abdal	Burhan Interchange	Burhan
Taxila and Wah	Barhama Bahtar Interchange	
Tarnol	Tarnol Interchange	N-80 Fatah Jangh
Islamabad	Islamabad interchange	N-80 Fatah Jangh

New linked motorways (Hazara and Swat Motorway) have shifted high traffic on M-1. This is the main reason behind the large queue lengths and delays on the south bond traffic at Islamabad interchanges during peak hours Moreover, due to unplanned design traffic of Swat and Hazara expressways design life of M-1 is depleting day by day.

1.2 Problem Statement

With the addition of SWAT and HAZARA expressway M-1 has seen a rise in overall traffic, freight vehicles along with passenger cars has crowded M-1. With the increase in traffic M-1 vehicles exiting toll plaza at Islamabad has seen a significant rise, causing delays and long vehicle queues. This has caused losses in terms of time and money. Due to idle burning of fuel it is also economically and ecologically not feasible. Also, with the consideration that M-1 was not planned for traffic input from both newly operational expressways it is also going to observe a loss in its design life.

Traffic congestion/ Queuing at M1 Toll Plaza Islamabad and distress analysis of Motorway M1; due to impact of unplanned traffic of Hazara and Swat Expressway.

1.2.1 Problem Location

M-1 toll plaza Islamabad and motorway 1

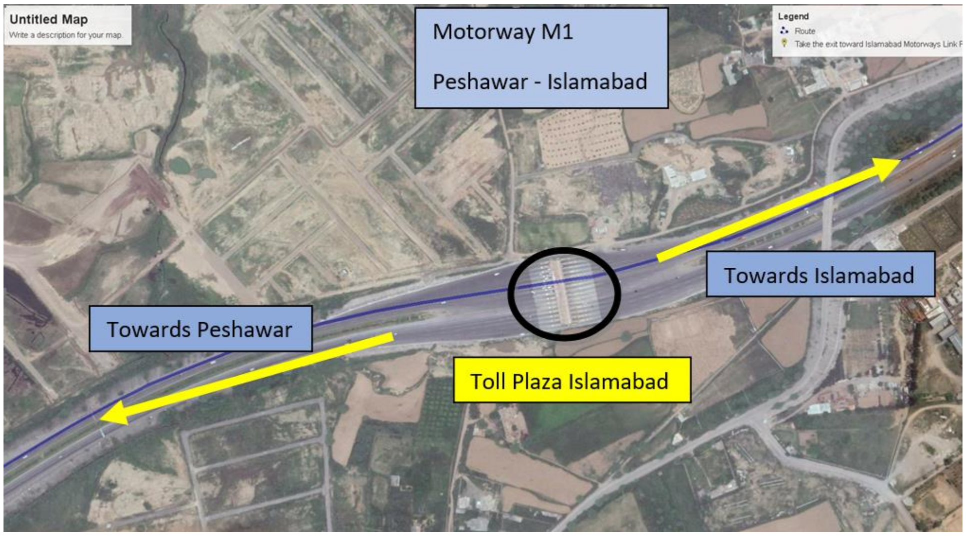


Figure 1. 1 M-1 toll plaza Islamabad

1.2.2 Toll Plaza Geometry

Figure 1. 2 Toll Plaza Geometry

1.3 Toll Plaza Details

Average Lane Width - 10 ft

Traffic Type - Heterogeneous (Trucks, Busses, Vans, Cars)

1.3.1 No. Of Approaches

- North Bound = 3
- South Bound = 3

No. of Toll Booths

- North Bound = 8
- South Bound = 14

1.3.2 Arrival and Service Rate

Arrival rate:

1700 vehicle per hour

Service rate:

M-Tag: 0.9sec per vehicle

General: 20-30sec per vehicle

1.4 Objectives of Study

As a performance measure, queue delay plays a pivotal and important role in evaluating levels of service and the number of channels related to the interchange that are causing system delays. Delay at the interchange is defined and used in many ways. Our objective is to focus on System delays, Queue lengths, and level of service due to these delays. These delays on interchange will improve by improving the traffic condition on interchange, reducing delays, and providing sufficient channels and taking corrective measures that must be a major concern. The specific objectives of this research can be summarized as the following points:

- To evaluate traffic flow performance under existing conditions at M-1 toll plaza Islamabad using VISSIM 9.
- Modeling and evaluating possible alternatives for projected traffic up to 10 Years.
- Evaluate the structural and functional performance of M-1.
- Evaluation of M-1 life under existing loads by PaveXpress.

1.5 Scope of Study

To accomplish the above-mentioned research objectives, a comprehensive research plan was prepared, and the following research tasks were outlined:

- Operational evaluation of M-1 by observing queue, delays, arrival rate and peak hour volume, using VISSIM.
- Traffic impact analysis and Functional performance evaluation of M-1.
- Structural or physical performance evaluation of M-1 using PaveXpress.

- Environmental evaluation of carbon footprint due to gas emissions by vehicle in queue.
- Cost analysis of burning fuel of vehicle in queue.

1.6 Limitations

- Traffic flow data does not incorporate the variations for VIP or emergency vehicular movement.
- Peak hour value is a mere imagery of the actual.
- Variations does not incorporate the seasonal changes in traffic flow.
- Implementation of load regime in Pakistan does not hold firmly especially in freight vehicles.
- Approximation of distresses in the pavement except of the original value.
- Growth rate may vary in the future.
- Fuel consumption is not exact but a mere imagery.
- Carbon footprint is also not exact.

Chapter No.2-Literature Review

2.1 Overview

One part of the chapter is a review of the literature and theory about the **operational Impact analysis** of M-1 within framework of queuing theory and toll plaza characteristics. This part includes the all operation characteristics of a highways and freeways. The other part contains an in-depth review to understand **structural Impact analysis** and structural deterioration of M-1 due to the additional traffic by newly build roads or traffic regime. This also include the strategies that can be implemented to mitigate issues in structural failure of the highway and contain the procedure for the increase of the overlay thickness on the pavement for rehabilitation purposes.

2.2 Operational Traffic Impact Analysis of Highways

Traffic impact analysis is very helpful in decision making by the public agencies, assists to evaluate whether the development is suitable for the specified site or not and defines the type of development is necessary for maintenance and to make satisfactory level of service. Traffic impact analysis is used to recommends the necessary operational and geometrical improvements to the transportation roadway, forecast the additional vehicular traffic linked with new development and assists in planning and land use decision making

2.2.1 Operational Element of Highway (Toll Plaza)

Toll plaza is a structure through which all vehicle must pass through it to pay fee. Generally, there are two types of toll plaza one is on-grade (on the highway) and other is off-grade (separately connected with highway) toll plaza. Toll plazas are the unique element of the transportation system. There are many factors which effects the performance of toll plaza such as arrival rate, service rate, number of toll booths, free flow speed of arriving vehicles and toll lane capacity. A special analysis and measures are required for the thorough understanding of its performance and operation.

2.2.1.1 Toll Operation at Toll Plaza

- **Arrival Process or Rate:**

  Arrival process is the sequence of intervals between consecutive arrivals. An arrival process is defined by the distribution of intervals, mean value, and variance. Counts are sometimes used instead of intervals. Rate by which vehicles are enter in the toll plaza along the toll road, called arrival rate.

Arrival rate represented by "***q***" ***q*** = arrival rate (veh/s, veh/h)

- **Service Rate:**

A service process is defined by the distribution of service time, its mean value and variance. The rate by which vehicles are to serve by toll booth, called service rate. Service rates represent by "*c*", *c* = service rate (capacity rate) of a single channel (veh/s, veh/h).

- **Service Time:**

Time taken by the server for service or time taken by the server at toll booth to take toll pricing from drivers, called service time of toll booth. Usually, service time for the manual toll lanes are high than E-toll and special tag lane.

- **Queue Length**

Queue length means the number of vehicles present along the toll road in the queue at toll plaza, waiting for their service. Basically, Queue length is the number of vehicles present in queue outside the service station

- **Queue System**

Number of vehicles in the system waiting for service. Queue system includes the number of vehicles present in the queue and vehicle present in the service station for service.

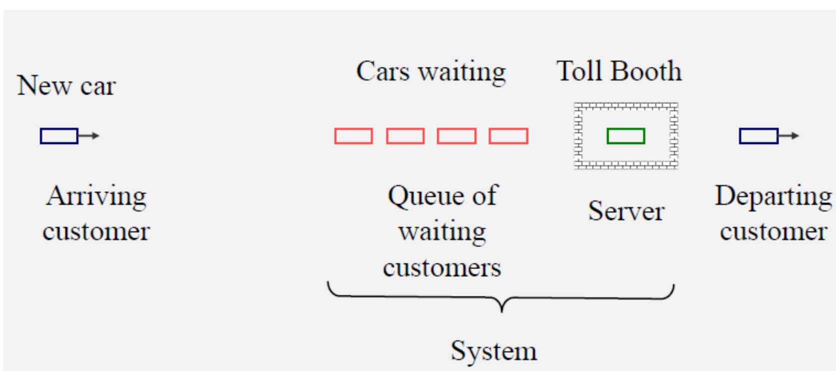


Figure 2. 1 Queuing

- **Total Time in System:**

Time spent by the vehicle present in the queue system. Time spent by vehicle in queue and the time spent in service at toll booth called total time in the system.

- **Total Time in Queue:**

Time spent by vehicle present in the queue along the toll road or the time spent for vehicle to wait of their turn to serve at toll booth.

- **Queue Capacity:**

A queue can be limited by its capacity. Queue capacity is a maximum number of customers that can be accommodated at the same time in the queue. A queue is also specified by its discipline. The queue discipline determines the order in which customers enter the server.

2.2.1.2 Toll Collection

Collection of toll pricing by service stations from drivers, which is used for the maintenance of toll plaza and highways.

- **E toll**

  Electronic toll collection is a system of collecting toll in which toll is collected by computer or detected from the driver's credit card when driver pass the toll both. This the easiest way of collecting toll for both driver and servers because driver do not need to stop completely, just slow down and then pass the toll booth. This system prevents the drivers to wait in the queue to pay the toll manually.

  .

- **Manual Toll**

  "Manual toll collection" is a system in which toll collected manually. Driver stops at the toll booth and pays the toll. This system is not efficient and cause the delay

2.2.2 Operational Characteristics of Highways

2.2.2.1 Flow Conditions

- **Uninterrupted Flow**

Flow which presents the smoothest form of travel having no obstructions and fixed causes of delay. Flow is totally dependent upon the traffic stream flow conditions. The purest form of uninterrupted flow with controlled ramp access is a freeway. The traffic stream conditions on these are dependent only on the vehicular interaction between them and the geometry of the roadway.

- **Interrupted Flow**

Traffic flow in facilities having fixed causes of delay or interruptions to the traffic flow. The traffic signals and stop control signals are the prime examples of the interrupted flow facilities. traffic stream characteristics are dependent upon geometry of the facility, vehicular interactions, and control delays at the intersections also the frequency of access to the facility.

- **Undersaturated Flow**

Flow conditions in which the capacity of the facility is greater than the existing density at the facility. The traffic flow stream is independent of the traffic conditions downstream. The capacity of the facility is greater than the arrival rate of vehicles. No queue is formed, or a residual queue is generated. The traffic flow conditions of the freeways are undersaturated in most cases and no queue generation occurs.

- **Oversaturated Flow**

Flow conditions in which the existing density of vehicles at a facility is greater than the capacity of the facility. The traffic flow is affected by the conditions downstream. The capacity of the facility is not greater than the arrival rate of the vehicles. A queue is generated when such conditions occur. Traffic flow conditions of bottleneck are examples of the oversaturated flows.

2.2.2.2 Traffic Flow Relationship

Traffic flow relationship states as.

$$k = q/u$$

Where.

q = flow rate (vphpl),

u = average speed (mph), and

k = density (vpmpl).

Following diagram shows the relationship between the speed-density, flow-speed, and flow-density of the traffic on highway.

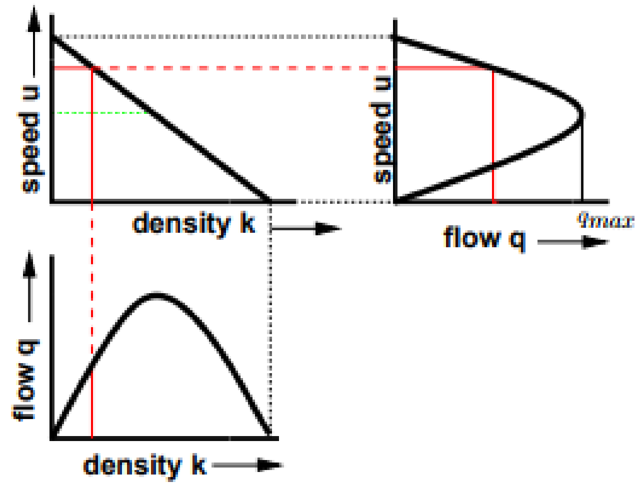


Figure 2. 2 Graphical representation of q, u and k

2.2.2.3 Optimal Flow Condition (Free Flow Speed)

It is a theoretical speed when the density and flow rate of vehicles are zero. Analysis of speed flow curves show that free flow speed is observed from flow rates in between 0-1000 veh/hr/lane. Chapter 10, of highway capacity manual 2010 present a methodology for the calculation of free flow speeds over segment if it cannot be directly measured. The manual shows the free flow speed to be a function of the under mentioned factors.

- Lane widths
- Lateral clearance
- Total ramp density

The operation of all basic merge, diverge, weaving segments is affected by the free flow speed of the freeway facility.

2.2.2.4 Peak Hour Volume

Capacity requirements of a facility are based on the peak hour volumes of traffic. Since, the maximum traffic operation is observed in this period. The peak hour volume is a varying from season to season and day to day. The peak hour volumes for a recreational site vary seasonally and little change is observed in the commuter traffic of urban streets.

2.2.2.5 Traffic Congestions

Road and their allied facilities are interconnected to each other. Urban production output highly depends on the effectiveness of its transport systems to move people and goods between numerous destinations. Thus, the most important transport problems on highways or motorways are often related to toll roads or toll plazas. One of the most significant highway transport problems is traffic congestion at toll booths. It is experienced when the supply of the highway or motorway can no longer be serviced efficiently by toll roads.

2.2.2.5.1 Causes of Traffic Congestion on Toll Roads

- Inadequate number of toll booths
- Break down of vehicle in jam packed lanes
- c. Too many trucks on the road cause more delays due to more time consumption while paying toll.
- Diversion of traffic from other transport facility to motorways due to different reasons.
- Hindrances in the toll lanes causing obstruction. These can be any of the following:
    - Non-functioning toll booths
    - Road work at toll booth
    - Lane closure due to utility work
    - Accident

2.2.3 Operational Performance Analysis of Traffic Flow of Highway

Following are the toll to describe the traffic flow at toll roads.

- Capacity Analysis
- Level of Service (LOS)
- Queuing theory

2.2.3.1 Capacity Analysis

As per HCM (Highway capacity Manual) 1985 the capacity of a facility is defined as, "the *maximum hourly rate at which vehicles can reasonably be expected* *to traverse a point or uniform section of a roadway during a given period under prevailing roadway, traffic, and control conditions.*"

Approximation of maximum number of vehicles that can be accommodate by a facility is the prime objective of capacity analysis. Generally capacity analysis is used to calculate service flow rate. Service flow rate is the maximum number of vehicles that can accommodate by a highway or any other facility while fulfilling all operational qualities. For example, a toll booth on the highway operate at its full capacity when toll collector remains always busy and queue is built.

2.2.3.2 Queuing Theory

The main way of measuring the operational characteristics of the transportation system is the queuing model. The queuing theory presents the model that inter-vehicular interactions happen at a roadway segment. The arrival rate, speed of vehicular movement on the roadway and the density of the roadway segment all play and important role in the identification of the queuing model. Some physical characteristics also influence the queuing model such as highway characteristics that are lane width, number of lanes, lateral clearance, interchange density and gradient of the roadway segment. The queuing model is also affected by the vehicular types on the segment under consideration. The movement of truck traffic, busses and recreational vehicles also affects the queuing model. The base free flow speed is also responsible for the changes in the queuing model. The arrival rates of the vehicles are of two types:

- Equal time arrivals (uniform, deterministic arrivals)
- Exponentially distributed time intervals (distributed, scholastic arrivals)

The traffic data simulations also require the departure speed of vehicles from the interchange for the calculation of queue dissipation characteristics. The queue dissipation will be useful in calculating the time taken for the queue formed to dissipate.

The importance of number of channels for any queue formation is of importance. More the number of channels available for the passage of vehicles the faster will be the rate at which vehicles will pass from the roadways segment. The single channel consideration of bottleneck on roadway segment is an example in which a single channel exists, while the multiple toll booths of a toll plaza is an example on multiple channel system. The more the number of channels the more will be the flow of vehicles through the specified segment. There are various disciplines that are followed by vehicular and non-vehicular traffic around the globe. The queue discipline also effects the rate at which the queue will dissipate and the way the queue dissipation takes places.

- First in first out (FIFO)

  The first in first out disciplines shows the discipline that is followed in the toll plazas and in banks. The first person to enter the queue will be served first.

- Last in first out (LIFO)

  The last in first out principle as the name identifies follows a way that is observed while vehicular crossings. The last vehicle to enter the queue will be the first to leave the queue.

- Priority

  The priority is the orientation of following the traffic discipline that is followed for ambulances and other high priority vehicles. The priority vehicles are served first, and queue of the remaining dissipates in due course.

On toll plazas the first in and first out discipline is followed except for ambulances and ambassadors and other high priority vehicular movements. The naming of queue model can be recognized using three alpha numeric values followed by queue discipline and capacity. The naming depends on whether the traffic arrival and service are deterministic or randomly varying. For a deterministic approach and constant rate of service for a single channel following FIFO protocol and infinite capacity of system the naming would be D/D/1 (FIFO, infinity). Similarly, for a randomly varying approach and random service rate and FIFO protocol the naming of the system with multiple channels will be M/M/#of channels (FIFO, infinity)

Measures of Queue Performance

Queue	Probability of busy or idling server	Average queue	Average no. of vehicles in the system
M/M/1	$P_b = x$	$Q_q = \frac{x^2}{1-x}$	$Q_s = x + Q_q = \frac{x}{1-x}$
M/D/1	$P_b = x$	$Q_q = \frac{x^2}{2(1-x)}$	$Q_s = x + Q_q = \frac{2x - x^2}{2(1-x)}$
M/G/1	$P_b = x$	$Q_q = \frac{x^2(1+A^2)}{2(1-x)}$	$Q_s = x + \frac{x^2(1+A^2)}{2(1-x)}$
M/M/n	$P_0 = \frac{1}{\sum_{i=0}^{n-1}\frac{(nx)^i}{i!} + \frac{(nx)^n}{n!(1-x)}}$	$Q_q = \frac{n^n P_0 x^{n+1}}{n!(1-x)^2}$	$Q_s = nx + Q_q$

$$A = \frac{\sqrt{\text{var of service time}}}{\text{mean service time}}$$

Little's formula: $d = \frac{Q}{q}$

mean service time = $1/c$

$A = 0$ for deterministic service (all service times are equal)

$A = 1$ for random service (Negative Exponential)

Figure 2. 3 Measure if Queue Performance

2.2.3.3 Level of Service (LOS)

Level of service of any facility is its qualitative measure, which defines its operational conditions with respect to the traffic stream and experience by motorists Measure of performance stratified quantitatively is Level of Service of a segment. Simply put the measure of performance of a segment is the level of service of the segment. Highway capacity manual has identified six categorical differentiation of the highway elements ranging from A to F. A is the best quality of service provided and F being the worst quality of service being provided. This converts the complex numerical analysis into a simple categorization of the level A to level F. following is the LOS criteria based on the control delay per vehicle.

Table 2 Level of Service vs Control Delay

Level of service **LOS**	**Control Delay/ Vehicle** **s/veh**
A	<10
B	10-20
C	20-35
D	35-55
E	55-80
F	>80

2.3 Impact Analysis on Structure

Structural impact analysis is the investigation or study which evaluates the sustainability of existing and future transportation infrastructure. This analysis compensates extra observations and estimations for a proposed development, land zoning and redevelopments. This analysis depends on the size, type and location and varies with range of detail and complexity of the infrastructure. Domain of the structural analysis are following:

- Assess pavement structural integrity/ load-carrying capacity
- Remaining Service Life (RSL) analysis
- Support Maintenance & Rehab (M&R) improvement program and evaluate M&R techniques Develop pavement performance prediction models
- Improve pavement design approaches and establish load limits

2.3.1 Structural Element of Highway (Pavement)

Pavement is the structural element of a highway. It composed of many layers, and each layer contributes the different load and provide the strength to overall structural pavement. Pavement act as the shield, provide the smooth riding surface, and give skidding resistance. Generally, there are two broad categories for the pavement

- Rigid pavement
- Flexible pavement

2.3.1.1 Rigid Pavements

Rigid pavement consists on top PCC layer, also known as concrete pavement. Generally, this layer is much stiffer than the flexible pavement because rigid pavement has less modulus of elasticity due to top PCC (plain cement concrete) layer. Moreover, these pavements can consist of reinforcing steel bars. These bars reduce the spacing between bars and control the pattern and development of cracks in rigid pavement. In concrete pavement concrete overpasses, the weak area in beneath weak supporting layer.

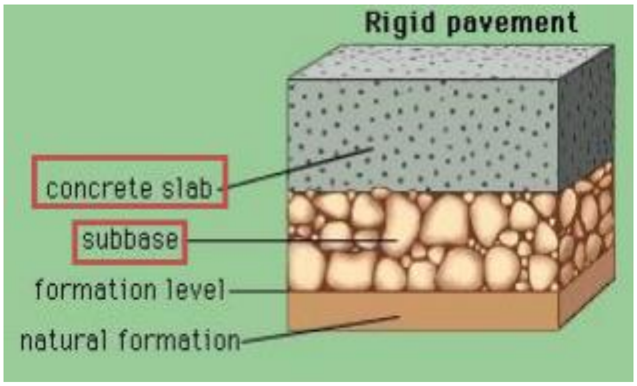


Figure 2. 4 Rigid Pavement

2.2.3.2 Flexible Pavement

In flexible pavement, the top bituminous layer covered the serval layers of granular material. The main objective of its design is to prevent from the excessive bending of any pavement layers. It flexes under the vehicle wheel or point load. Whereas, over stressing of any layer leads the pavement to fail. In this type of pavement, load distribution of applied traffic load or stress varies from one layer to another layers. Conventional structure of flexible pavement is shown in fig:

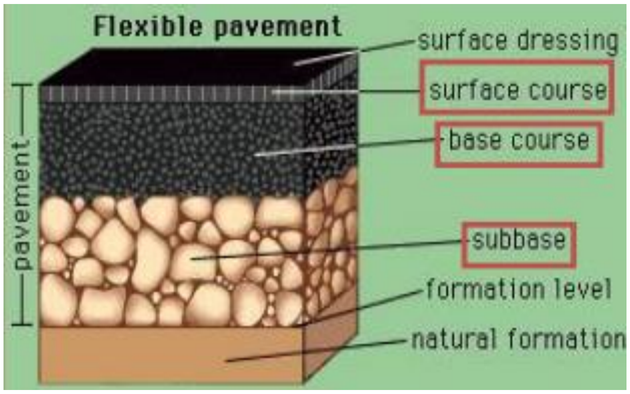


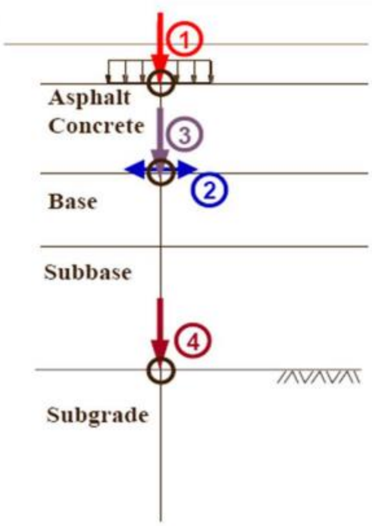
Figure 2. 5 Flexible Pavement

2.3.2 Load Response on The Flexible Pavement

When we apply load on the pavement, load distributes from the upper layer to lower layer throughout the pavement. The load response helps us to identify the critical locations in the pavement. Due to this reason load responses are necessary in pavement design. Load response is different in the different type of pavement depends on the granular base, weather the base of pavement is unbonded or bounded. Load response in both type of pavement is shown in fig.

2.3.2.1 Load Related Critical Response on The Unbounded Granular Base Flexible Pavement

In unbound granular base flexible pavement critical tension due to bending is at the lowest point of all bound layers is bottom of AC. Other critical load response locations are following.



Point 1: Vertical Compressive Stress, AC Rutting

Point 2: Horizontal Tensile Strain, AC Fatigue

Point 3: Vertical Compressive Stress, Base Rutting

Point 4: Vertical Compressive Stress, Subgrade Rutting

Point 5: Load response on the bounded base flexible pavement:

Figure 2. 6 Load related critical response

2.3.2.2 Load Related Critical Response on The Bounded Granular Base Flexible Pavement

In bound granular base flexible pavement critical tension due to bending is at the lowest point of all bound layers is bottom of stabilized base. Other critical load response locations are following.

Point 1: Vertical Compressive Stress, AC Rutting

Point 2: Horizontal Tensile Strain, AC Fatigue

Point 3: Vertical Compressive Stress, Base Rutting

Point 4: Vertical Compressive Stress, Subgrade Rutting

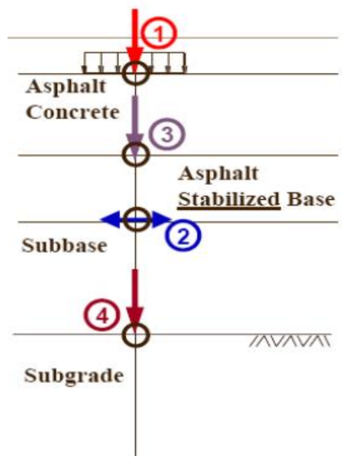


Figure 2. 7 Load related critical response

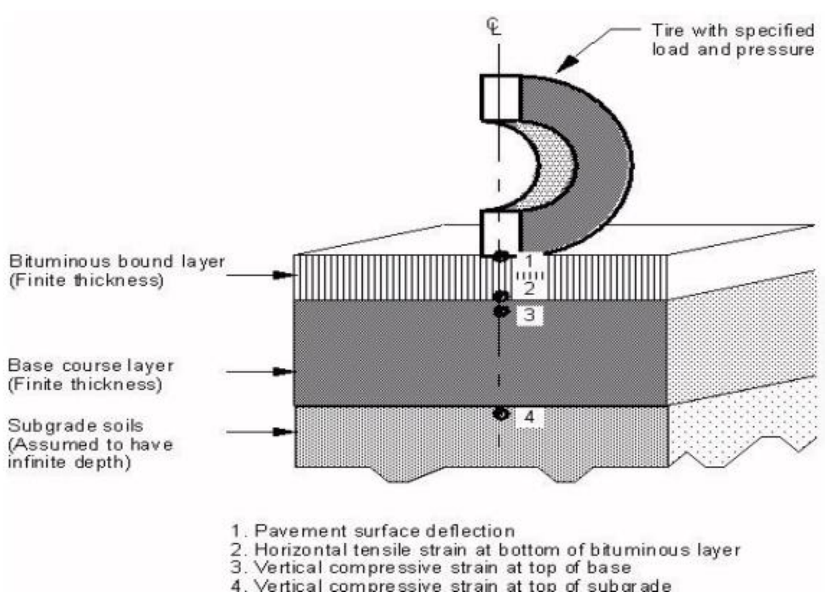


Figure 2. 8 Pavement surface deflection

Critical Analysis Locations in Pavement Structure is shown in table:

Table 3 Critical Analysis Locations in Pavement Structure

Location	**Response**	**Reason for use**
Pavement surface	Deflection	Used in imposing load restrictions for overlay design
Bottom of hot mix asphalt layer	Horizontal tensile strain	Used to predict fatigue failure in the HMA
Top of intermediate layer (base and sub-base)	Vertical compression strain	Used to predict rutting failure in the base or subbase
Top of subgrade	Vertical compression strain	Used to predict rutting failure in the subgrade

2.3.3 Factors Influencing the Structural Performance of a Pavement

2.3.3.1 Traffic

The major factor influencing the structural performance of a pavement is the traffic that it is subjected to. For each pass of a vehicle the pavement undergoes a damage equivalent to the damage done by its axle. Each pavement is built for a certain number of equivalent single axle loads, so for each pass of a vehicle the damage is translated in terms of ESALs. When a certain number of passes are reached the pavement will show different deterioration characteristics.

2.3.3.2 Moisture (water)

The moisture enters the through the loose bonding of the surface of the pavement and seeps into the grains of the soil. The moisture enters the granular structure of the soil and causes displacement in the bonding of the subbase of the pavement and causes visible deterioration. The moisture that enters also carries with itself a frost effect that will take up more space than permissible and causes breaking and distortion of the granular bonds in the pavement.

2.3.3.3 Subgrade

The soil on which the loads of the pavement are transmitted to is the subgrade. The composition of subgrade is of vital importance to the functional characteristics of the subgrade. The subgrade if not made up adequately strengthened material will deflect under normal loads. This deflection in the particulate matter will result in the soil below the pavement to diverge from beneath it and to areas surrounding the pavement hence drastically decreasing the load carrying capacity of the pavement and also visible bulges in the pavement will be observed.

2.3.3.4 Construction quality

Poor construction quality results from a whole lot of reasons. The improper compaction leads to the pavement being heavy in volume of air present leading to moisture seepage and resulting in the afore-mentioned factors. Improper temperatures during preparation of hot mix asphalt will result in the pavement being subjected to bleeding and separation of asphaltic content from the aggregates. The poor construction quality results in the life of pavement being decreased and the pavement deteriorating under fewer load repetitions than the predicted.

2.3.3.5 Maintenance

The maintenance of the pavement has a tendency for increasing the pavement life for up to 10 percent of the original pavement life. Since the damage on a pavement that is already in a poor physical condition is much drastic. The untimely and delayed maintenance results in decreased life of the pavement than after maintenance that should have increased the proposed life. The timely maintenance increases the life of the pavement up to 3 to four years and keeps the deterioration in the pavements in check.

2.3.4 Structural Performance Evaluation of Pavement

Structural performance evaluation of pavement is done based on different paraments. These parameters are like the scale on which we estimated the structural condition of the pavement. Rehabilitation and other maintenance procedure are based and carried out upon these structural evaluation parameters. For example in the case of the deflection on the surface of pavement , there is the scale by which we estimate the condition of pavement, like, less deflection is less harmful and we can recover the pavement by some maintenance and optimization but on the other hand, high deflections in pavement will move us towards the overall rehabilitation to gain the desire life of pavement. Following data requires for data collection and analysis to estimate the structural performance evaluation of pavement.

- Pavement condition (distress, surface friction, smoothness, and deflections).
- Previous structural rehabilitation activities.
- Pavement design characteristics (layer thicknesses, joint spacing, shoulder type, and lane width).
- Pavement Geometric design characteristics.
- Pavement material composition.
- Traffic counts and loadings.
- Climate conditions.
- Miscellaneous factors of pavement (clearances and utilities).

The primary step for the structural evaluation process involves in evaluating the overall current condition of the pavement and current pavement problems. Some required data can be extracted from the design diagram of pavement and some are historic data can be extracted from previous records, but other required data for structural evaluation is obtained by different testing. Testing for the structural evaluation is categories as the:

- Destructive Testing
- Non- Destructive Testing

2.3.4.1 Destructive Testing

Destructive testing involves damage of pavement to get the testing sample (undisturbed or disturbed) for the observation of pavement material condition like bonding, PCC D-cracking, PCC ASR or AC stripping. Mostly, these tests are used to conduct on site. Some destructive tests test is simple like, coring (Estimation of the Pavement thickness by measuring the length of core). Some are complex and need high energy and time like dynamic modulus test on recovered AC cores, Elastic modulus, and strength test of PCC cores.

Destructive tests have many limitations, when these tests are conducted on the major highways, with heavy traffic loads, may cause the risk of worker's life and practical restrain, in term of money, time and energy. Destructive tests also have some advantages like it gives the detail Examination of the subsurface conditions and bounding between the layers of pavement

2.3.4.2 Non- Destructive Testing

Nondestructive tests (NDT) are performed to provide the investigation and evaluation of pavement structure and materials properties by means of do not introduce the physical removal and damage of the structure. Nondestructive tests ranges from the easy and simple tests like GPR (Ground penetration test) to estimate the on field thickness of layers of pavement and subsurface condition, Profile tests to estimate the pavement surface smoothness, Friction tests to estimate the skid resistance between the vehicle tire and pavement surface, to the well-known and conventional test, Falling weight deflectometer(FWD) test, for deflection calculation

Following are advantages of NDT:

- Reduces the risk of workers life and accidents due to lane closures.
- Reduces the testing cost.
- Improves testing reliability.
- Provides detailed information for selection between the available rehabilitation options.
- Provides information for rehabilitation (overlay) design.

2.3.5 Deflection testing

Usually deflection testing is the non-destructive testing (NDT), used for the structural evaluation and restoration or rehabilitation process. Structural performance is directly relating with the pavement deflection under the action of the various loads. Many organizations relate the maximum estimated deflection to the load repetition on the pavement, as the failure criteria of that road. Deflection testing devices calculate the deflection by applying a load on the pavement structure and measure the resulting maximum surface deflection. At non distress locations, deflection testing are generally used to determine the following for the flexible pavements.

- Elastic modulus of pavement layers

- Structural suitability

2.3.5.1 Falling Weight Deflectometer (FWD) Test

Failing weight deflectometer test is conducted for the calculation of deflection testing for the structural evaluation. The FWD is a device that provides the temporary force in the form of impulse on the pavement surface. In this device, there is a weight that is used to drop from the specified given height and then it drops on the pavement. This failing weight strikes on the set of the rubber buffers to the 12 in circular foot plate, which generate force in the form of impulse that transmits to the pavement surface. By changing the weight of the load and the height of lift, the impulse force can be varied. Schematic view of FWD is shown in fig.

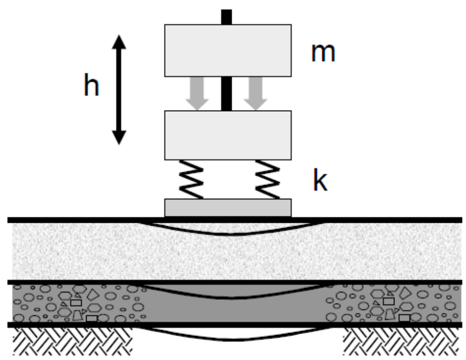


Figure 2. 9 FWD Test

Generally, seven deflection sensor s or geophones are used for the measure of the deflection due to the impulse force by y the falling weight. A sensor placed at the center of the plate, while the other six sensors are placed with specific spacing in the 12 ft range from the center of plate. Sensor spacing depends on the length of the pavement structure and the level of the examination.

FWD can be performed on the center of the lane, on the outer wheel path or can conduct on the both sides. FWD test is carried out at the 40°F to +90°F pavement temperature. One can calculate the deflection at the given temperature and then the deflections can be adjusted accordingly to counter the effect of temperature on pavement material modulus in deflection testing. Generally, the falling load used in FWD test is ranges between the 9 to 12 kips depends on the pavement response under heavy wheel load.

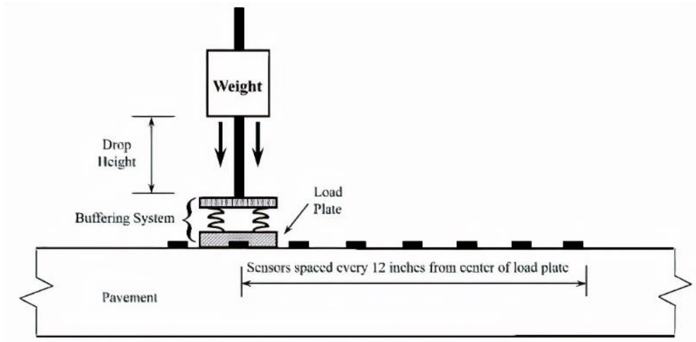


Figure 2. 10 FWD Test

2.3.6 Flexible Pavement Overlay for Structural Rehabilitation

Flexile pavement when it experiences the heavy traffic loads and environmental impacts, can cause them to generate the following deterioration or deficiencies in pavement:

- Increase in rutting
- Increase in cracking
- Insufficient pavement ride quality
- Insufficient skid resistance

It is possible that a pavement has no above-mentioned deficiencies, but it can have the issues like, insufficient structural capacity for the expected traffic load impact in future and high maintenance costs. In these condition, treatments of the pavement with overlay is best and most used solution for rehabilitating or restoring.

2.3.6.1 Deflection-Based Overlay Design

Deflection-based overlay design, we first estimate the structural performance of the pavement by using the surface deflection and then provide the additional overlay thickness, to achieve the desired structural performance level. In this design the surface deflection and existing performance are estimated by the nondestructive testing NDT (commonly used failing weight deflectometer FWD). Generally, site conditions (climate, pavement material and soil type) and the level of examination decides which nondestructive test is to choose for deflection-based overlay design.

2.3.6.1.1 Procedures for Deflection Based Overlay Design of Flexible Pavement

Basically, this design procedure includes the deflection-based analysis method. In this procedure, the structural performance of the pavement is quantified as the structural number (SN). By increasing the overlay thickness of pavement, the effective SN of the existing pavement will increase to the required structural number, to overcome the upcoming traffic demand. Following formula is used for the required overlay structural number in this procedure design.

$$SN_{ol} = a_{ol} * D_{ol} = SN_f - SN_{eff}$$

SN_{ol} = required structural number of overlays

a_{ol} = structural coefficient of AC overlay

D_{ol} = required thickness of overlay in inches

SN_f = required structural number for future traffic demand

SN_{eff} = effective structural number of the existing pavement

2.3.6.1.2 Determination of SN_{eff} of Existing Pavement

For the calculation of the effective structural number SN_{eff} of the existing pavement generally following methods are used:

- Non-Destructive Tests (NDT)
- Condition survey (using a component analysis), or
- Life cycle analysis

2.6.3.1.3 Determination of SN_{eff} by Non- Destructive Tests

SN_{eff}, which is calculated by the NDT is based upon the assumption that total overlay thickness and stiffness are correspondence corelated with the structural capacity of the pavement.

$$SN_{eff} = 0.0045 \text{ x } D \text{ x } \sqrt[3]{Ep} \qquad \frac{ai}{MR} = \frac{0.14}{30{,}000} = 0.0045$$

Ep = Effective modulus of the layers of pavement above the subgrade (psi)

D = collective thickness layers above the subgrade

So, resilient modulus should be known for the calculation of effective SN, then after calculating M_R, we can easily calculate SN_{eff} and then putting the value in above equation, SN_{ol} can be calculated easily.

2.6.3.1.4 Calculation of M_R from NDT

M_R can be calculated through the following steps:

- Conduct Falling Weight Deflectometer (FWD) test on the current pavement in which failing load is approximated to the 9000lbs.
- Then measure the deflection at the center as well as the r distance from the center
- Back calculate subgrade modulus, M_R

$$M_R = \frac{0.24 * P}{dr * r}$$

dr = FWD deflection at a distance r from the center of the plate load.

P = Falling weight

r = distance from center of the plate load to deflection sensor in inches

2.3.7 Structural Deterioration of Pavement

Development of the distress in pavement due to the environmental impact and excessive traffic loading and impact, is generally known as the Pavement deterioration. Pavement deterioration of the highways is considered as very serious problem in the transportation, because the traffic flow, serviceability, quality of pavement, and safety of passengers and vehicle are greatly affect by the damages and deterioration of pavement and sometimes it may cause the permanent failure of pavement After the construction of the pavement, road start to deteriorate with the time , so to overcome the defects od road there is the need to be rehabilitate the pavement to ensure the required level of service, efficiency and safety of road.

2.3.7.1 Types and Major Contributing Factors of Pavement Deterioration

Types of the structural distress in pavement are following:

- Cracking
- Surface deflection and deformation and
- Disintegration of pavement
- Surface defects

Table 4 Types and Major Contributing Factors of Pavement Deterioration

General Description	Distress Type	Major Contributing Factors
Cracking	Fatigue Cracking	Load
	Long. Cracking	Load
	Reflection Cracking	Load, materials, climate, construction
	Transverse Cracking	Materials, climate
	Block Cracking	Materials, climate, construction
Surface deformation	Rutting	Load, materials
	Shoving	Load
Surface defects	Raveling	Materials, climate, construction
	Bleeding	Materials, climate, construction
Miscellaneous distress	Lane-to-Shoulder Drop-off	Materials, climate, construction
	Pumping	Load, materials, climate, construction
Patching and potholes	Patch Deterioration	Load, materials, climate, construction
	Potholes	Load

Figure 2. 11 Tranverse Cracks in Pavement

Figure 2. 12 Longitudnal Cracks in Pavement

Figure 2. 13 Permanent Deformation in Pavement

2.3.7.2 Causes of Pavement Deterioration

- Temperature variation throughout the year, causing change from 50º C to less than zero major cause of pavement deterioration.
- Unplanned increase of loading of traffic especially due to the formations of new road, is major cause of the cracking (Alligator Cracking). Due to the formation of link roads, major traffic shifts on that road causes the increase in traffic loading on that road, causing the deterioration in that road.
- Poor design shoulder causes the edge failure in pavement.
- Poor subgrade also causes the deterioration in the pavement specially presence of the clayey subgrade cause corrugation on the surface and unevenness of surface
- Poor drainage also causes the deterioration in pavement, during the rainy season rainwater try to penetrate through the layer of pavement from the sides and the top of the pavement, forcefully. Due to this water bound between the layer and the detachment between the top and bottom layers occur.

2.4 Pavements Functional Performance Criteria

Functional performance of road is defined as the ability of a road to fulfil its primary objectives like smooth and safe driving. In this performance criteria we need the data that give properties of the pavement which are directly related to the pavement functional performance like skid resistance, surface texture, serviceability, and roughness.

Performance evaluation criteria use for functional performance based on:

- Present Serviceability Rating (PSR)
- Present Serviceability Index (PSI)
- Riding Comfort Index (RCI)
- Ride Number (RN)
- Roughness as International Roughness Index (IRI)

2.4.1 International Roughness Index (IRI)

International surface index is the toll to determine the functional performance of the road. This surface roughness index can be obtained by longitudinal road profiles. This index is calculated by the quarter-car vehicle math model, through this model's response roughness index is usually calculated. Units of the roughness index are like the slope (in/mile). Following are the ranges of the IRI, through these ranges we estimate the functional performance of the pavement.

Table 5 International Roughness Index (IRI)

IRI	Road Condition	Treatment
< 3.5	Good	Routine maintenance
3.5 < IRI < 5.8	Fair	Periodic maintenance
5.8 < IRI < 9.0	Damaged	Road improvement
IRI > 9.0	Seriously damaged	Road reconstruction

Chapter No.3-Methodology

3.0 Overview

The chapter aims at identifying the use of different techniques to identify the problem and other portion in the problem-solving methods used. This will give an in-depth persona of the way that the problem was resolved to acquire the needed results in the end.

3.1 Introduction

This chapter emphasizes the focus on the methodologies used in the research work to reach the desired goals mentioned in chapter 1. This methodology expresses the LOS criteria for the interchange based on Queue time, queue delay, time in the system, time in queue, service time, number of toll booths, arrival rate, deceleration time and acceleration time. This also comprises Cost analysis deals with idle fuel burning cost involve in the time during queue time, comprising the fuel wastage during the initial deceleration and the final acceleration also the idle fuel burning cost. Environmental hazards such as carbon footprint is also a part of this project hence a part of methodology also explains the techniques used in dealing with the said hazard. Involving the fuel burnt during the time in the system. Considering the current situations at toll plaza and the growth rate, this methodology also focuses on the techniques utilized in the evaluation of the pavement distresses and the life remaining of the pavement.

Methodology also includes revenue generations for future model of the toll plaza and time till investment in the interchange can be recouped by a small increase in the toll tax. Use of growth rate as a conundrum for future predictions and utilizing the emergence of electric vehicle for a positive view in the future.

This whole chapter comprises the two parts which are following:

- Methodology for analysis of m-1 Islamabad interchange
- Methodology of analysis of pavement structure

3.2 Overall Methodology

Methodology for the performance evaluation mainly consist of two aspects

- Operational Evaluation
- Structural Evaluation

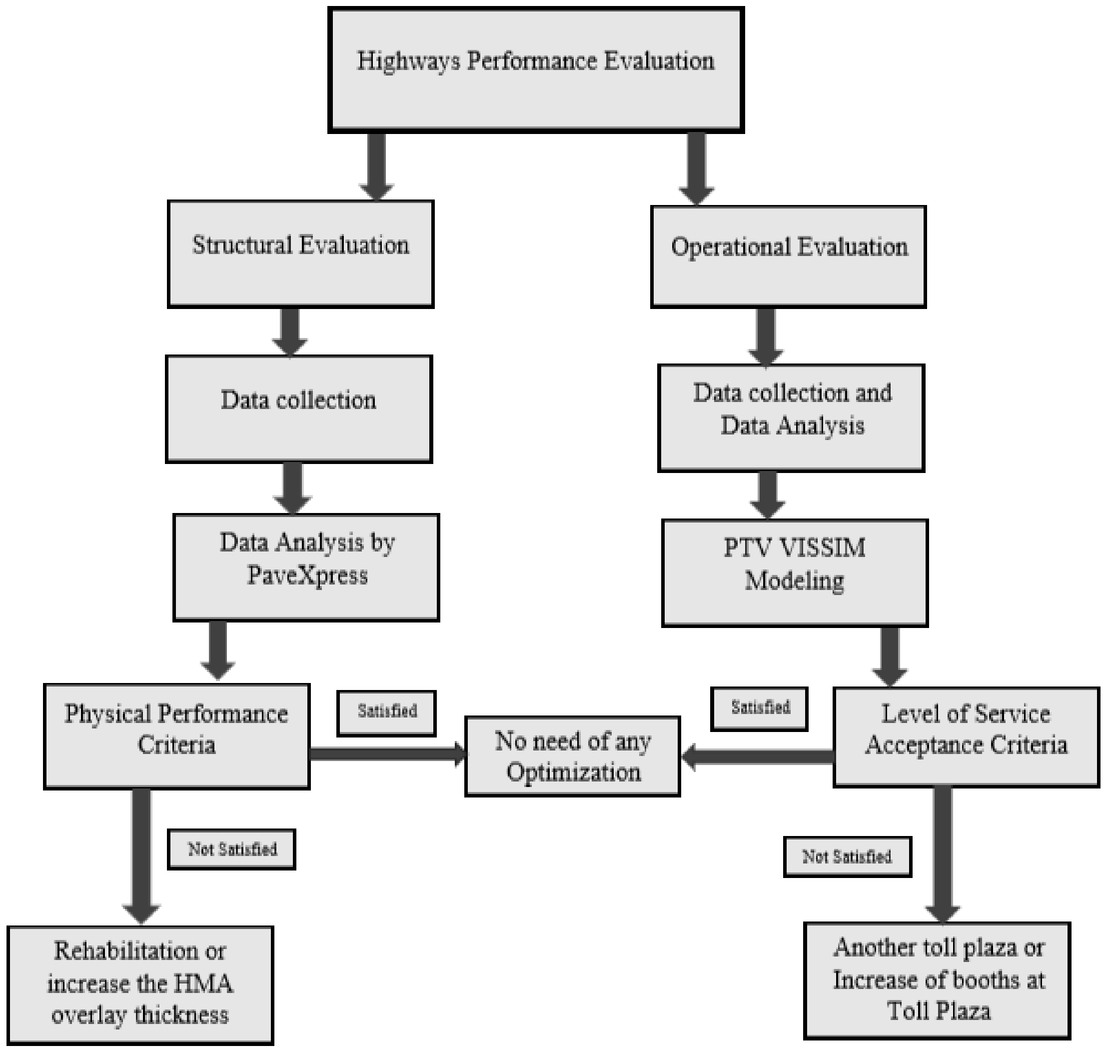


Figure 3. 1 Methodology

3.2.1 Methodology for Operational Evaluation

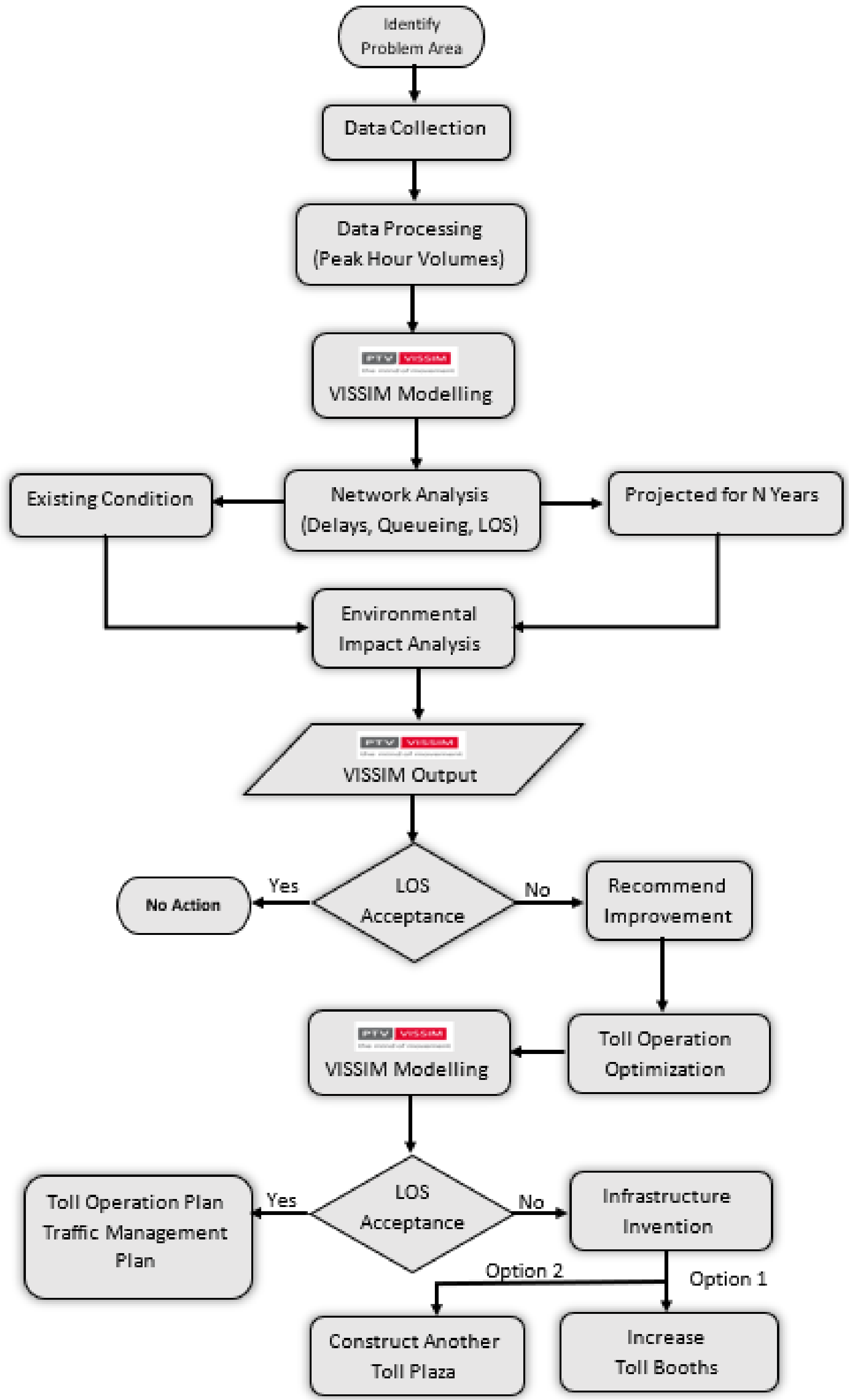


Figure 3. 2 Methodology

3.2.2 Methodology for Analysis of M-1 Islamabad Interchange

Practice of different methods to reach a desired objective has been observed. Methods used are as follows:

- Highway capacity manual
- Microscopic simulation models

The method in practice for the capacity analysis of motorway-1 interchange Islamabad is highway capacity manual 2010. Following are the steps which contain the methodology for the analysis of interchange.

3.2.2.1 Selection of Problem Location

After careful analysis of M-1 it was selected on the basis that travel on M-1 itself is quite satisfactory but at the interchange a different scenario is observed, LOS criteria changes drastically as the interchange is approached, this ruins the overall experience on M-1. After due consideration and running of simulations on the interchange it was noted that due to traffic operations increasing on M-1 the traffic density at M-1 interchange Islamabad have seen a boom in arrival rate, causing traffic congestions on the interchange. Queue analysis has shown that the region near the M-1 Islamabad interchange has a lower capacity to volume rate during peak hours. Also, the queue time during the delay has shown a carbon footprint of due notice. Estimation of fuel burnt during queue has been selected for cost of fuel burnt estimation for depth cost analysis.

Moreover, that during the planning phase of M-1 it was not considered for the traffic entering from SWAT and Hazara expressways. Increment in the loads entering M-1 especially freight vehicles from SWAT and Hazara entering M-1 will lead to the deterioration of the pavement existing state of M-1. Keeping in view the current conditions on the motorway and a futuristic approach the motorway-1 was selected for impact analysis.

3.2.2.2 Data Collection

An important step in the process was data collection. This involved visiting the site physically, talking to the interchange staff, collection of daily vehicles on M-1 from the M-

1 headquarter Thalian and video data collection. Following data was collected during the duration of project:

- Data collection from M-1 officials Thalian.
- Data collection from M-1 interchange visit.
- Data collections from various sources related to M-1

3.2.2.2.1 Data Collection from M-1 Officials Thalian

Data collection from M-1 officials Thalian included the total number of vehicles entering and exiting M-1 during a day. An in-detail list of category wise vehicles entering and exiting M-1 daily, tabulated to monthly vehicles and yearly vehicles for use.

3.2.2.2.2 Data Collection from M-1 Interchange Visit

Data collection from M-1 interchange visit will include queue related data, the following are the types of data gathered from M-1 interchange visit:

- Arrival rate of vehicles
- Time headway between vehicles
- Service time at manually operated toll booths
- Service time for M-tag vehicles
- Peak hour vehicles
- Number of lanes
- Total M-tag equipped lanes
- Vertical clearance
- Grade %
- Average lane width

3.2.2.2.3 Data Collections from various sources related to M-1

Data gathered included various design characteristics of M-1 such as lane width, shoulders, sub-grade thickness and asphalt thickness. This data is vital for the life of motorway evaluation. Also, this data will help us in better understanding of the design ESALs that it has been designed for. Also acquiring tender for the previous toll plaza construction for use in future.

3.2.2.3 Data Processing

The data acquired was then put through various methods to obtain the required information necessary to move forward with the project. This step involved the following processes:

- Queue analysis at the interchange
- Queue capacity analysis of the interchange
- Queue length during peak hour
- Maximum delay during peak hour
- Level of service at the interchange
- Calculating cost of enhancements in the toll plaza
- Approximating the total carbon footprint over the toll plaza due to the delays caused by the toll plaza
- Cost return
    - Fuel
    - Time
    - Carbon footprint

3.2.2.3.1 Queue Analysis at the interchange

The process of identifying queue at an interchange is in line with the methodology mentioned in HCM 2010. The process involves using concepts of queueing and using it for estimation of queues. VISSIM software is also used for queue analysis that gives us a visual display of how vehicles approach the interchange and how a queue is formed. Percentage of truck traffic was incorporated for the delays and since the traffic data used only was related to the vehicles exiting the motorway though segregate Fateh Jhang interchange the directional distribution factor was taken as 1. Also, all traffic was considered as commuter traffic since no data was available.

3.2.2.3.2 Queue capacity Analysis of the Interchange

In this process the total capacity of the interchange was calculated. By using the total no. of lanes provide and the length of the widened channel for the toll plaza the capacity will be calculated.

3.2.2.3.3 Maximum Delay During Peak Hour

The data gathered was used for the estimation of peak hour volume. The daily traffic values with maximum values that were constantly observed were used and converted into peak hour volume by multiplying it with k factor that is the portion of AADT during peak hour volume. The volume was used for creating simulations and estimating maximum delays for present situations and future simulations. The maximum delays during peak hour will be the leading delays since delays are directly related to density and it is directly related to the volumes and maximum value for traffic is during peak hour values.

3.2.2.3.4 Level of Service at Interchange

The level of service for the interchange is considered like that of a signalized intersection. Hence, using instructions and criteria mentioned for **level of service at a signalized intersection** in **exhibit 18-4 of automobile mode in HCM 2010** the level of service was established during peak hours. The VISSIM simulation gave us the peak hour delays at the interchange, dependent on control delays the value of seconds/vehicle gave us the required level of service at the interchange.

3.2.2.3.5 Calculating Cost of Enhancement at Interchange

Using previous models and costs in enhancements the future cost can be calculated by using previous such projects inflation and interest rates that have occurred during the time period. This will be very helpful in obtaining an estimated value for the project.

3.2.2.3.6 Approximating the Total Carbon Footprint over the toll plaza due to the delays caused by the toll plaza

Using VISSIM modeling the approximate carbon footprint can be obtained due to cars and heavy vehicles waiting in queue the carbon foot is to increase significantly damaging the ozone layer the total carbon footprint will be helpful in environmental control factors

3.2.2.3.7 Cost returns

There will be two types of cost returns in the enhancements if queue time is reduced. the following mentioned under will be the returns of enhancements and can be calculated by using VISSIM modelling.

3.2.2.3.8 Fuel

The direct benefit will be the reduction in idle burning of fuel at interchange the reduced time will be directly affecting the idle burning of fuel during queue. The reduction in time under improved circumstances will be useful in estimating idle fuel burning which can then be transformed into cash benefits

3.2.2.3.9 Time

As the well-known phrase "time is money", indicates the time value of money per person per day. This can be calculated by averaging the total number of passengers per vehicle and total number of vehicles per day and the total difference in time. As it will accumulate over time it will also be a cash return of worth note

3.2.2.3.10 Carbon footprint

Like the fuel burning, the carbon footprint is dependent on the idle burning of fuel in vehicles if the idle burning is reduced the total carbon footprint over the interchange will be considerably reduced. Considering that the reversion of the carbon footprint will involve plantation in the said area the cost can also be added to the cost returns.

3.2.2.4 VISSIM Modelling of the Said Interchange

VISSIM modelling of the interchange will give us a real-life simulation of traffic flow on the interchange

- **Network analysis**

The network of the interchange is quite simple since it only involves the 3 approaching lanes that open into 17 lanes and after they have passed the interchange, they again converge back to 3 lanes.

- **Present conditions**

The present conditions modelling will indicate the traffic flow that is observed at the interchange and the queue formation at the interchange.

- **Future conditions**

The future analysis of the interchange will give us what the traffic flow and the queue formation will be in future if no changes are made to the interchange

3.2.2.4.1 Environmental Impact Analysis

The environmental impact analysis will give us the environmental impact i.e. the carbon footprint observed in the area. This will be dependent upon the daily traffic.

3.2.2.4.2 First VISSIM Modelling

The initial VISSIM modelling will be done without any changes to the current conditions in the interchange characteristics.

- **Level of service acceptance**

The level of service of the interchange will give us the conditions at the interchange. There will be two possible conditions that will be observed at the interchange.

- **Conditions are satisfied**

After running VISSIM simulations if the conditions at the interchange are within limits and are in range from A-C there will be no need for enhancements at the moment. Also, same could be applied if future conditions are also satisfied.

- **Conditions are not satisfied**

If it is observed from simulations that the delay is too much, and level of service is D and below intervention will prove to be necessary. Same could be applied if the traffic conditions do not meet the future requirements.

3.2.2.4.2.1 Optimization of the interchange

If the conditions of the interchange are requiring a change and the LOS is not acceptable the first step in trial would be running simulations based on optimized interchange characteristics, such as, only **E-Tag** vehicles to be entertained, channelization of lanes properly, restrictions on E-Tag lanes to be strict so as no mixing of non E-tag and E-tag lanes is reduced. Also, providing signs as to which lanes have least traffic, providing pre-toll operations such as toll payments at different hotels on motorway.

3.2.2.4.3 Second VISSIM Modelling

If the first set of VISSIM modelling yields unsatisfactory results, after the necessary optimization protocols are done the second phase of modelling on VISSIM will begin. In this stage of modelling the vehicles are restricted to be only E-Tag vehicles and the time for toll operations is better improved and reduced.

- **Level of service acceptance**

After the running of second phase of VISSIM modelling the level of service at the interchange is calculated with the time delays observed. There will be two possible outcomes of the said VISSIM modelling.

- **Conditions are satisfied**

If the conditions after the optimization of the interchange meet the requirements and LOS criteria is acceptable the only changes required will be optimization of interchange.

- **Conditions are not satisfied**

If the LOS criteria after the optimization of interchange does not produce desired results the interchange will be requiring major changes and for that either new toll plazas at the interchange will be made or some other geometrical changes will have to take place.

3.2.1.4.4 Changes at the interchange

If the LOS is not met after optimization of interchange protocols are put in place and a VISSIM model is created. Then it means that the interchange requires major changes.

- **Construction of new toll booths**

Firstly, if the toll plaza requires changes the first will be the construction of new toll booths dependent upon traffic volume and existing LOS criteria the construction of toll booths will be such to take traffic off the already existing and further divide the traffic volumes.

- **Construction of a secondary toll plaza**

If the first option after a series of addition does not significantly improve the LOS of the interchange a second option that can be put into use is the construction of a secondary toll plaza. This will be constructed like the junction from where trains cross each other. Toll plaza will be provided on the secondary route and this secondary route will take traffic off the already existing interchange. Although, this option is costlier the affect will be significant and provide room for future construction of toll booths at both the interchanges. Also, this way the division of vehicles according to category can be strictly observed.

3.2.3 Method of Analysis of Pavement Structure

The second phase of project involve dealing with pavement distresses. The process involves remaining life of the pavement and latest by which surface overlay will be required and accessing when the pavement will fail.

3.2.3.1 Flow-Chart of the Methodology for the Distress Analysis of Pavement

Below is the flowchart of the methodology used for distress analysis of pavement

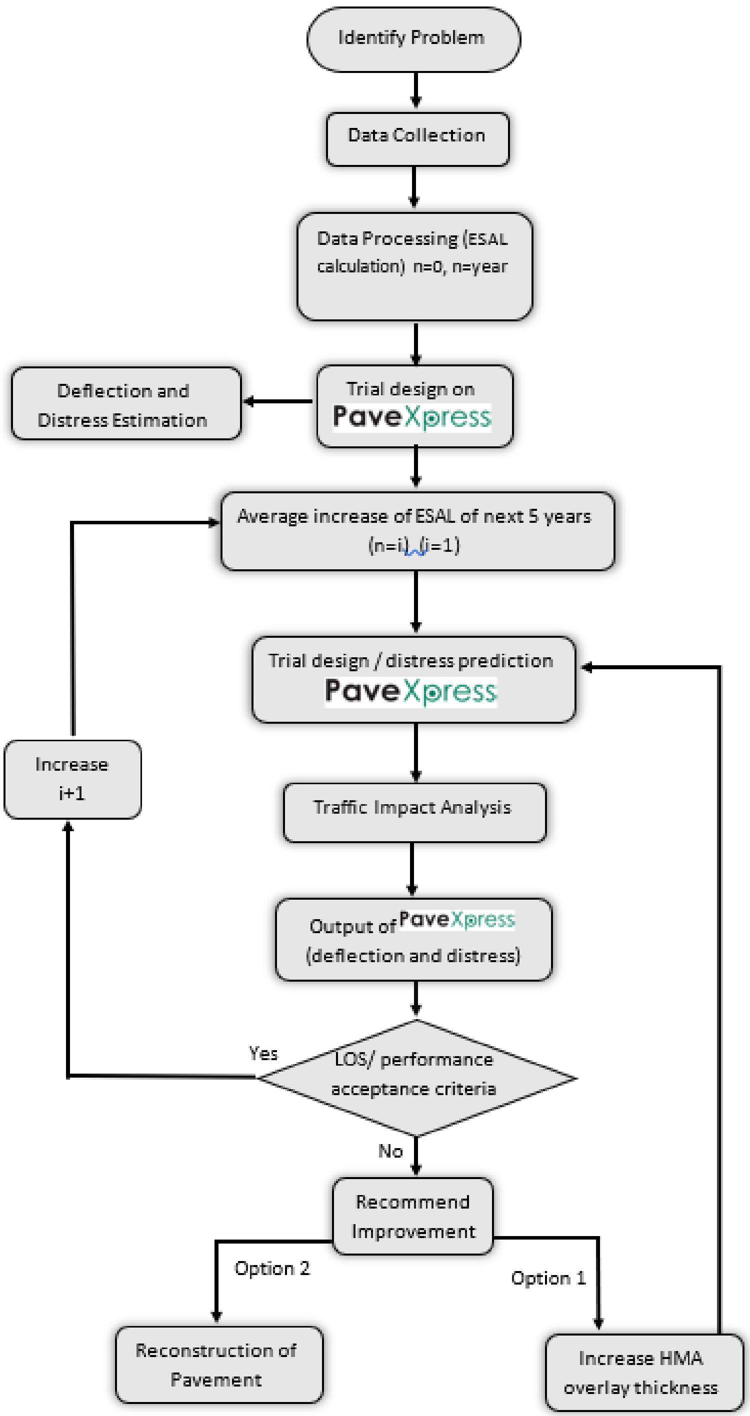


Figure 3. 3 Flow-chart of the methodology

3.2.3.2 Identification of Problem Area

The motorway 1 from Peshawar to Islamabad has been experiencing increase in yearly traffic after the opening of two expressways on the motorway. SWAT and Hazara expressways have had their major portion of traffic entering M-1 at their respective interchanges. As a cause of this it is estimated that it will take a toll on the remaining life of motorway. Hence, the selection of the problem area.

3.2.3.3 Data Collection

For the analysis of the motorway pavement data was acquired through various sources were used. The data acquired was then used for calculating the deflections and no. of ESALs. Following are the sources used for the acquisition of data:

- **M-1 officials**
- **Miscellaneous sources**
- **M-1 officials Thalian**

M-1 officials

The data acquired from the officials was the thickness of the motorway and recent rehabilitation

Miscellaneous

The data included the modulus of elasticity of the pavement structure that was required for input in PaveXpress

M-1 officials Thalian

The data acquired included the total vehicles travelling on the motorway daily. The data was latter used for calculations of ESALs.

3.2.3.3.1 Growth Rate in GDP

The growth rate in GDP is directly related to number of travelling vehicles, hence from different sources this data was collected

3.2.3.4 Data Processing

3.2.3.4.1 ESAL Calculation

The data acquired from M-1 motorway of daily traffic was used for the calculation of ESALs. The maximum daily average traffic was used as basis for the calculation of M-1 motorway. The data was also used for calculating the future ESALs that was done by keeping the percentage of truck traffic constant and increasing traffic according to the increase in GDP.

3.2.3.4.2 Trial Design of Motorway

Using the data acquired from M-1 officials and other sources and using **PAVEXPRESS** software a trial section of M-1 was made. This was done by using the design specifications of the M-1 that included the thickness of various layers on the motorway and the $\mathbf{M_r}$ value from the data. This section was designed as to estimate the actual distresses in the pavement structure under ideal conditions

3.2.3.4.3 Existing Distresses in the Surface of M-1

Using the trial section and the ESALs the existing conditions of M-1 were estimated. This estimation was done by using PAVEXPRESS and it involved the transformation of all traffic in terms of simple six-wheeler trucks as a basic.

3.2.3.4.4 Average Increase in ESALs for Next Years

ESAL calculation was done similarly to the method mentioned before. ESALs were increased gradually and it was compound increase in ESAL. Also, the ESAL growth rate was taken as ZERO since it was considered weight per ESAL was not increasing yearly, only the traffic was subject to increase.

3.2.3.4.5 Distress Analysis at n=i years

Yearly analysis of trial section under increasing loads was done such that at first i was taken equal to 1. This meant the distresses were considered on the pavement after 1 year. This meant an increase in ESALs and deflections in the service life of the motorway.

3.2.3.4.6 Traffic Impact Analysis

The software PAVEXPRESS was used for calculating the pavement distresses at year n=i and so on. The results were given in terms of rutting, deflection, horizontal strain, loads to failure i.e. rutting and fatigue.

3.2.3.4.7 Deflections and Rutting

The data was put into the software and run it gave a result in the form of pavement distresses. These deflections and rutting were the physical conditions of the motorway pavement under existing loads i.e. ESALs*Growth rate amplified to the next year. Also, there were given results of loads to failure.

3.2.3.4.8 Performance Acceptance Criteria

The results of the simulated conditions were tested against the performance acceptance criteria for a motorway. the reason for this comparison was to evaluate if the pavement needed rehabilitation and when in the future a major rehabilitation of the motorway should be planned.

Two outcomes were stipulated for the results either, the motorway was in acceptable physical condition for the vehicular transport or, the motorway conditions were not favorable, and a rehabilitation of the motorway was required.

3.2.3.4.9 Conditions are Satisfied

If the conditions of the motorway were satisfied and no rehabilitation was required at n=i years, it meant the conditions are still favorable for the vehicular transport over the motorway. In such a case the trial section was tested for the year n=i+1 and so on until the results were no longer acceptable.

3.2.3.4.9 Conditions are not Satisfied

In the case that the conditions are not satisfied indicates that the rutting and deflection on the pavement are not acceptable and a rehabilitation of the motorway is required. The value of n at failure indicates the years from now that the rehabilitation is required.

Depending upon the conditions the method of rehabilitation is selected. Below mentioned are the techniques that will be used for rehabilitation of the pavement

3.2.3.4.10 Reconstruction of the Pavement

If the conditions after n years of use are such that the pavement is in very poor state and requires a major rehabilitation the pavement will have to be reconstructed. Also, if the deflections on under-lying layers are too high than this method of rehabilitation will be employed

3.2.3.4.11 Increase in HMA Overlay Thickness

If the deflections of under-lying surfaces are tolerable and only the top surface has experienced major deflections than a cheaper alternative that is HMA overlay can be done.

Chapter No.4-Introduction to PaveXpress & PTV VISSIM

4.1 Introduction to PaveXpress:

PaveXpress is a free web-based pavement design tool available for use by local agencies, engineers and architects who need a reliable way to quickly determine the necessary pavement thickness for a given section of roadway or project. PaveXpress creates technically sound pavement structural designs for both asphalt and concrete pavements based on widely accepted industry standards from the American Association of State Highway Transportation Officials (AASHTO)

PaveXpress was designed to be an extension of AASHTO 93/98 and has been adopted by public agencies such as the Washington state department of transportation as an accepted tool to help assess, scope, and design pavements. New features are added regularly. Since its initial release, PaveXpress has expanded to help users design asphalt overlays, porous asphalt sections, and life cycle cost analyses.

4.1.1 Working on PaveXpress:

Getting started PaveXpress, first determine the pavement structure as per design data of M-1, and then analyze the pavement structure.

1- Login and making Account on PaveXpress:

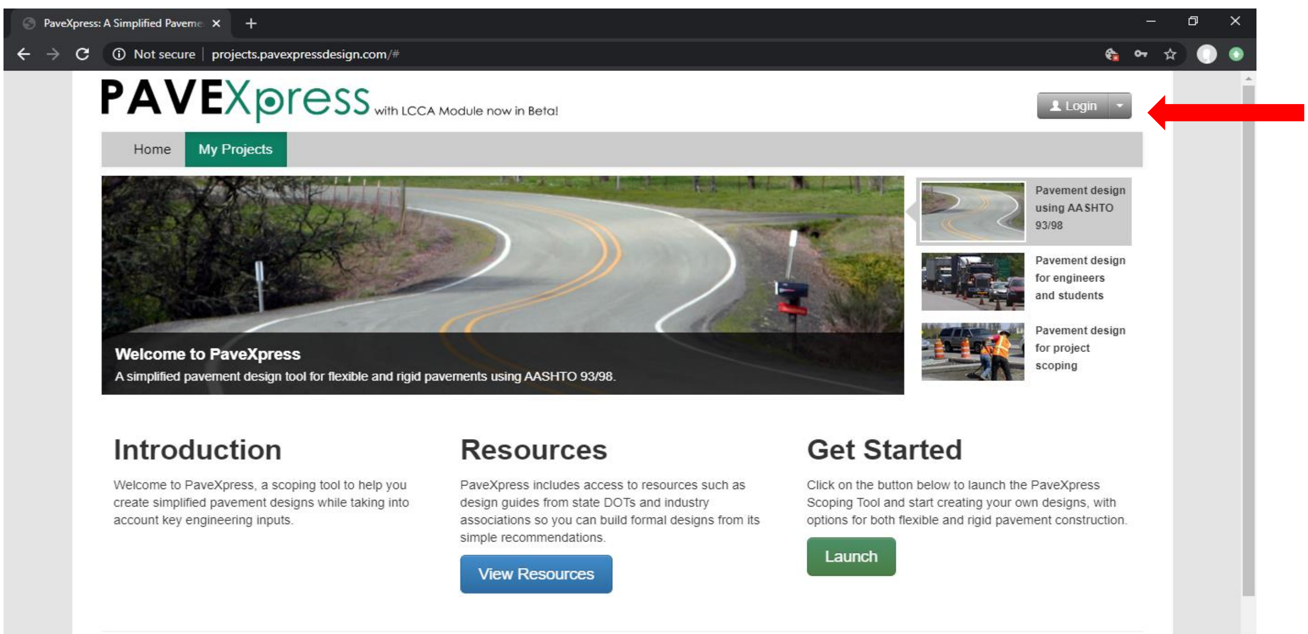


Figure 4. 1 Login

2- Add new project and name the project. **Select the determine the pavement structure**.

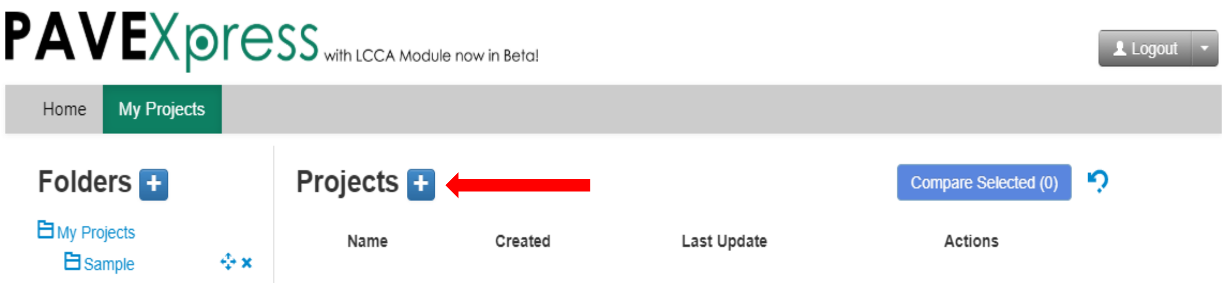


Figure 4. 2 Add new project

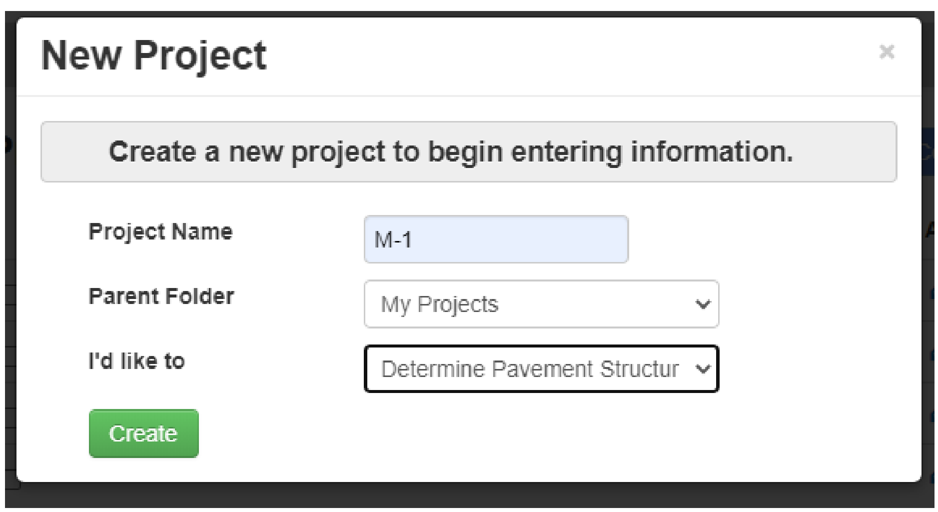


Figure 4. 3 Add new project

3- Add scenario name, design life, type, and estimated year completion. Then click save and click next.

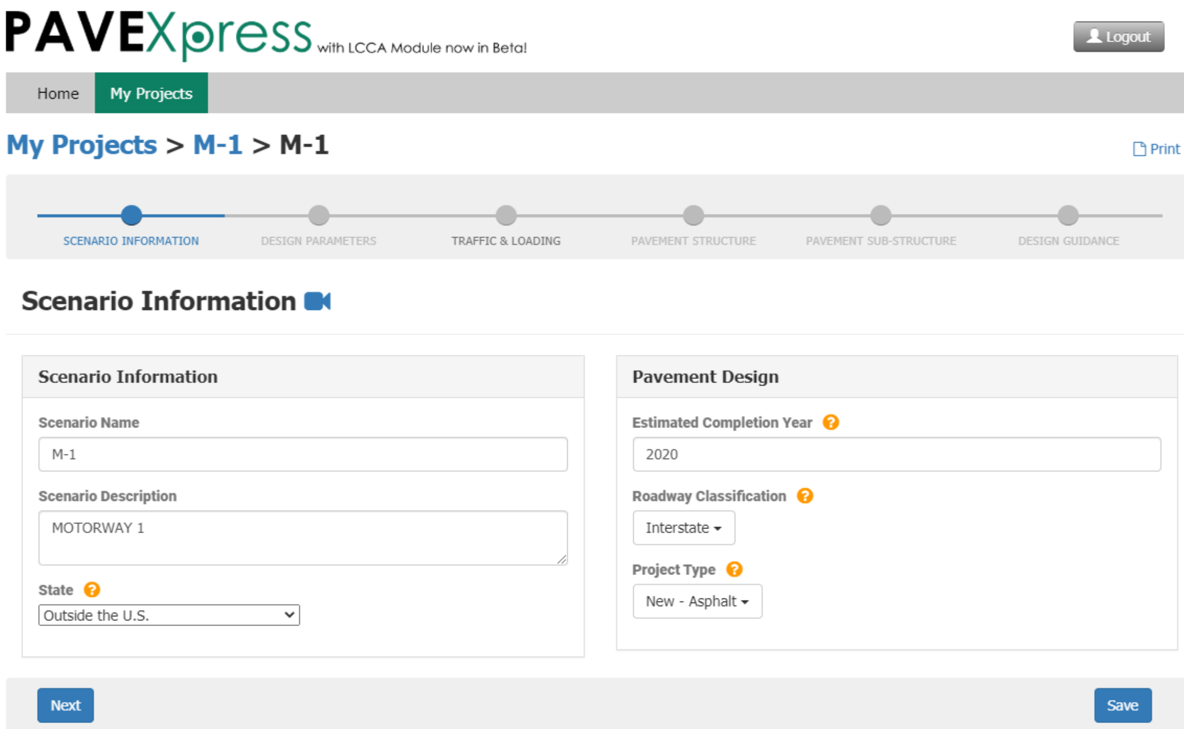


Figure 4. 4 Add scenario name

4- Then add design parameters as per design data of M-1. As show in fig. click save and then next.

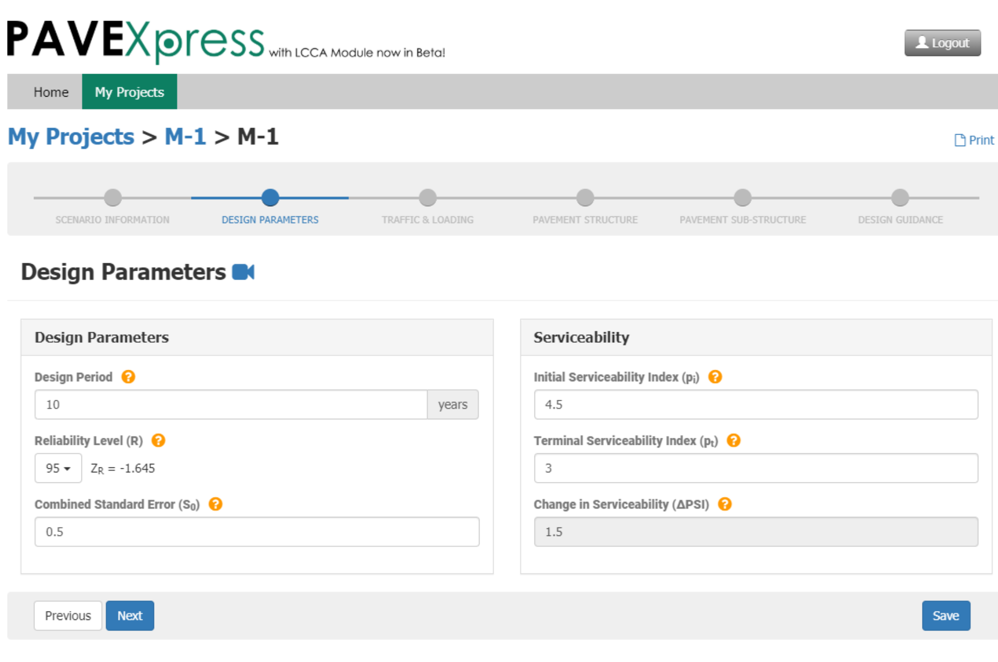


Figure 4. 5 add design parameters

5- for Traffic loading and ESAL calculation for pavement. we enter the design ESALs which are calculated by the ESALs calculation procedure. The calculation is described in the next chapter thoroughly. We just put these ESALs here in PaveXpress.

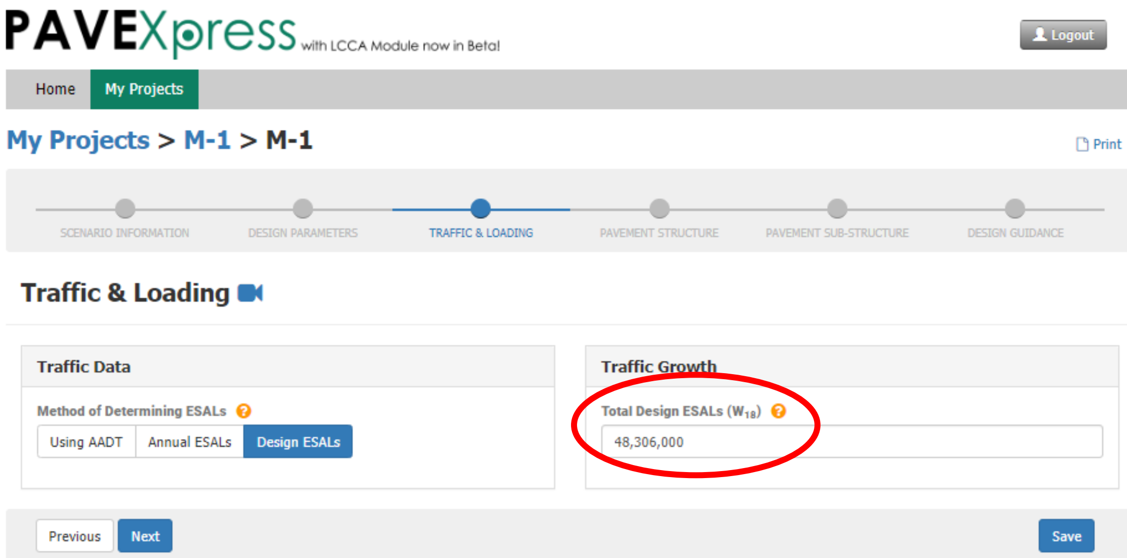


Figure 4. 6 Traffic loading and ESAL calculation

7- Enter design properties data the **asphaltic pavement structure** as per given design parameters of M-1.

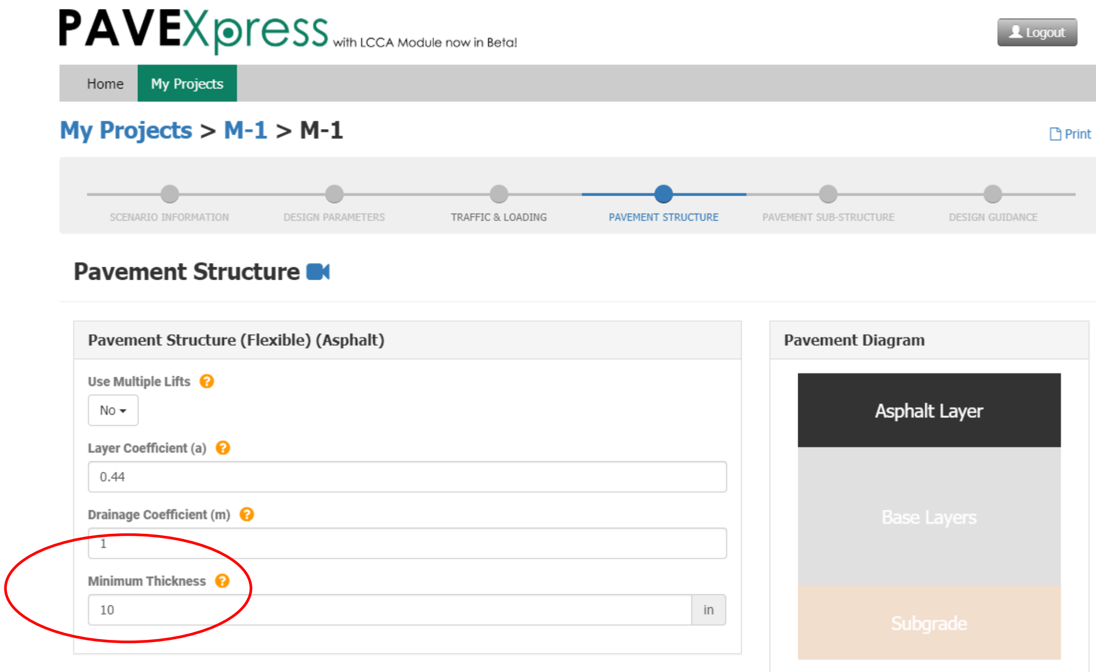


Figure 4. 7 Enter design properties

8- Similarly, add **sub-structure pavement** data. Click sane and then click next.

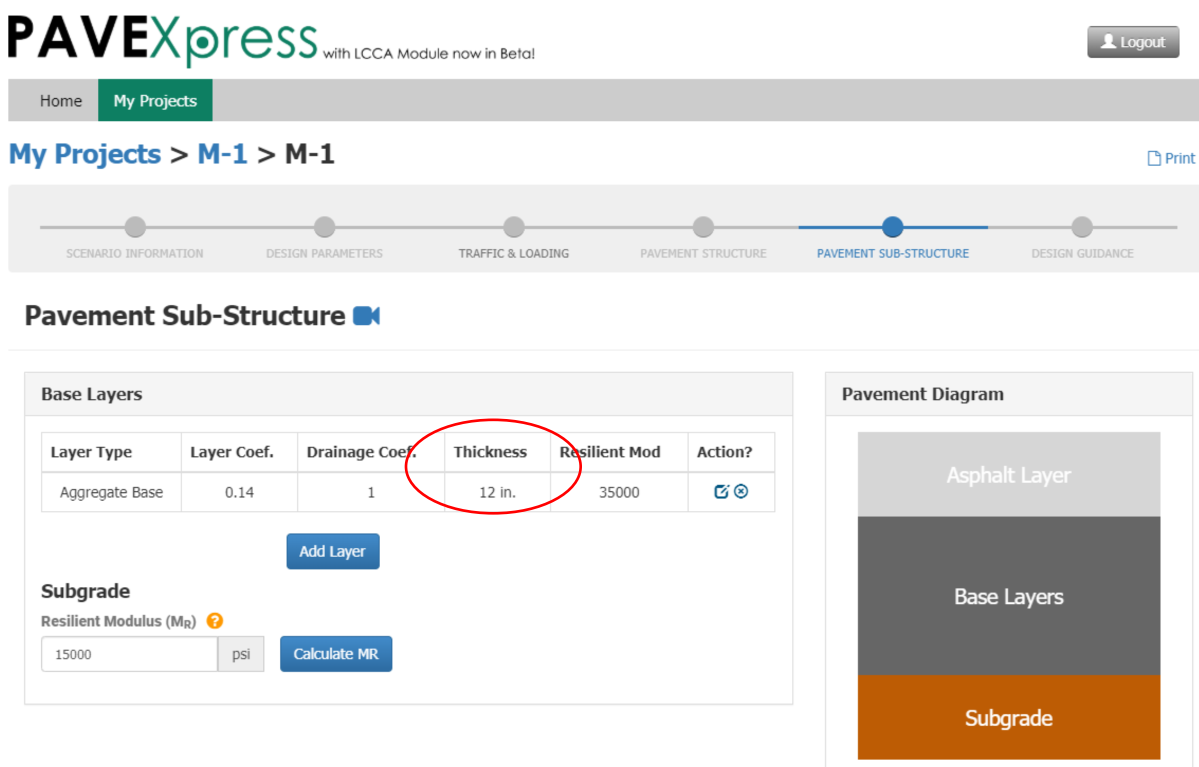


Figure 4. 8 add sub-structure pavement data

9- Design guidance will display on the by PaveXpress as show in fig**. Compare the Required and total SN and Adjust the thickness.**

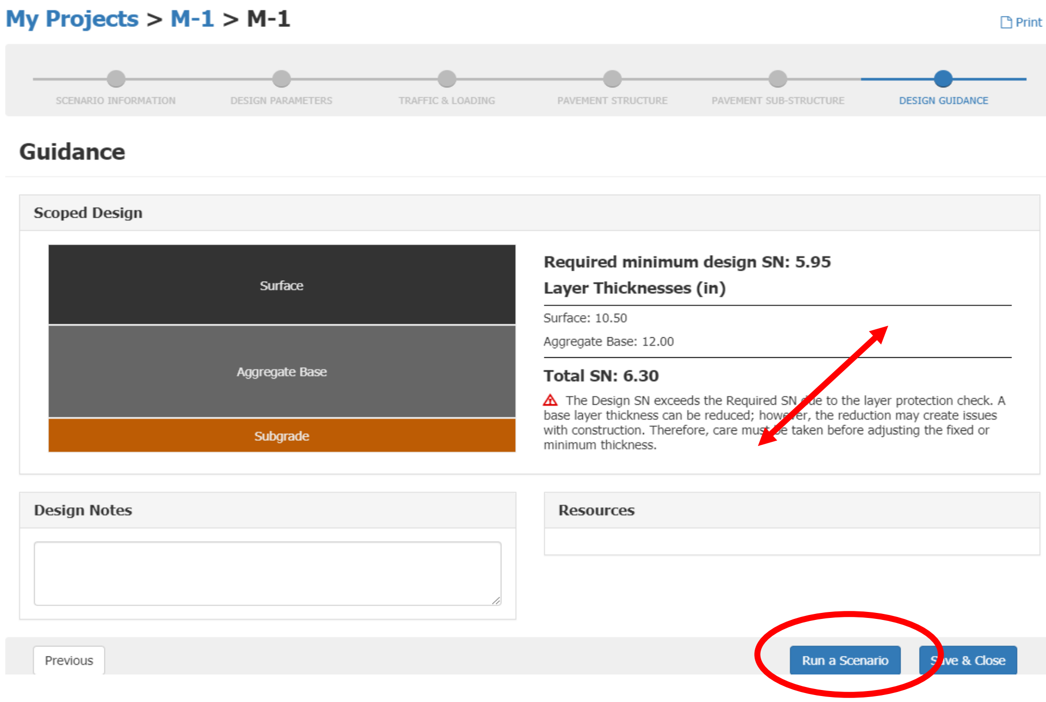


Figure 4. 9 Design guidance

10- Then Run the scenario and select the **Analyze pavement structure**. Give name and click **create Scenario**.

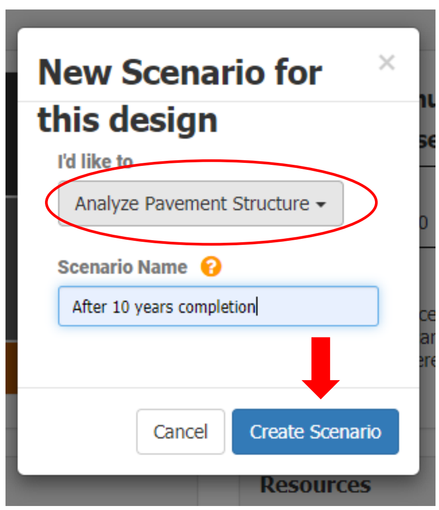


Figure 4. 10 Analyze pavement structure

11- Enter design properties accordingly like passion ratio modulus and **thickness** as mention in design parameters of M-1. Then save and click next.

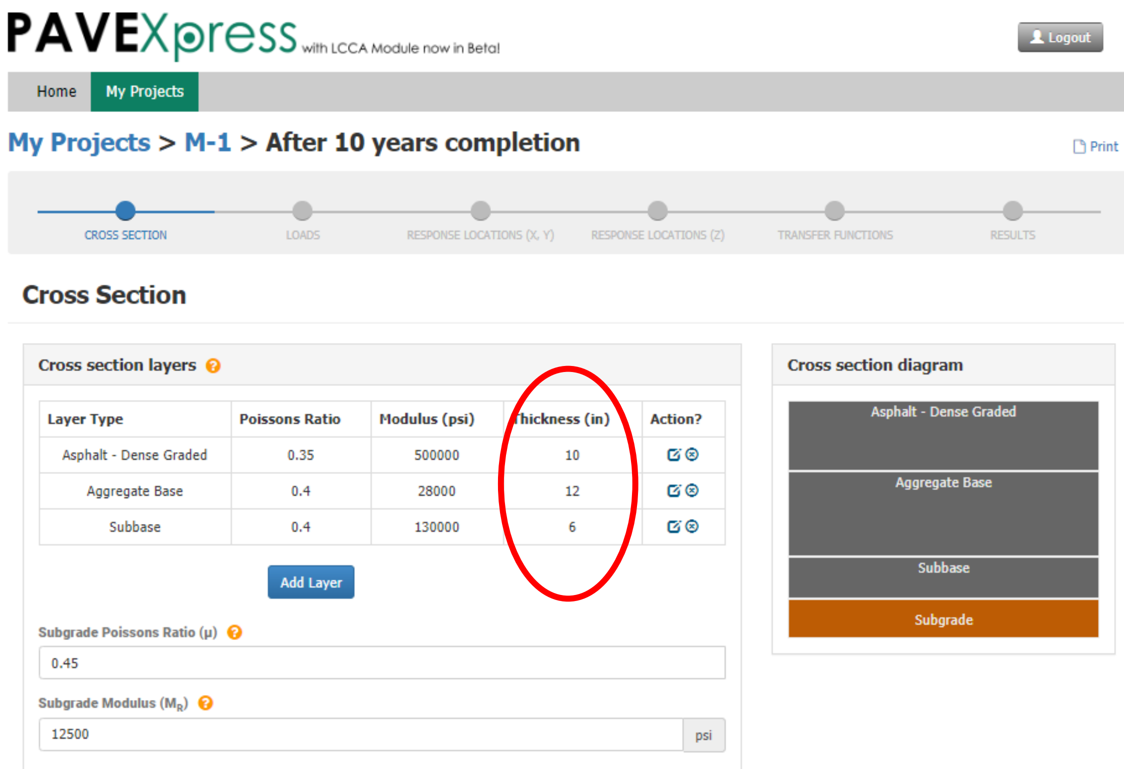


Figure 4. 11 passion ratio modulus and thickness

12- Click load configuration, and select **Typical Single Axle with Dual Tires**, because our selected pavement is interstate or a motorway. For load location, load, and tire pressure, use by default values. Click save and then click next.

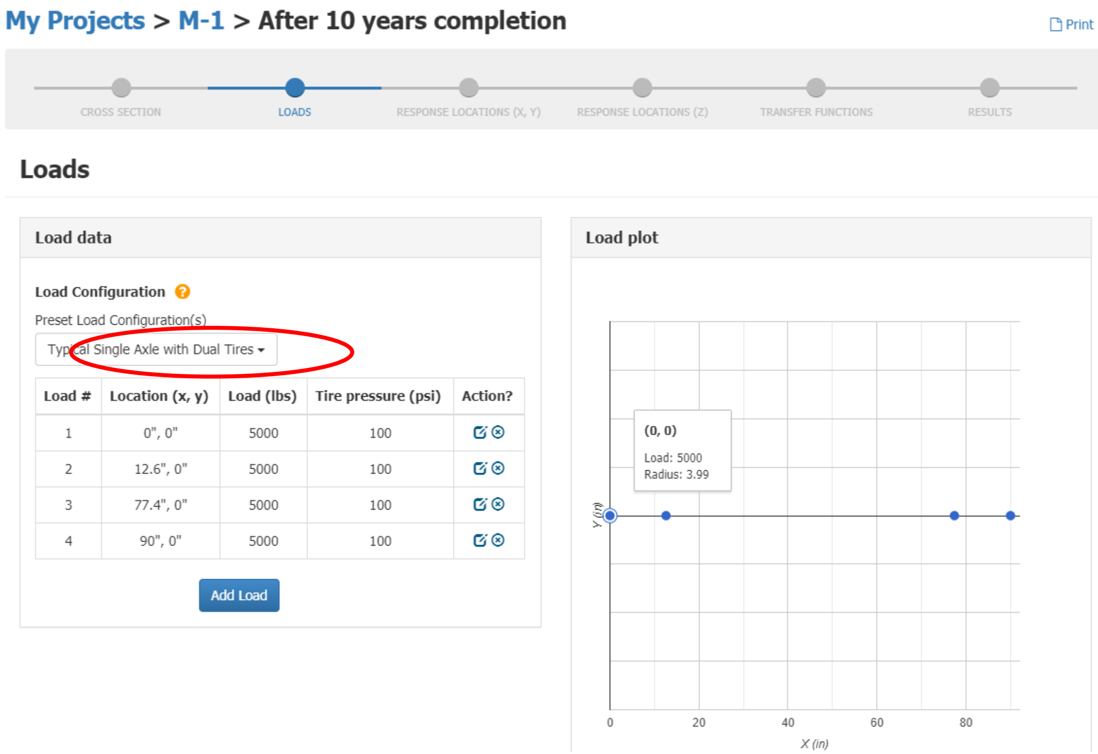


Figure 4. 12 load configuration

13- Response location in X and Y axis, use the software generated response location. Click next.

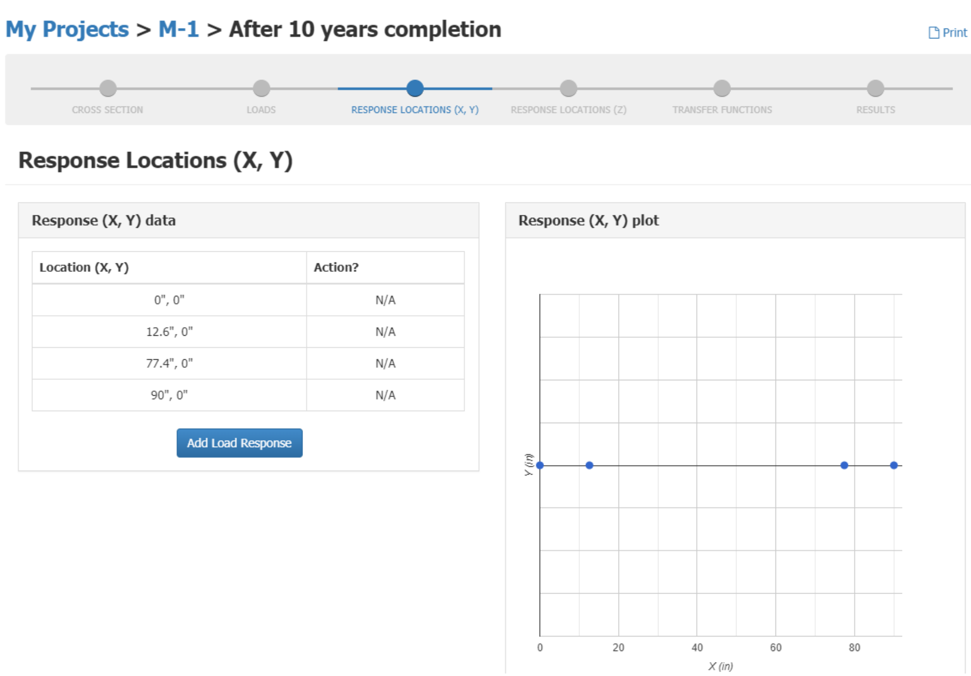


Figure 4. 13 Response location in X and Y axis

14- for response location in Z axis, add layers and then adjust depth as already given in first step. and select the type of stain in every layer. As shown in fig. then click save and click next.

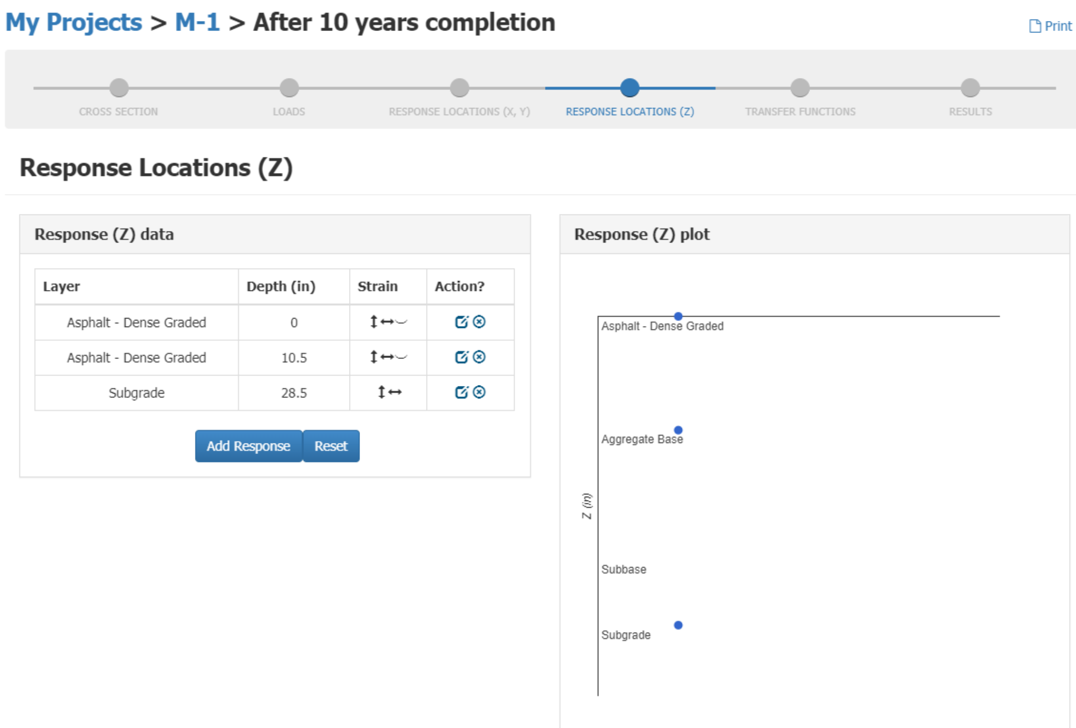


Figure 4. 14 response location in Z axis

15- For Transfer functions, like fatigue and rutting use the software generated values. Click next.

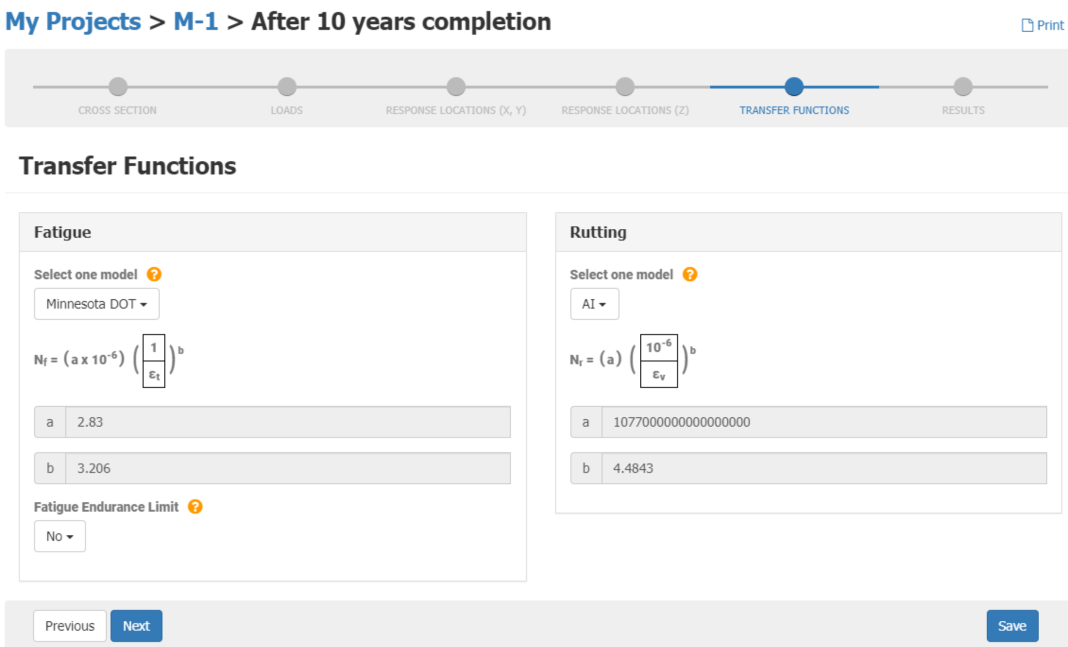


Figure 4. 15 Transfer functions

16- Primary response like, deflections, horizontal and vertical strain and fatigue and rutting will be generated by software, as shown in fig. Which will help in estimate the condition at the end of pavement's design life or at the end of design ESALs travelled. Then print the result.

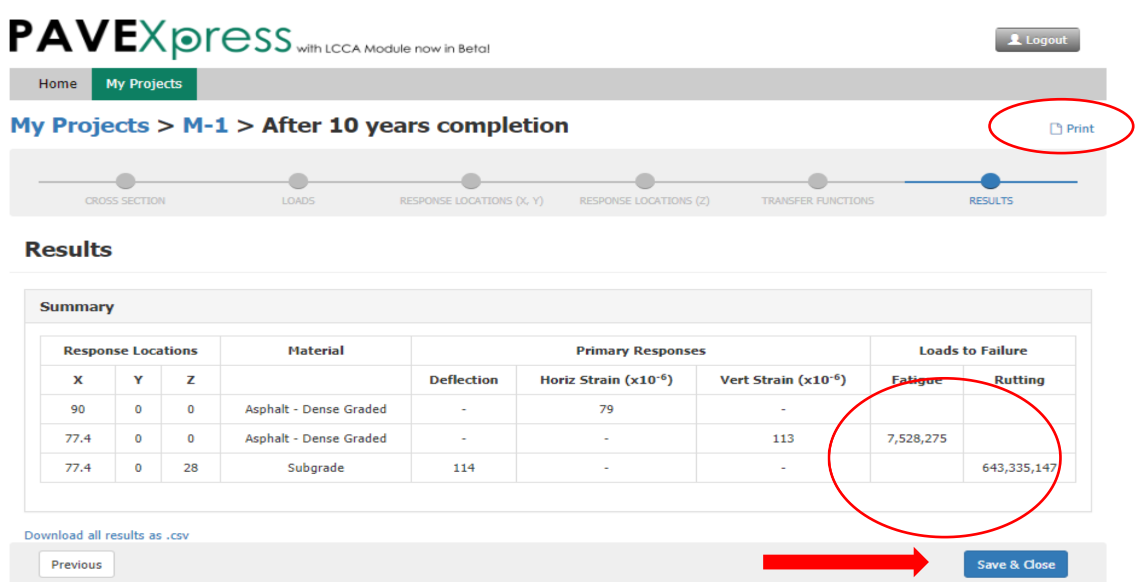


Figure 4. 16 Primary response

4.2 Introduction to PTV VISSIM

VISSIM software is widely used for the graphical presentation of traffic flow through different modes. It is used for evaluating intra vehicular operations. It is by far the best tool in use which gives graphical representation and detailed analysis of traffic flow at certain points along a transportation system. the VISSIM software by virtue of the availability of links and connectors is ahead of the other software's for traffic analysis. The software also is used for design of complex traffic streams and intersections and for analysis of such systems.

Positions of all elements are accurately presented using the software for a detailed network. Weaving segments, merge segments and diverge segments are easily allocated and observed using the software, detailed analysis can be performed than on these segments. Environmental analysis can also be done using the software by estimating the carbon monoxide emission of vehicles. The software provides appealing and realistic models for the analysis and design of roadways segments using real based geometry. Different control systems can also be integrated in the system using the software and complex systems can be easily modelled.

4.2.1 Working on PTV VISSIM

To add new Background Image: Click **Background** in network objects. Right click anywhere on the network editor and select the desired picture in pop-up window and click open.

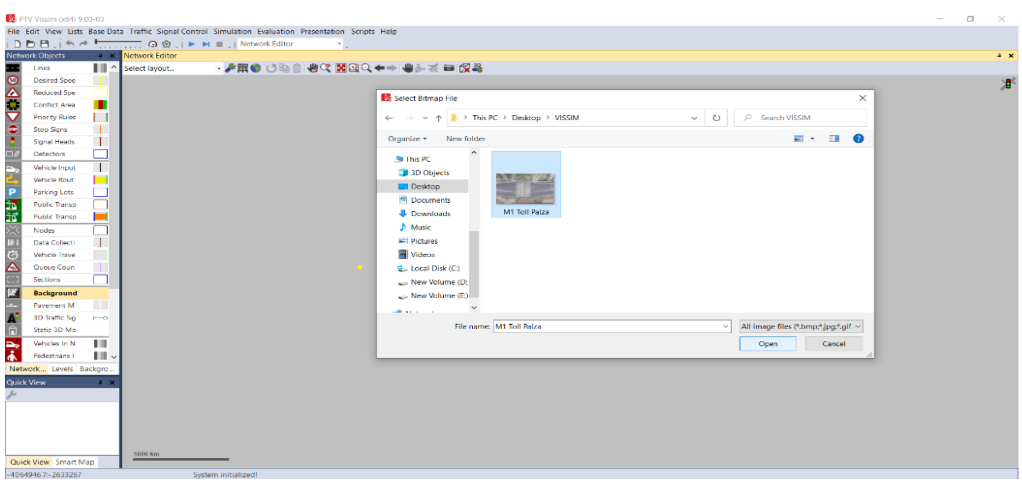


Figure 4. 17 Background in network objects

To Adjust scale of Background Image: Press Ctrl + Right click on the picture and select ‘**set scale’**

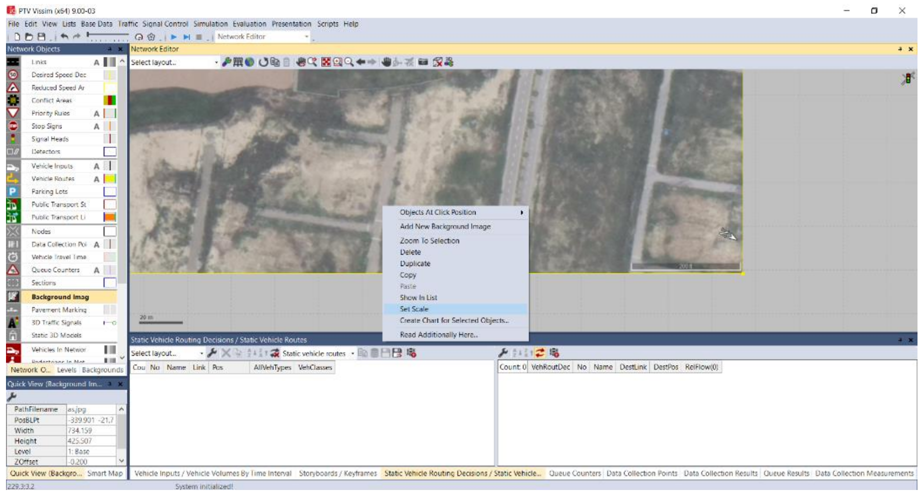


Figure 4. 18 Adjust scale of Background Image

To add a link: Select **link** in the Network Objects menu. Click and hold right click > drag > release to create a link. A pop-up window will appear, select desired options, and click OK.

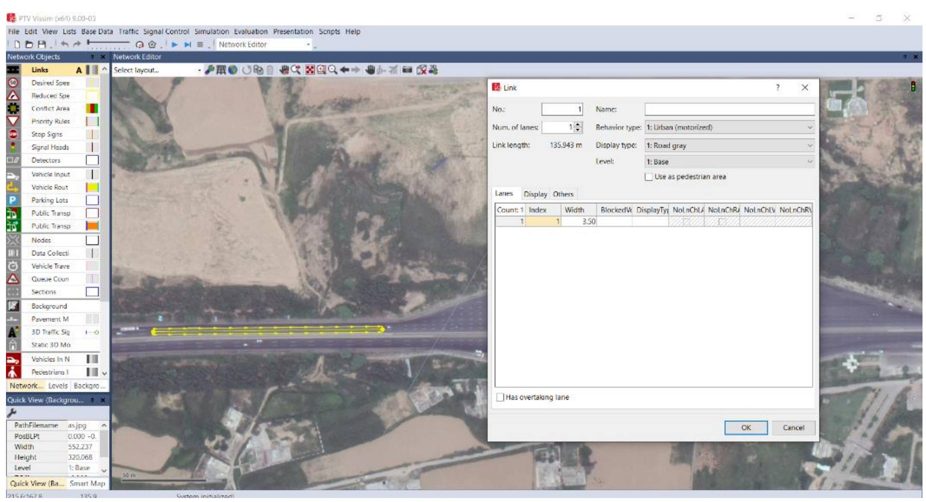


Figure 4. 19 add a link

To add a connector: (Between two links) Right click + drag from end of first link to the start of second. A pop-up window will appear, adjust different attributes in connector menu and click ‘OK’.

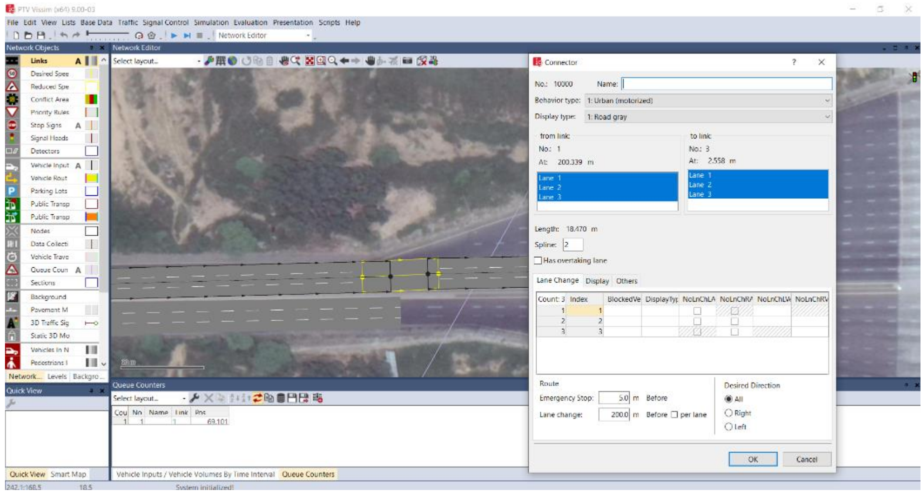


Figure 4. 20 add a connector

Vehicles Input: Select **Vehicle input** in network objects menu or Click on Lists in menu bar > Private Transport > Inputs. Right click on the link and add vehicle attributes in bottom menu.

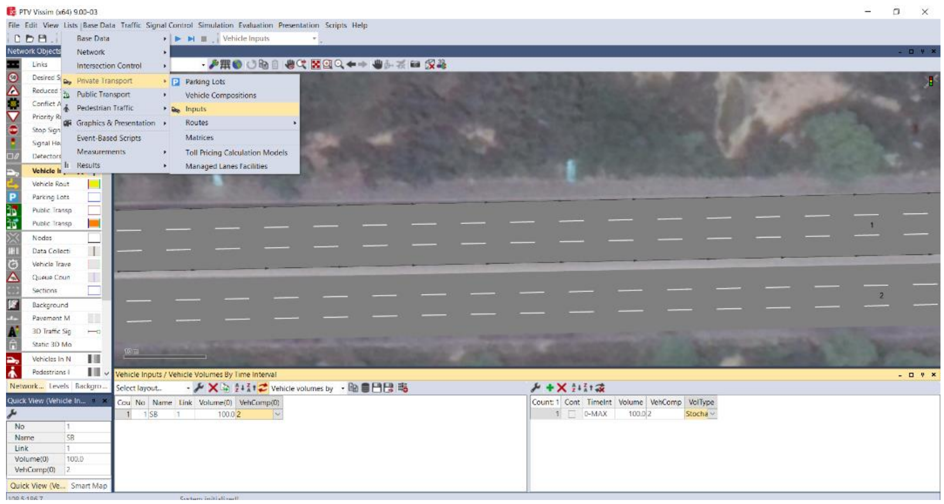


Figure 4. 21 Vehicles Input

Adding Stop Sign: Click on **stop sign** in Network objects menu. Click on the link to add stop sign. Add **Vehicle class** and **Dwell Time** in pop-up menu

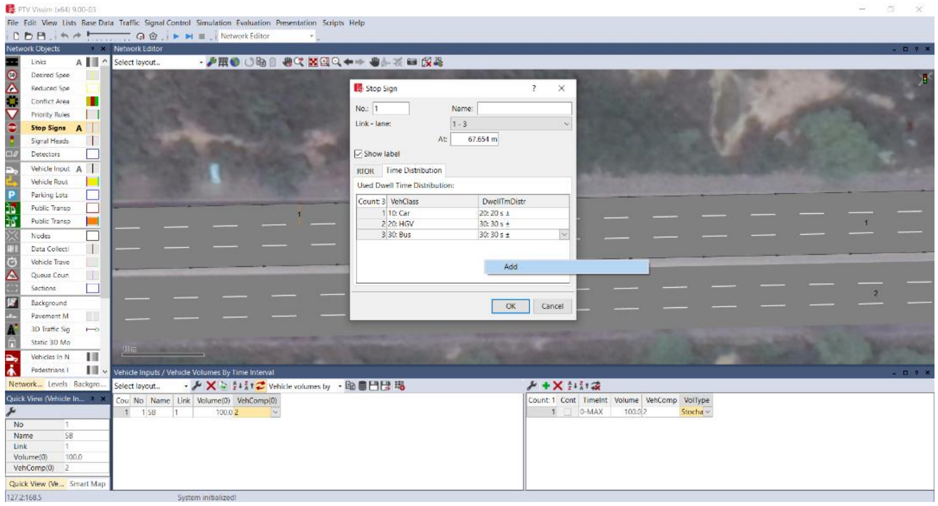


Figure 4. 22 Adding Stop Sign

Chapter No.5-Recommended Solution and Analysis

5.1 Overview

This chapter deals with the possible solutions and recommendations for the best practice that can be adapted. After results from PAVEXPRESS and PTV VISSIM have been tabulated into useful information, the recommended solutions can be put into practice. The two characteristics of transportation i.e. functional and operational characteristics are dealt with and made improvements in the existing conditions. The solutions recommended are put forth such that they are feasible and economical.

5.2 Toll plaza

The operational characteristics of the transportation system is reliant on the level of service at the said transportation system. The queue at the toll plaza indicates that the LOS criteria is not acceptable, and improvements are required at the interchange. The toll plaza is dealt as a signalized intersection.

5.2.1 Proposed Solution

The proposition of solutions for the toll plaza are required since the existing conditions are not in acceptance with the LOS criteria. The two solutions were put forth in the methodology. After the toll optimization protocols even put into practice the LOS criteria were not acceptable. Hence the first solution was to increase the number of lanes and toll booths for the interchange. The second was a construction of a secondary toll plaza as a type of bypass to the existing toll plaza taking traffic off the toll plaza and distributing it to the secondary toll plaza. The second solution is not economical and feasible since large costs are involved in the building of the toll plaza, acquirement of land and two complete ramp junctions to be created which is not feasible and tedious work. Hence the second suggestion is dropped.

5.2.1.1 Enhancement of Toll Plaza / Addition of Lanes or Toll Booths

Since the option feasible and economical is to increase the number of lanes and toll booths hence the solution is recommended. The toll plaza is not only increased in lanes and booths the toll operations are also optimized. All toll booths are converted into E-tag lanes and strict compliance with Motorway rules is applied. The aftermath of this will be the traffic is distributed to the increased number of lanes and more toll plazas will result in the reduction of queue time per vehicle. This in-turn means less idle burning of fuel and less costs affiliated with commuter traffic.

From the VISSIM analysis it is evident that the LOS criteria for non-E-tag lanes is not acceptable and a large queue is observed. The queue delay is also not acceptable at many of the toll booths causing delays which are not acceptable. For the E-tag lane analysis under current conditions exhibits a LOS criterion of C which is satisfactory but other lanes that are manually operated exhibit LOS varying between D to F.

Under existing conditions 6 lanes already exhibit LOS criterion of F which is very poor under consideration. Three lanes exhibit LOS criterion of E and three lanes exhibiting LOS criterions of LOS D respectively. Considering the following data an improvement is very necessary for traffic to experience less delays. Also, if conditions are not changed and current geometry and number of lanes and toll booths is kept and considering a 4% increase in overall traffic it exhibits even poor LOS criterion. After 5 years of increase in traffic show that all lanes exhibit a LOS of F and delay times for some lanes eclipsing 200 seconds. Also, after 5 years even E-tag lanes have a LOS of F. If no enhancements are made that is increase in no. of lanes and toll booths a data analysis on the traffic on today at 4% increase in traffic show that all lanes are experiencing delays that are highly un-economical and LOS criterion of F on all lanes. Delay times exceeding 500 sec mark on many lanes.

Considering this a consequent enhancement is required for the up-raising of traffic flow. Increasing LOS can be done by decreasing the delay times. For this purpose, an increase in number of lanes and toll booths plus additional strictness on M-tag should be implemented. Only M-tag vehicles will be allowed to enter M-tag lanes and an increase in the percentage of M-tag traffic to 25% to take place. This will reduce the traffic congestion and delay times significantly not only for present scenario but also future for next 10 years. Also, an increase in number of lanes is to be done for smooth traffic flow in the next 10 years of traffic flow. An increase from 14 to 20 lanes will be done for the smooth flow of traffic at the toll plaza. This will bring down the queue delay timing under 35 seconds for non-M-tag vehicles and under 10 seconds for M-tag vehicular movement. Both cases represent LOS criterions of C and A respectively showing a very good increase in the LOS criterion of the toll plaza. This LOS criteria are both acceptable and tolerable for commuter traffic and especially M-tag vehicular flow. This improvement can be recouped by cost analysis that is cost saved from idle burning of the traffic at the toll plaza. Also, restricting 4 lanes to only M-tag vehicles and none other and prompting M-tag vehicles to use these lanes.

Another solution proposition is that the number of lanes of the motorway to be increased to 4 causing the bottleneck opening less drastic and improving the traffic flow on the motorway. In turn, the increase in the number of lanes of the toll plaza can be minimized. The increased number of lanes of the motorway in total in this case will be 18 with 4 lanes for primarily only M-tag vehicles and rest for the non-M-tag vehicles. The LOS in this case is also acceptable and results in fewer lane construction but in turn the expansion of motorway will occur. This method will also result in the LOS of the motorway-1 to be bettered and an increase in the base free flow speed will take place and in turn the density of the segment is reduced prompting a futuristic view that if at some time an increase in the motorway was required this would have already taken place. The M-tag vehicles projected for this traffic will be around 35% of the total traffic flowing on the motorway. This approach is possible considering all public transit and freight vehicles to be mandated for having M-tag for entry to motorway.

5.2.2 Building a Proposed Network on VISSIM

The PTV VISSIM software was used for analyzing the present conditions on the motorway of both present and future conditions. The toll plaza enhancements that is the increase in number of lanes and M-tag vehicles. Also, restriction of M-tag vehicles to certain lanes only. The VISSIM solution and modelling will give a visible representation and detailed flow of vehicles in conditions that are close to real world but not exactly ideal nor real.

Present infrastructure under traffic existing traffic conditions

Figure 4. 23 Present infrastructure under traffic existing traffic conditions

Present infrastructure under traffic conditions after 5 years with 4% traffic growth

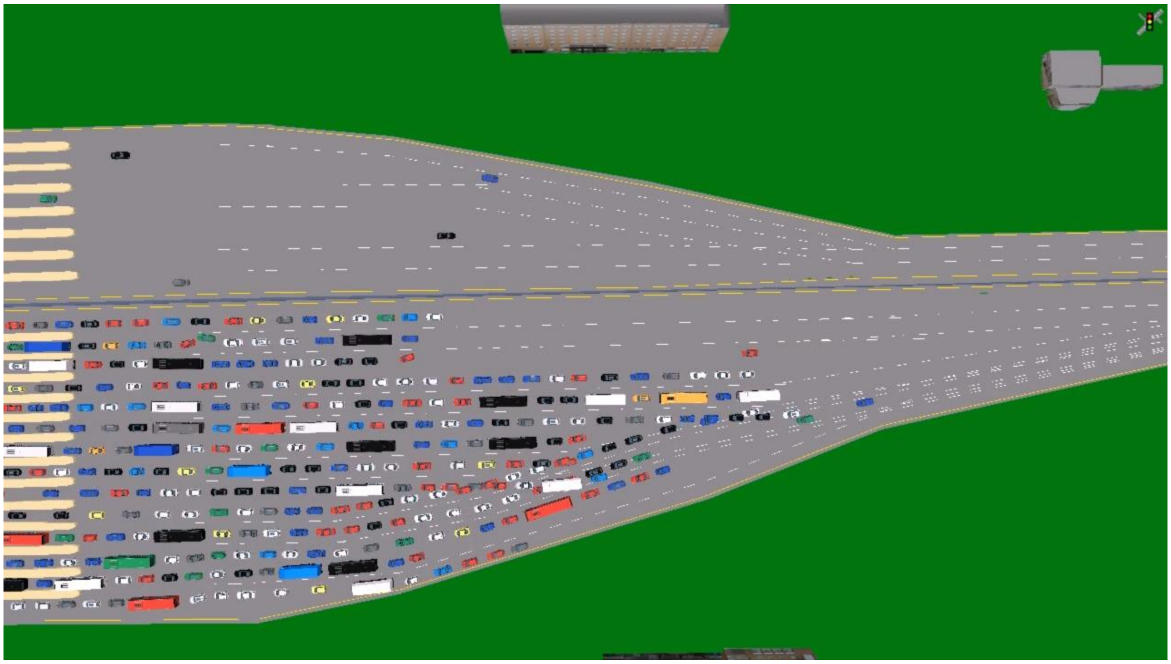


Figure 4. 24 Present infrastructure under traffic conditions after 5 years with 4% traffic growth

Present infrastructure under traffic conditions after 10 years with 4% traffic growth

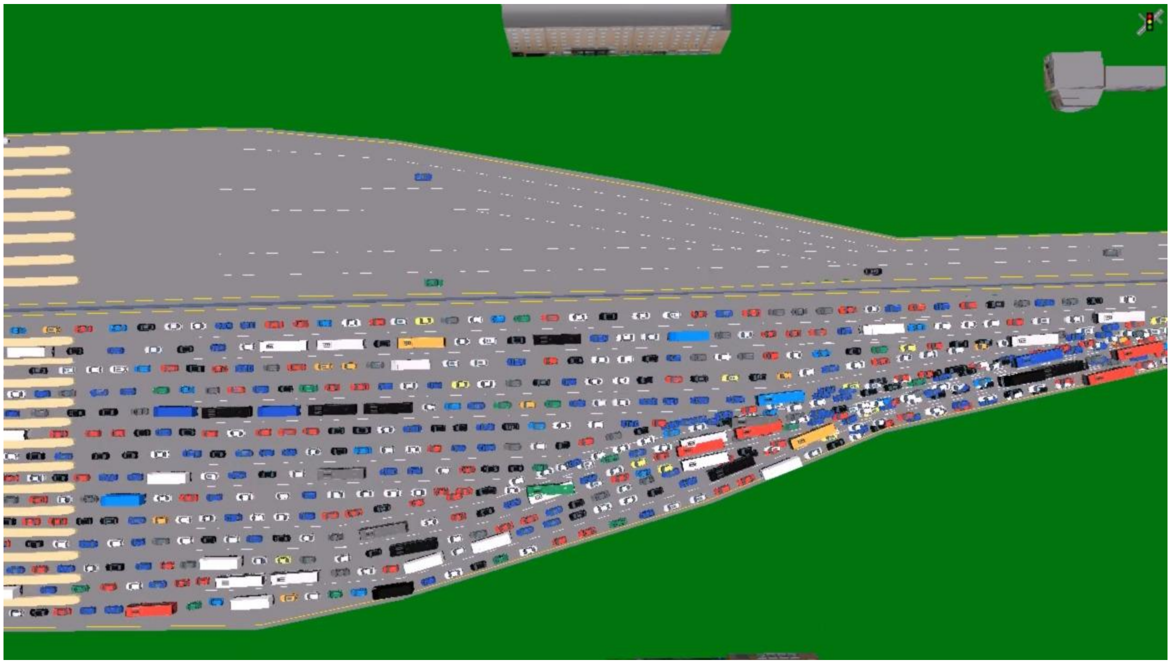


Figure 4. 25 Present infrastructure under traffic conditions after 10 years with 4% traffic growth

5.2.3 Comparison of Toll Operations Before and After Optimization

The toll operations before and after the optimizations have a clear change in the flow characteristics of the vehicles. Change in LOS criteria of the toll plaza are observed. The time in delays of vehicles are very much even at present after 5 and 10 years the change in flow of the traffic under current conditions were very poor having delays above 200 seconds and 500 seconds respectively for toll operations. After improvement, the time for delay was reduced to under 35 seconds for most lanes and under 10 seconds for M-tag lanes.

5.2.3.1 Comparison Table

Given under are the LOS, average queue delays, queue lengths, vehicles per lane, maximum queue lengths and average length of vehicles under peak hour considerations. Both considerations mentioned below are under present physical conditions and traffic for years present, 5 years from now and 10 years from now. All data counts are for 1 hour of simulation.

Table 6 Comparison Current conditions

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)	QUEUE LENGTH	QUEUE LENGTH MAX
1	C	105	4.82	27.15	6.5	63.12
2	E	118	4.99	64.82	16.49	67.63
3	F	120	4.63	115.62	28.05	63.11
4	F	119	5.01	103.63	26.53	63.36
5	F	125	4.6	82.96	20.98	63.2
6	D	119	4.91	51.04	13.35	51.83
7	D	120	5.1	49.45	14.39	45.13
8	C	91	4.62	34.51	7.29	44.08
9	F	129	4.86	144.24	41.99	86.82
10	F	125	5.05	148.83	42.87	87.16
11	F	120	4.76	147.07	39.72	87.52
12	E	126	5.07	77.38	24.2	51.28
13	E	129	4.87	71.92	22.01	51.11
14	D	110	4.6	41.67	10.43	49.3

Table 7 After 5 years with 4% growth rate per year with no improvements

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)	QUEUE LENGTH	QUEUE LENGTH MAX
1	F	122	5.02	115.84	36.48	126.87
2	F	125	5.04	125.96	41.3	126.91
3	F	124	4.74	203.12	60.31	128.47
4	F	118	5.01	199.37	58.85	128.72
5	F	120	4.74	197.63	56.66	128.56
6	F	123	5.06	208.18	69.04	165.2
7	F	122	5.25	209.63	69.01	165.27
8	F	120	4.74	206.87	65.93	164.89
9	F	126	4.89	243.31	75.63	140.55
10	F	122	5.38	234.89	74.64	140.88
11	F	126	4.41	247.68	73.99	141.25
12	F	127	4.86	228.27	72.75	149.36
13	F	126	5.14	215.64	72.02	149.28
14	F	127	4.34	228.45	67.6	149.2

Table 8 After 10 years with 4% growth rate per year with no improvements

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)	QUEUE LENGTH	QUEUE LENGTH MAX
1	F	127	5.02	397.13	133.62	288.21
2	F	125	5.24	333.75	131.64	288.24
3	F	124	5.2	459.47	162.94	315.48
4	F	123	5.01	464.4	162.66	315.73
5	F	122	4.74	469.21	161.43	315.57
6	F	125	5.06	483.47	181.5	429
7	F	122	5.25	470.45	182.24	429.07
8	F	125	4.74	500.11	180.47	428.69
9	F	127	4.98	511.12	185.02	426.76
10	F	126	5.38	520.95	185.51	427.09
11	F	128	4.41	532.72	184.93	427.46
12	F	127	4.89	538.43	202.11	426.08
13	F	126	5.49	488.68	201.63	426
14	F	128	4.34	572.4	201.38	425.92

Table 9 Present traffic conditions with 14 lanes and 3 restricted lanes for M-tag and 35% traffic on M-TAG lane

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)
1	C	102	4.56	34.81
2	D	116	5.01	39.34
3	C	108	5.34	21.68
4	C	105	4.99	33.08
5	A	88	4.47	2.57
6	B	97	5.14	18.39
7	C	106	5.31	33.21
8	A	71	4.37	6.8
9	B	121	4.91	20.71
10	C	122	5.14	22.48
11	A	79	4.39	7.2
12	A	222	4.84	0.93
13	A	209	5.18	1.27
14	A	152	4.37	0.31

Table 10 After 10 years 14 lanes with 3 M-tag lanes and Almost 40% M-tag traffic

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)
1	E	124	4.7	72.92
2	D	114	5.3	36
3	E	124	5.03	76
4	E	120	5.03	72.01
5	D	122	4.58	48.66
6	D	119	4.96	48.61
7	D	115	5.52	60.89
8	B	100	4.39	10.41
9	F	124	5.03	139.14
10	F	115	5.76	123.91
11	F	115	4.31	129.68
12	A	383	4.85	9.98
13	A	386	5.18	8.38
14	A	345	4.36	5.77

Table 11 After 10 years with lanes increased to 20 and no m-tag lanes

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)
1	E	118	4.35	54.1
2	B	107	4.5	13.48
3	B	103	4.52	17.5
4	D	113	4.53	45.51
5	D	121	4.39	50.88
6	C	112	4.43	28.89
7	F	127	4.4	144.59
8	F	120	4.52	127.31
9	F	123	4.41	113.92
10	F	124	4.5	89.8
11	F	123	4.59	94.56
12	F	128	4.53	122.91
13	F	127	4.42	112.6
14	F	121	4.54	89.43
15	E	125	4.38	67.81
16	E	120	4.48	60.28
17	C	112	4.5	30.78
18	D	108	4.49	40.86
19	F	127	4.45	96.44
20	E	121	4.6	68.73

Table 12 After 10 years with lanes increased to 20 and no m-tag lanes

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)	Q LEN	Q LEN MAX
1	A	100	4.42	17.71	3.52	33.88
2	A	81	4.44	5.66	1.03	25.94
3	A	95	4.62	6.52	1.31	15.1
4	A	96	4.37	50.52	9.54	45.13
5	B	102	4.47	55.26	10.76	48.26
6	A	90	4.52	7.83	1.48	22.36
7	A	97	4.49	23.78	4.64	43.79
8	B	115	4.39	50.95	12.42	48.32
9	A	100	4.44	12.7	3.49	43.48
10	A	95	4.55	36.18	7.37	42.58
11	A	212	4.47	1.03	0.54	27.25
12	A	225	4.56	1.04	0.6	27.32
13	A	227	4.5	0.68	0.44	23.84
14	A	208	4.47	0.68	0.39	17.81
15	B	114	4.41	51.54	11.98	47.27
16	A	100	4.41	26.65	5.06	46.86
17	A	100	4.4	28.94	5.91	41.72
18	A	96	4.49	39.34	8.44	48.61
19	A	108	4.5	15.52	3.67	36.89
20	A	97	4.57	18.79	3.83	34.42

Table 13 After 10 years 4 lanes of motorway with 16 lanes of toll plaza and 4 M-tag lanes.

LANE	LOS	VEHS(ALL)	LENGTH(ALL)	QUEUEDELAY(ALL)
1	C	96	4.44	33.33
2	C	98	4.41	27.47
3	C	96	4.42	26.93
4	D	115	4.42	39.56
5	B	103	4.41	14.83
6	A	81	4.44	4.95
7	A	96	4.64	12.97
8	B	95	4.36	45.92
9	A	102	4.47	55.19
10	A	89	4.53	6.45
11	A	322	4.5	4.73
12	A	342	4.47	4.39
13	A	333	4.51	6.43
14	A	296	4.5	1

15	B	107	4.55	10.3
16	A	102	4.57	34.45

5.2.4 Environmental Impact Analysis

The environmental effects of the queue interchange are due to the factor that idle fuel is burnt at approach and retreat from interchange. This is due to the fact that excessive queue stops require constant acceleration and deceleration in the process. The density of carbon exhausted is dense at and near the interchange. The fuel also burnt during the idle time is taken into consideration. The results are quite prominent that before and after the enhancements and optimization the situation has greatly improved for the better. The number of starts and stops that is the queue stops have reduced in number. Also, it is worth considering that a major portion of vehicular traffic will not stop more than one time this traffic is that which is flowing through the M-tag lanes. The changes will result in the carbon footprint across the interchange will be reduced significantly. With the inauguration of E-vehicles and hybrid vehicles it can also be expected that the carbon emissions averaged per vehicle will also be reduced. That in turn will also contribute to the fact that the conditions at the interchange will be better than those experienced now.

5.2.5 Cost Analysis

The cost analysis deals with the cost wasted in the idle burning of fuel during delays during the queue system. The cost is analyzed by taking into consideration that the traffic configuration that the percentage of car traffic, wagons, busses, 2 axle trucks and 4 axle trucks remains constant. Also, a supposition is made that the prices of fuel remain same and the time value of money is constant.

Table 14 Cost analysis on present conditions.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 36.863	P.RUPEES 16.038	P.RUPEES 37.461	P.RUPEES 2.253	P.RUPEES 3.514	P.RUPEES 96.128
P.RUPEES 98.905	P.RUPEES 43.030	P.RUPEES 100.510	P.RUPEES 6.046	P.RUPEES 9.428	P.RUPEES 257.918
P.RUPEES 179.408	P.RUPEES 78.054	P.RUPEES 182.319	P.RUPEES 10.967	P.RUPEES 17.101	P.RUPEES 467.848

P.RUPEES 159.463	P.RUPEES 69.377	P.RUPEES 162.050	P.RUPEES 9.748	P.RUPEES 15.200	P.RUPEES 415.837
P.RUPEES 134.093	P.RUPEES 58.339	P.RUPEES 136.269	P.RUPEES 8.197	P.RUPEES 12.782	P.RUPEES 349.679
P.RUPEES 78.539	P.RUPEES 34.169	P.RUPEES 79.813	P.RUPEES 4.801	P.RUPEES 7.486	P.RUPEES 204.809
P.RUPEES 76.732	P.RUPEES 33.383	P.RUPEES 77.977	P.RUPEES 4.690	P.RUPEES 7.314	P.RUPEES 200.096
P.RUPEES 40.608	P.RUPEES 17.667	P.RUPEES 41.267	P.RUPEES 2.482	P.RUPEES 3.871	P.RUPEES 105.895
P.RUPEES 240.604	P.RUPEES 104.678	P.RUPEES 244.508	P.RUPEES 14.707	P.RUPEES 22.934	P.RUPEES 627.432
P.RUPEES 240.563	P.RUPEES 104.660	P.RUPEES 244.466	P.RUPEES 14.705	P.RUPEES 22.930	P.RUPEES 627.323
P.RUPEES 228.209	P.RUPEES 99.285	P.RUPEES 231.912	P.RUPEES 13.950	P.RUPEES 21.753	P.RUPEES 595.109
P.RUPEES 126.074	P.RUPEES 54.850	P.RUPEES 128.120	P.RUPEES 7.707	P.RUPEES 12.017	P.RUPEES 328.768
P.RUPEES 119.968	P.RUPEES 52.194	P.RUPEES 121.915	P.RUPEES 7.333	P.RUPEES 11.435	P.RUPEES 312.846
P.RUPEES 59.271	P.RUPEES 25.787	P.RUPEES 60.233	P.RUPEES 3.623	P.RUPEES 5.650	P.RUPEES 154.564
cost per vehicle type per hour					
P.RUPEES 1,819.300	P.RUPEES 791.511	P.RUPEES 1,848.817	P.RUPEES 111.209	P.RUPEES 173.415	
			total cost per hour		P.RUPEES 4,744.253
			cost per year		P.RUPEES 17,316,521.63

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Table 15 If present conditions are kept and traffic increases at 4% per annum and after 5 years.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 182.745	P.RUPEES 79.506	P.RUPEES 185.710	P.RUPEES 11.171	P.RUPEES 17.419	P.RUPEES 476.551
P.RUPEES 203.596	P.RUPEES 88.577	P.RUPEES 206.900	P.RUPEES 12.445	P.RUPEES 19.407	P.RUPEES 530.926
P.RUPEES 325.688	P.RUPEES 141.695	P.RUPEES 330.972	P.RUPEES 19.908	P.RUPEES 31.045	P.RUPEES 849.308
P.RUPEES 304.207	P.RUPEES 132.349	P.RUPEES 309.143	P.RUPEES 18.595	P.RUPEES 28.997	P.RUPEES 793.291
P.RUPEES 306.663	P.RUPEES 133.418	P.RUPEES 311.639	P.RUPEES 18.746	P.RUPEES 29.231	P.RUPEES 799.696
P.RUPEES 331.109	P.RUPEES 144.054	P.RUPEES 336.482	P.RUPEES 20.240	P.RUPEES 31.561	P.RUPEES 863.446
P.RUPEES 330.705	P.RUPEES 143.878	P.RUPEES 336.070	P.RUPEES 20.215	P.RUPEES 31.523	P.RUPEES 862.391
P.RUPEES 321.001	P.RUPEES 139.656	P.RUPEES 326.209	P.RUPEES 19.622	P.RUPEES 30.598	P.RUPEES 837.085
P.RUPEES 396.422	P.RUPEES 172.469	P.RUPEES 402.854	P.RUPEES 24.232	P.RUPEES 37.787	P.RUPEES 1,033.764
P.RUPEES 370.554	P.RUPEES 161.215	P.RUPEES 376.566	P.RUPEES 22.651	P.RUPEES 35.321	P.RUPEES 966.307
P.RUPEES 403.542	P.RUPEES 175.566	P.RUPEES 410.089	P.RUPEES 24.667	P.RUPEES 38.466	P.RUPEES 1,052.331
P.RUPEES 374.869	P.RUPEES 163.092	P.RUPEES 380.951	P.RUPEES 22.915	P.RUPEES 35.732	P.RUPEES 977.560
P.RUPEES 351.340	P.RUPEES 152.855	P.RUPEES 357.040	P.RUPEES 21.476	P.RUPEES 33.490	P.RUPEES 916.201
P.RUPEES 375.165	P.RUPEES 163.221	P.RUPEES 381.252	P.RUPEES 22.933	P.RUPEES 35.761	P.RUPEES 978.331
cost per vehicle type per hour					
P.RUPEES 4,577.608	P.RUPEES 1,991.550	P.RUPEES 4,651.877	P.RUPEES 279.817	P.RUPEES 436.337	
			total cost per hour		P.RUPEES 11,937.189
			cost per year		P.RUPEES 43,570,738.838

Table 16 If present conditions are kept and traffic increases at 4% per annum and after 10 years.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 652.2	P.RUPEES 283.7	P.RUPEES 662.8	P.RUPEES 39.9	P.RUPEES 62.2	P.RUPEES 1,700.7
P.RUPEES 539.5	P.RUPEES 234.7	P.RUPEES 548.2	P.RUPEES 33.0	P.RUPEES 51.4	P.RUPEES 1,406.8
P.RUPEES 736.7	P.RUPEES 320.5	P.RUPEES 748.7	P.RUPEES 45.0	P.RUPEES 70.2	P.RUPEES 1,921.2
P.RUPEES 738.6	P.RUPEES 321.3	P.RUPEES 750.6	P.RUPEES 45.2	P.RUPEES 70.4	P.RUPEES 1,926.1
P.RUPEES 740.2	P.RUPEES 322.0	P.RUPEES 752.2	P.RUPEES 45.2	P.RUPEES 70.6	P.RUPEES 1,930.3
P.RUPEES 781.5	P.RUPEES 340.0	P.RUPEES 794.1	P.RUPEES 47.8	P.RUPEES 74.5	P.RUPEES 2,037.8
P.RUPEES 742.2	P.RUPEES 322.9	P.RUPEES 754.2	P.RUPEES 45.4	P.RUPEES 70.7	P.RUPEES 1,935.4
P.RUPEES 808.4	P.RUPEES 351.7	P.RUPEES 821.5	P.RUPEES 49.4	P.RUPEES 77.1	P.RUPEES 2,108.0
P.RUPEES 839.4	P.RUPEES 365.2	P.RUPEES 853.0	P.RUPEES 51.3	P.RUPEES 80.0	P.RUPEES 2,188.9
P.RUPEES 848.8	P.RUPEES 369.3	P.RUPEES 862.5	P.RUPEES 51.9	P.RUPEES 80.9	P.RUPEES 2,213.4
P.RUPEES 881.7	P.RUPEES 383.6	P.RUPEES 896.0	P.RUPEES 53.9	P.RUPEES 84.0	P.RUPEES 2,299.3
P.RUPEES 884.2	P.RUPEES 384.7	P.RUPEES 898.6	P.RUPEES 54.1	P.RUPEES 84.3	P.RUPEES 2,305.8
P.RUPEES 796.2	P.RUPEES 346.4	P.RUPEES 809.1	P.RUPEES 48.7	P.RUPEES 75.9	P.RUPEES 2,076.3
P.RUPEES 947.4	P.RUPEES 412.2	P.RUPEES 962.8	P.RUPEES 57.9	P.RUPEES 90.3	P.RUPEES 2,470.6
cost per vehicle type per hour					

P.RUPEES 10,936.9	P.RUPEES 4,758.2	P.RUPEES 11,114.3	P.RUPEES 668.5	P.RUPEES 1,042.5	
			total cost per hour		P.RUPEES 28,520.5
			cost per year		P.RUPEES 104,099,850.6

Table 17 Under current traffic if number of lanes are not increased but 3 M-tag lanes are strictly used for M-tag vehicles and 35% traffic is having M-tag equipped and all vehicles go to M-tag strictly terminals.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 45.9	P.RUPEES 20.0	P.RUPEES 46.7	P.RUPEES 2.8	P.RUPEES 4.4	P.RUPEES 119.7
P.RUPEES 59.0	P.RUPEES 25.7	P.RUPEES 60.0	P.RUPEES 3.6	P.RUPEES 5.6	P.RUPEES 153.9
P.RUPEES 30.3	P.RUPEES 13.2	P.RUPEES 30.8	P.RUPEES 1.9	P.RUPEES 2.9	P.RUPEES 79.0
P.RUPEES 44.9	P.RUPEES 19.5	P.RUPEES 45.6	P.RUPEES 2.7	P.RUPEES 4.3	P.RUPEES 117.1
P.RUPEES 2.9	P.RUPEES 1.3	P.RUPEES 3.0	P.RUPEES 0.2	P.RUPEES 0.3	P.RUPEES 7.6
P.RUPEES 23.1	P.RUPEES 10.0	P.RUPEES 23.4	P.RUPEES 1.4	P.RUPEES 2.2	P.RUPEES 60.2
P.RUPEES 45.5	P.RUPEES 19.8	P.RUPEES 46.3	P.RUPEES 2.8	P.RUPEES 4.3	P.RUPEES 118.7
P.RUPEES 6.2	P.RUPEES 2.7	P.RUPEES 6.3	P.RUPEES 0.4	P.RUPEES 0.6	P.RUPEES 16.3
P.RUPEES 32.4	P.RUPEES 14.1	P.RUPEES 32.9	P.RUPEES 2.0	P.RUPEES 3.1	P.RUPEES 84.5
P.RUPEES 35.5	P.RUPEES 15.4	P.RUPEES 36.0	P.RUPEES 2.2	P.RUPEES 3.4	P.RUPEES 92.5
P.RUPEES 7.4	P.RUPEES 3.2	P.RUPEES 7.5	P.RUPEES 0.4	P.RUPEES 0.7	P.RUPEES 19.2
P.RUPEES 2.7	P.RUPEES 1.2	P.RUPEES 2.7	P.RUPEES 0.2	P.RUPEES 0.3	P.RUPEES 7.0
P.RUPEES 3.4	P.RUPEES 1.5	P.RUPEES 3.5	P.RUPEES 0.2	P.RUPEES 0.3	P.RUPEES 9.0

P.RUPEES 0.6	P.RUPEES 0.3	P.RUPEES 0.6	P.RUPEES 0.0	P.RUPEES 0.1	P.RUPEES 1.6
cost per vehicle type per hour					
P.RUPEES 339.8	P.RUPEES 147.8	P.RUPEES 345.3	P.RUPEES 20.8	P.RUPEES 32.4	
			total cost per hour		P.RUPEES 886.1
			cost per year		P.RUPEES 3,234,297.0

Table 18 After 10 years if above conditions are followed and traffic increases @4%/annum.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 116.9	P.RUPEES 50.9	P.RUPEES 118.8	P.RUPEES 7.1	P.RUPEES 11.1	P.RUPEES 304.9
P.RUPEES 53.1	P.RUPEES 23.1	P.RUPEES 53.9	P.RUPEES 3.2	P.RUPEES 5.1	P.RUPEES 138.4
P.RUPEES 121.9	P.RUPEES 53.0	P.RUPEES 123.8	P.RUPEES 7.4	P.RUPEES 11.6	P.RUPEES 317.8
P.RUPEES 111.7	P.RUPEES 48.6	P.RUPEES 113.6	P.RUPEES 6.8	P.RUPEES 10.7	P.RUPEES 291.4
P.RUPEES 76.8	P.RUPEES 33.4	P.RUPEES 78.0	P.RUPEES 4.7	P.RUPEES 7.3	P.RUPEES 200.2
P.RUPEES 74.8	P.RUPEES 32.5	P.RUPEES 76.0	P.RUPEES 4.6	P.RUPEES 7.1	P.RUPEES 195.1
P.RUPEES 90.5	P.RUPEES 39.4	P.RUPEES 92.0	P.RUPEES 5.5	P.RUPEES 8.6	P.RUPEES 236.1
P.RUPEES 13.5	P.RUPEES 5.9	P.RUPEES 13.7	P.RUPEES 0.8	P.RUPEES 1.3	P.RUPEES 35.1
P.RUPEES 223.1	P.RUPEES 97.1	P.RUPEES 226.7	P.RUPEES 13.6	P.RUPEES 21.3	P.RUPEES 581.8
P.RUPEES 184.3	P.RUPEES 80.2	P.RUPEES 187.2	P.RUPEES 11.3	P.RUPEES 17.6	P.RUPEES 480.5
P.RUPEES 192.8	P.RUPEES 83.9	P.RUPEES 196.0	P.RUPEES 11.8	P.RUPEES 18.4	P.RUPEES 502.9
P.RUPEES 49.4	P.RUPEES 21.5	P.RUPEES 50.2	P.RUPEES 3.0	P.RUPEES 4.7	P.RUPEES 128.9
P.RUPEES 41.8	P.RUPEES 18.2	P.RUPEES 42.5	P.RUPEES 2.6	P.RUPEES 4.0	P.RUPEES 109.1
P.RUPEES 25.7	P.RUPEES 11.2	P.RUPEES 26.2	P.RUPEES 1.6	P.RUPEES 2.5	P.RUPEES 67.1
cost per vehicle type per hour					

P.RUPEES 1,376.4	P.RUPEES 598.8	P.RUPEES 1,398.7	P.RUPEES 84.1	P.RUPEES 131.2	
			total cost per hour		P.RUPEES 3,589.2
			cost per year		P.RUPEES 13,100,476.8

Table 19 If only lanes are increased to 20 and no M-tag vehicles are present and traffic conditions in 10 years and 4%/annum growth rate.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 82.5	P.RUPEES 98.5	P.RUPEES 83.9	P.RUPEES 5.0	P.RUPEES 7.9	P.RUPEES 277.9
P.RUPEES 18.7	P.RUPEES 22.3	P.RUPEES 19.0	P.RUPEES 1.1	P.RUPEES 1.8	P.RUPEES 62.8
P.RUPEES 23.3	P.RUPEES 27.8	P.RUPEES 23.7	P.RUPEES 1.4	P.RUPEES 2.2	P.RUPEES 78.5
P.RUPEES 66.5	P.RUPEES 79.4	P.RUPEES 67.6	P.RUPEES 4.1	P.RUPEES 6.3	P.RUPEES 223.9
P.RUPEES 79.6	P.RUPEES 95.0	P.RUPEES 80.9	P.RUPEES 4.9	P.RUPEES 7.6	P.RUPEES 268.0
P.RUPEES 41.8	P.RUPEES 49.9	P.RUPEES 42.5	P.RUPEES 2.6	P.RUPEES 4.0	P.RUPEES 140.8
P.RUPEES 237.4	P.RUPEES 283.4	P.RUPEES 241.3	P.RUPEES 14.5	P.RUPEES 22.6	P.RUPEES 799.3
P.RUPEES 197.5	P.RUPEES 235.8	P.RUPEES 200.8	P.RUPEES 12.1	P.RUPEES 18.8	P.RUPEES 665.0
P.RUPEES 181.2	P.RUPEES 216.3	P.RUPEES 184.1	P.RUPEES 11.1	P.RUPEES 17.3	P.RUPEES 609.9
P.RUPEES 144.0	P.RUPEES 171.9	P.RUPEES 146.3	P.RUPEES 8.8	P.RUPEES 13.7	P.RUPEES 484.7
P.RUPEES 150.4	P.RUPEES 179.5	P.RUPEES 152.8	P.RUPEES 9.2	P.RUPEES 14.3	P.RUPEES 506.3
P.RUPEES 203.4	P.RUPEES 242.8	P.RUPEES 206.7	P.RUPEES 12.4	P.RUPEES 19.4	P.RUPEES 684.8
P.RUPEES 184.9	P.RUPEES 220.7	P.RUPEES 187.9	P.RUPEES 11.3	P.RUPEES 17.6	P.RUPEES 622.5
P.RUPEES 139.9	P.RUPEES 167.0	P.RUPEES 142.2	P.RUPEES 8.6	P.RUPEES 13.3	P.RUPEES 471.0

P.RUPEES 109.6	P.RUPEES 130.8	P.RUPEES 111.4	P.RUPEE S 6.7	P.RUPEE S 10.4	P.RUPEES 369.0
P.RUPEES 93.5	P.RUPEES 111.6	P.RUPEES 95.1	P.RUPEE S 5.7	P.RUPEE S 8.9	P.RUPEES 314.9
P.RUPEES 44.6	P.RUPEES 53.2	P.RUPEES 45.3	P.RUPEE S 2.7	P.RUPEE S 4.2	P.RUPEES 150.1
P.RUPEES 57.1	P.RUPEES 68.1	P.RUPEES 58.0	P.RUPEE S 3.5	P.RUPEE S 5.4	P.RUPEES 192.1
P.RUPEES 158.4	P.RUPEES 189.0	P.RUPEES 160.9	P.RUPEE S 9.7	P.RUPEE S 15.1	P.RUPEES 533.1
P.RUPEES 107.5	P.RUPEES 128.4	P.RUPEES 109.3	P.RUPEE S 6.6	P.RUPEE S 10.3	P.RUPEES 362.0
cost per vehicle type per hour					
P.RUPEES 2,322.0	P.RUPEES 2,771.5	P.RUPEES 2,359.7	P.RUPEE S 141.9	P.RUPEE S 221.3	
			total cost per hour		P.RUPEES 7,816.4
			cost per year		P.RUPEES 28,529,856.2

Table 20 If traffic increases @4%/annum and 20 lanes are made and 25% traffic is M-tag vehicles and 4 lanes are restricted specifically for M-TAG vehicles and all M-tag vehicles go through M-tag lanes.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 22.9	P.RUPEES 10.0	P.RUPEES 23.3	P.RUPEES 1.4	P.RUPEES 2.2	P.RUPEES 59.7
P.RUPEES 5.9	P.RUPEES 2.6	P.RUPEES 6.0	P.RUPEES 0.4	P.RUPEES 0.6	P.RUPEES 15.5
P.RUPEES 8.0	P.RUPEES 3.5	P.RUPEES 8.1	P.RUPEES 0.5	P.RUPEES 0.8	P.RUPEES 20.9
P.RUPEES 62.7	P.RUPEES 27.3	P.RUPEES 63.7	P.RUPEES 3.8	P.RUPEES 6.0	P.RUPEES 163.5

P.RUPEES 72.9	P.RUPEES 31.7	P.RUPEES 74.1	P.RUPEES 4.5	P.RUPEES 6.9	P.RUPEES 190.1
P.RUPEES 9.1	P.RUPEES 4.0	P.RUPEES 9.3	P.RUPEES 0.6	P.RUPEES 0.9	P.RUPEES 23.8
P.RUPEES 29.8	P.RUPEES 13.0	P.RUPEES 30.3	P.RUPEES 1.8	P.RUPEES 2.8	P.RUPEES 77.8
P.RUPEES 75.8	P.RUPEES 33.0	P.RUPEES 77.0	P.RUPEES 4.6	P.RUPEES 7.2	P.RUPEES 197.6
P.RUPEES 16.4	P.RUPEES 7.1	P.RUPEES 16.7	P.RUPEES 1.0	P.RUPEES 1.6	P.RUPEES 42.8
P.RUPEES 44.4	P.RUPEES 19.3	P.RUPEES 45.2	P.RUPEES 2.7	P.RUPEES 4.2	P.RUPEES 115.9
P.RUPEES 2.8	P.RUPEES 1.2	P.RUPEES 2.9	P.RUPEES 0.2	P.RUPEES 0.3	P.RUPEES 7.4
P.RUPEES 3.0	P.RUPEES 1.3	P.RUPEES 3.1	P.RUPEES 0.2	P.RUPEES 0.3	P.RUPEES 7.9
P.RUPEES 2.0	P.RUPEES 0.9	P.RUPEES 2.0	P.RUPEES 0.1	P.RUPEES 0.2	P.RUPEES 5.2
P.RUPEES 1.8	P.RUPEES 0.8	P.RUPEES 1.9	P.RUPEES 0.1	P.RUPEES 0.2	P.RUPEES 4.8
P.RUPEES 76.0	P.RUPEES 33.1	P.RUPEES 77.2	P.RUPEES 4.6	P.RUPEES 7.2	P.RUPEES 198.1
P.RUPEES 34.5	P.RUPEES 15.0	P.RUPEES 35.0	P.RUPEES 2.1	P.RUPEES 3.3	P.RUPEES 89.9
P.RUPEES 37.4	P.RUPEES 16.3	P.RUPEES 38.0	P.RUPEES 2.3	P.RUPEES 3.6	P.RUPEES 97.6
P.RUPEES 48.8	P.RUPEES 21.2	P.RUPEES 49.6	P.RUPEES 3.0	P.RUPEES 4.7	P.RUPEES 127.3
P.RUPEES 21.7	P.RUPEES 9.4	P.RUPEES 22.0	P.RUPEES 1.3	P.RUPEES 2.1	P.RUPEES 56.5

P.RUPEES 23.6	P.RUPEES 10.3	P.RUPEES 24.0	P.RUPEES 1.4	P.RUPEES 2.2	P.RUPEES 61.5
cost per vehicle type per hour					
P.RUPEES 599.6	P.RUPEES 260.9	P.RUPEES 609.3	P.RUPEES 36.7	P.RUPEES 57.2	
			total cost per hour		P.RUPEES 1,563.6
			cost per year		P.RUPEES 5,707,313.7

Table 21 If the motorway has increased lanes that is 4, and 16 lanes are in use of which 4 lanes are M-tag restricted and 30% traffic is M-tag equipped and flows through these lanes.

cost/vehicle type/lane/hr					cost per lane per hour
P.RUPEES 41.4	P.RUPEES 18.0	P.RUPEES 42.0	P.RUPEES 2.5	P.RUPEES 3.9	P.RUPEES 107.9
P.RUPEES 34.8	P.RUPEES 15.1	P.RUPEES 35.4	P.RUPEES 2.1	P.RUPEES 3.3	P.RUPEES 90.8
P.RUPEES 33.4	P.RUPEES 14.5	P.RUPEES 34.0	P.RUPEES 2.0	P.RUPEES 3.2	P.RUPEES 87.2
P.RUPEES 58.8	P.RUPEES 25.6	P.RUPEES 59.8	P.RUPEES 3.6	P.RUPEES 5.6	P.RUPEES 153.4
P.RUPEES 19.8	P.RUPEES 8.6	P.RUPEES 20.1	P.RUPEES 1.2	P.RUPEES 1.9	P.RUPEES 51.5
P.RUPEES 5.2	P.RUPEES 2.3	P.RUPEES 5.3	P.RUPEES 0.3	P.RUPEES 0.5	P.RUPEES 13.5
P.RUPEES 16.1	P.RUPEES 7.0	P.RUPEES 16.4	P.RUPEES 1.0	P.RUPEES 1.5	P.RUPEES 42.0
P.RUPEES 56.4	P.RUPEES 24.5	P.RUPEES 57.3	P.RUPEES 3.4	P.RUPEES 5.4	P.RUPEES 147.1
P.RUPEES 72.8	P.RUPEES 31.7	P.RUPEES 74.0	P.RUPEES 4.4	P.RUPEES 6.9	P.RUPEES 189.8
P.RUPEES 7.4	P.RUPEES 3.2	P.RUPEES 7.5	P.RUPEES 0.5	P.RUPEES 0.7	P.RUPEES 19.4

P.RUPEES 19.7	P.RUPEES 8.6	P.RUPEES 20.0	P.RUPEES 1.2	P.RUPEES 1.9	P.RUPEES 51.4
P.RUPEES 19.4	P.RUPEES 8.4	P.RUPEES 19.7	P.RUPEES 1.2	P.RUPEES 1.9	P.RUPEES 50.6
P.RUPEES 27.7	P.RUPEES 12.0	P.RUPEES 28.1	P.RUPEES 1.7	P.RUPEES 2.6	P.RUPEES 72.2
P.RUPEES 3.8	P.RUPEES 1.7	P.RUPEES 3.9	P.RUPEES 0.2	P.RUPEES 0.4	P.RUPEES 10.0
P.RUPEES 14.3	P.RUPEES 6.2	P.RUPEES 14.5	P.RUPEES 0.9	P.RUPEES 1.4	P.RUPEES 37.2
P.RUPEES 45.4	P.RUPEES 19.8	P.RUPEES 46.2	P.RUPEES 2.8	P.RUPEES 4.3	P.RUPEES 118.5
cost per vehicle type per hour					
P.RUPEES 476.4	P.RUPEES 207.3	P.RUPEES 484.1	P.RUPEES 29.1	P.RUPEES 45.4	
			total cost per hour		P.RUPEES 1,242.4
			cost per year		P.RUPEES 4,534,651.9

From the above data presented it is clear that by improvement in the lanes cost of idle fuel burning is reduced.

Table 22 present conditions comparison

savings/vehicle type/lane/hr					savings per lane per hour
P.RUPEES (9.0)	P.RUPEES (3.9)	P.RUPEES (9.2)	P.RUPEES (0.6)	P.RUPEES (0.9)	P.RUPEES (23.6)
P.RUPEES 39.9	P.RUPEES 17.4	P.RUPEES 40.5	P.RUPEES 2.4	P.RUPEES 3.8	P.RUPEES 104.0
P.RUPEES 149.1	P.RUPEES 64.9	P.RUPEES 151.6	P.RUPEES 9.1	P.RUPEES 14.2	P.RUPEES 388.9
P.RUPEES 114.5	P.RUPEES 49.8	P.RUPEES 116.4	P.RUPEES 7.0	P.RUPEES 10.9	P.RUPEES 298.7

P.RUPEES 131.2	P.RUPEES 57.1	P.RUPEES 133.3	P.RUPEES 8.0	P.RUPEES 12.5	P.RUPEES 342.1
P.RUPEES 55.5	P.RUPEES 24.1	P.RUPEES 56.4	P.RUPEES 3.4	P.RUPEES 5.3	P.RUPEES 144.7
P.RUPEES 31.2	P.RUPEES 13.6	P.RUPEES 31.7	P.RUPEES 1.9	P.RUPEES 3.0	P.RUPEES 81.4
P.RUPEES 34.4	P.RUPEES 15.0	P.RUPEES 34.9	P.RUPEES 2.1	P.RUPEES 3.3	P.RUPEES 89.6
P.RUPEES 208.2	P.RUPEES 90.6	P.RUPEES 211.6	P.RUPEES 12.7	P.RUPEES 19.8	P.RUPEES 542.9
P.RUPEES 205.1	P.RUPEES 89.2	P.RUPEES 208.4	P.RUPEES 12.5	P.RUPEES 19.5	P.RUPEES 534.8
P.RUPEES 220.9	P.RUPEES 96.1	P.RUPEES 224.4	P.RUPEES 13.5	P.RUPEES 21.1	P.RUPEES 575.9
P.RUPEES 123.4	P.RUPEES 53.7	P.RUPEES 125.4	P.RUPEES 7.5	P.RUPEES 11.8	P.RUPEES 321.8
P.RUPEES 116.5	P.RUPEES 50.7	P.RUPEES 118.4	P.RUPEES 7.1	P.RUPEES 11.1	P.RUPEES 303.9
P.RUPEES 58.7	P.RUPEES 25.5	P.RUPEES 59.6	P.RUPEES 3.6	P.RUPEES 5.6	P.RUPEES 153.0
savings per vehicle type per hour					
P.RUPEES 1,479.5	P.RUPEES 643.7	P.RUPEES 1,503.5	P.RUPEES 90.4	P.RUPEES 141.0	
			savings per hour		P.RUPEES 3,858.1
			savings per year		P.RUPEES 14,082,224.6

The following data is clearly identifying the savings of up to 14 million in just one year. The comparison is between the infrastructure existing and the case if same number of lanes are used and 3 lanes are specifically used for M-tag vehicles and 35% traffic is equipped with M-tag and uses these specified lanes only.

Comparison between 10 years

First comparison no enhancements and 20 lanes with no M-tag lanes

Table 23 comparison no enhancements and 20 lanes with no M-tag lanes

savings/vehicle type/lane/hr					saving per lane per hour
P.RUPEES 569.6	P.RUPEES 185.2	P.RUPEES 578.9	P.RUPEES 34.8	P.RUPEES 54.3	P.RUPEES 1,422.8
P.RUPEES 520.8	P.RUPEES 212.4	P.RUPEES 529.3	P.RUPEES 31.8	P.RUPEES 49.6	P.RUPEES 1,344.0
P.RUPEES 713.4	P.RUPEES 292.7	P.RUPEES 725.0	P.RUPEES 43.6	P.RUPEES 68.0	P.RUPEES 1,842.7
P.RUPEES 672.1	P.RUPEES 242.0	P.RUPEES 683.0	P.RUPEES 41.1	P.RUPEES 64.1	P.RUPEES 1,702.3
P.RUPEES 660.6	P.RUPEES 227.0	P.RUPEES 671.3	P.RUPEES 40.4	P.RUPEES 63.0	P.RUPEES 1,662.3
P.RUPEES 739.6	P.RUPEES 290.0	P.RUPEES 751.6	P.RUPEES 45.2	P.RUPEES 70.5	P.RUPEES 1,897.0
P.RUPEES 504.7	P.RUPEES 39.5	P.RUPEES 512.9	P.RUPEES 30.9	P.RUPEES 48.1	P.RUPEES 1,136.1
P.RUPEES 610.8	P.RUPEES 115.9	P.RUPEES 620.7	P.RUPEES 37.3	P.RUPEES 58.2	P.RUPEES 1,443.0
P.RUPEES 658.2	P.RUPEES 148.9	P.RUPEES 668.9	P.RUPEES 40.2	P.RUPEES 62.7	P.RUPEES 1,578.9
P.RUPEES 704.8	P.RUPEES 197.4	P.RUPEES 716.2	P.RUPEES 43.1	P.RUPEES 67.2	P.RUPEES 1,728.7
P.RUPEES 731.3	P.RUPEES 204.1	P.RUPEES 743.2	P.RUPEES 44.7	P.RUPEES 69.7	P.RUPEES 1,793.0
P.RUPEES 680.8	P.RUPEES 141.9	P.RUPEES 691.8	P.RUPEES 41.6	P.RUPEES 64.9	P.RUPEES 1,621.0
P.RUPEES 611.3	P.RUPEES 125.7	P.RUPEES 621.2	P.RUPEES 37.4	P.RUPEES 58.3	P.RUPEES 1,453.8

P.RUPEES 807.5	P.RUPEES 245.2	P.RUPEES 820.6	P.RUPEES 49.4	P.RUPEES 77.0	P.RUPEES 1,999.6
P.RUPEES (109.6)	P.RUPEES (130.8)	P.RUPEES (111.4)	P.RUPEES (6.7)	P.RUPEES (10.4)	P.RUPEES (369.0)
P.RUPEES (93.5)	P.RUPEES (111.6)	P.RUPEES (95.1)	P.RUPEES (5.7)	P.RUPEES (8.9)	P.RUPEES (314.9)
P.RUPEES (44.6)	P.RUPEES (53.2)	P.RUPEES (45.3)	P.RUPEES (2.7)	P.RUPEES (4.2)	P.RUPEES (150.1)
P.RUPEES (57.1)	P.RUPEES (68.1)	P.RUPEES (58.0)	P.RUPEES (3.5)	P.RUPEES (5.4)	P.RUPEES (192.1)
P.RUPEES (158.4)	P.RUPEES (189.0)	P.RUPEES (160.9)	P.RUPEES (9.7)	P.RUPEES (15.1)	P.RUPEES (533.1)
P.RUPEES (107.5)	P.RUPEES (128.4)	P.RUPEES (109.3)	P.RUPEES (6.6)	P.RUPEES (10.3)	P.RUPEES (362.0)
cost per vehicle type per hour					
P.RUPEES 8,614.9	P.RUPEES 1,986.8	P.RUPEES 8,754.7	P.RUPEES 526.6	P.RUPEES 821.2	
			total savings per hour		P.RUPEES 20,704.1
			savings per year		P.RUPEES 75,569,994.5

The analysis between both clearly shows that a saving of 75 million in the 10th year can be made if only lanes are increased.

Table 24 Comparison between 20 lanes with no m tags and 20 lanes with 4 M-tag lanes.

savings/vehicle type/lane/hr					saving per lane per hour
P.RUPEES 59.6	P.RUPEES 88.6	P.RUPEES 60.6	P.RUPEES 3.6	P.RUPEES 5.7	P.RUPEES 218.2
P.RUPEES 12.7	P.RUPEES 19.7	P.RUPEES 12.9	P.RUPEES 0.8	P.RUPEES 1.2	P.RUPEES 47.3
P.RUPEES 15.3	P.RUPEES 24.3	P.RUPEES 15.5	P.RUPEES 0.9	P.RUPEES 1.5	P.RUPEES 57.6
P.RUPEES 3.8	P.RUPEES 52.1	P.RUPEES 3.8	P.RUPEES 0.2	P.RUPEES 0.4	P.RUPEES 60.3

P.RUPEES 6.7	P.RUPEES 63.3	P.RUPEES 6.8	P.RUPEES 0.4	P.RUPEES 0.6	P.RUPEES 77.9
P.RUPEES 32.7	P.RUPEES 46.0	P.RUPEES 33.3	P.RUPEES 2.0	P.RUPEES 3.1	P.RUPEES 117.1
P.RUPEES 207.6	P.RUPEES 270.4	P.RUPEES 211.0	P.RUPEES 12.7	P.RUPEES 19.8	P.RUPEES 721.5
P.RUPEES 121.8	P.RUPEES 202.8	P.RUPEES 123.8	P.RUPEES 7.4	P.RUPEES 11.6	P.RUPEES 467.4
P.RUPEES 164.8	P.RUPEES 209.1	P.RUPEES 167.4	P.RUPEES 10.1	P.RUPEES 15.7	P.RUPEES 567.1
P.RUPEES 99.5	P.RUPEES 152.5	P.RUPEES 101.2	P.RUPEES 6.1	P.RUPEES 9.5	P.RUPEES 368.8
P.RUPEES 147.6	P.RUPEES 178.3	P.RUPEES 150.0	P.RUPEES 9.0	P.RUPEES 14.1	P.RUPEES 498.9
P.RUPEES 200.4	P.RUPEES 241.5	P.RUPEES 203.7	P.RUPEES 12.3	P.RUPEES 19.1	P.RUPEES 676.9
P.RUPEES 182.9	P.RUPEES 219.8	P.RUPEES 185.9	P.RUPEES 11.2	P.RUPEES 17.4	P.RUPEES 617.3
P.RUPEES 138.1	P.RUPEES 166.2	P.RUPEES 140.3	P.RUPEES 8.4	P.RUPEES 13.2	P.RUPEES 466.3
P.RUPEES 33.6	P.RUPEES 97.8	P.RUPEES 34.2	P.RUPEES 2.1	P.RUPEES 3.2	P.RUPEES 170.8
P.RUPEES 59.1	P.RUPEES 96.7	P.RUPEES 60.0	P.RUPEES 3.6	P.RUPEES 5.6	P.RUPEES 225.0
P.RUPEES 7.2	P.RUPEES 36.9	P.RUPEES 7.3	P.RUPEES 0.4	P.RUPEES 0.7	P.RUPEES 52.5
P.RUPEES 8.2	P.RUPEES 46.9	P.RUPEES 8.4	P.RUPEES 0.5	P.RUPEES 0.8	P.RUPEES 64.7
P.RUPEES 136.7	P.RUPEES 179.6	P.RUPEES 138.9	P.RUPEES 8.4	P.RUPEES 13.0	P.RUPEES 476.6

P.RUPEES 84.0	P.RUPEES 118.1	P.RUPEES 85.3	P.RUPEES 5.1	P.RUPEES 8.0	P.RUPEES 300.5
savings per vehicle type per hour					
P.RUPEES 1,722.4	P.RUPEES 2,510.6	P.RUPEES 1,750.3	P.RUPEES 105.3	P.RUPEES 164.2	
			total savings per hour		P.RUPEES 6,252.8
			savings per year		P.RUPEES 22,822,542.5

The above analysis shows that further 22 million rupees can be saved if 4 lanes are restricted to M-tag and 25% traffic are M-tag equipped vehicles.

Table 25 Comparison between 20 lanes increased infrastructure with 4 M-tag lanes and 16 lanes with 4 M-tag lanes and 30% M-tag vehicles

savings/vehicle type/lane/hr					saving per lane per hour
P.RUPEES (18.5)	P.RUPEES (8.0)	P.RUPEES (18.8)	P.RUPEES (1.1)	P.RUPEES (1.8)	P.RUPEES (48.2)
P.RUPEES (28.9)	P.RUPEES (12.6)	P.RUPEES (29.4)	P.RUPEES (1.8)	P.RUPEES (2.8)	P.RUPEES (75.3)
P.RUPEES (25.4)	P.RUPEES (11.1)	P.RUPEES (25.8)	P.RUPEES (1.6)	P.RUPEES (2.4)	P.RUPEES (66.3)
P.RUPEES 3.9	P.RUPEES 1.7	P.RUPEES 3.9	P.RUPEES 0.2	P.RUPEES 0.4	P.RUPEES 10.1
P.RUPEES 53.1	P.RUPEES 23.1	P.RUPEES 54.0	P.RUPEES 3.2	P.RUPEES 5.1	P.RUPEES 138.6
P.RUPEES 3.9	P.RUPEES 1.7	P.RUPEES 4.0	P.RUPEES 0.2	P.RUPEES 0.4	P.RUPEES 10.2
P.RUPEES 13.7	P.RUPEES 6.0	P.RUPEES 13.9	P.RUPEES 0.8	P.RUPEES 1.3	P.RUPEES 35.8
P.RUPEES 19.4	P.RUPEES 8.4	P.RUPEES 19.7	P.RUPEES 1.2	P.RUPEES 1.8	P.RUPEES 50.5
P.RUPEES (56.4)	P.RUPEES (24.5)	P.RUPEES (57.3)	P.RUPEES (3.4)	P.RUPEES (5.4)	P.RUPEES (147.0)

P.RUPEES 37.0	P.RUPEES 16.1	P.RUPEES 37.6	P.RUPEES 2.3	P.RUPEES 3.5	P.RUPEES 96.5
P.RUPEES (16.9)	P.RUPEES (7.3)	P.RUPEES (17.1)	P.RUPEES (1.0)	P.RUPEES (1.6)	P.RUPEES (44.0)
P.RUPEES (16.4)	P.RUPEES (7.1)	P.RUPEES (16.7)	P.RUPEES (1.0)	P.RUPEES (1.6)	P.RUPEES (42.7)
P.RUPEES (25.7)	P.RUPEES (11.2)	P.RUPEES (26.1)	P.RUPEES (1.6)	P.RUPEES (2.4)	P.RUPEES (67.0)
P.RUPEES (2.0)	P.RUPEES (0.9)	P.RUPEES (2.0)	P.RUPEES (0.1)	P.RUPEES (0.2)	P.RUPEES (5.2)
P.RUPEES 61.7	P.RUPEES 26.9	P.RUPEES 62.7	P.RUPEES 3.8	P.RUPEES 5.9	P.RUPEES 161.0
P.RUPEES (11.0)	P.RUPEES (4.8)	P.RUPEES (11.2)	P.RUPEES (0.7)	P.RUPEES (1.0)	P.RUPEES (28.6)
P.RUPEES 37.4	P.RUPEES 16.3	P.RUPEES 38.0	P.RUPEES 2.3	P.RUPEES 3.6	P.RUPEES 97.6
P.RUPEES 48.8	P.RUPEES 21.2	P.RUPEES 49.6	P.RUPEES 3.0	P.RUPEES 4.7	P.RUPEES 127.3
P.RUPEES 21.7	P.RUPEES 9.4	P.RUPEES 22.0	P.RUPEES 1.3	P.RUPEES 2.1	P.RUPEES 56.5
P.RUPEES 23.6	P.RUPEES 10.3	P.RUPEES 24.0	P.RUPEES 1.4	P.RUPEES 2.2	P.RUPEES 61.5
savings per vehicle type per hour					
P.RUPEES 123.2	P.RUPEES 53.6	P.RUPEES 125.2	P.RUPEES 7.5	P.RUPEES 11.7	
		total savings per hour			P.RUPEES 321.3
			savings per year		P.RUPEES 1,172,661.8

the analysis shows that the savings are just above 1 million in this case but the cost of construction the fourth lane of the motorway will be too high.

Hence, the recommended solution is 20 lanes with 4 M-tag lanes and 25% traffic are M-tag vehicles which use these 4 lanes specifically designated for the M-tag vehicles.

5.3 Performance of Pavement

Pavement is the structural element and it determines the structural performance of the highway. All structural performance criteria have discussed in the chapter no.2. Due to the traffic impact of the unplanned traffic of Swat and Hazara motorways on M-1, its structural performance has declined.

5.3.1 Structural Performance Evaluation

Generally, for the structural performance deflection tests are conducted. Through the calculation of deflection of surface, we estimate the current performance of pavement. In our case study, there was need to calculate the deflection by FWD, but due to the current conditions and lack of equipment we could not perform the FWD properly. Procedure for the measuring the SN_f and SN_{eff} has discussed in the chapter 2. By substituting these values in overlay design equations, overlay thickness can be easily estimated. By applying the calculated overlay on the existing pavement, better structural performance of M-1 will be achieved till its remaining life. There is another alternative method for checking of the structural performance of M-1. By comparing the design ESALs, number of ESALs which have passed on the pavement and load to failure (can be calculated by PaveXpress), we can find out the remaining design life of M-1.

5.3.2 Proposed Solution

5.3.2.1 ESAL Calculation

Equivalent Single Axle Load (ESAL) is the total number of passes of a standard axle load during the design period that causes the same damage to the pavement as that of actual traffic. For ESAL calculation, first step is to calculate Load equivalent factor (LEF) of every axle of every traffic distribution. AASHTO 1993 guidelines, suggest that the LEFs should obtained from the AASHTO road test, based on the empirical data. The damage of the pavement by vehicles, depends on the axle load and wheel configuration of the vehicle.

So, it is important to determine the axle load of the heavy commercial vehicles in the given traffic mix that is likely to use proposed alignment over the design life. Projected damage due to the axles is related to stander axle of 18000 lbs., using the following equivalent load factors.

$$\text{LEF} = \left[\frac{\text{Actual weight on the axle}}{18000}\right]^{x}$$

For ASSHTO design value of x usually used as 4.5. It is based on AASHTO Road Test and varies from 3.8 to 4.1 depending on the axle load, desired terminal serviceability index and pavement structure.

In order to determine the cumulative axle load damage that a pavement will sustain during its design life, it is necessary to express the total number of heavy vehicles that will use the road during the design period in terms of the cumulative number of equivalent standard axles load (ESAL).

$$\text{ESAL} = \sum(LEFi * Ni)$$

LEF_i is the load equivalent factor for i^{th} axle load group or a traffic distribution and N_i the no of vehicle passes for i^{th} axle load group.

Axle Load Survey / Equivalence Factors

Table 26 Axle Load Survey / Equivalence Factors

Vehicle Type	Weighted Avg. Eq. Axle Factors		Loaded: Empty
	Loaded	**Empty**	**80: 20**
2 – Axle Truck	4.67	0.043	3.7446
4 – Axle Trailer	12.99	0.072	10.4064
Passenger Bus	0.939	0.939	0.939
Vans / Pickups /HiAce	0.09	0.09	0.09
Cars/ Jeeps	0.0002	0.0002	0.0002

Table 27 No. of ESALs of the vehicular count on the Segregated Fatah Jangh interchange, M-1. Estimated ESALs of a year, 2020

Vehicle Type	Vehicle counts	Equivalence Factors	Equivalent single axles (vehicle x E. factor)	Total Axles per year of vehicles (2020) (ESAL x 30 x 12)
Cars/ Jeeps	2537148	0.0002	507.43	1,014.86
Vans / Pickups /HiAce	136659	0.0900	12,299.31	24,598.62
Coaches	396799	0.9390	372,594.26	745,188.52
Passenger Bus	58635	0.9390	55,058.27	110,116.53
2 – Axle Truck	86116	3.7446	322,469.97	644,939.95
4 – Axle Trailer	46240	10.4064	481,191.94	962,383.87
				Total ESALs of year 2020 = 2,488,242.35

5.3.3 Growth Rate Factor and Sensitivity Analysis

Growth factors are used to estimate the future traffic demand for the rehabilitation and new development. The growth factors depend upon number of factors e.g. population growth in the area, proposed developments, historic GDP growth in the country. Japan International Cooperation Agency (JICA) in collaboration with the National Transport Research Centre (NTRC) carried out the Pakistan Transport Plan Study in March 2006. The study suggests land transport demand for freight is assumed to grow at an average annual rate of 4-6% for next five years. Despite historical data and studies, it should be noted that growth projections are not exact, and it may vary subject to project to project because of the involvement of number of factors. The historical registered vehicles and population in the area growth rate was analyzed to find the suitable growth rate. The review of growth rate adopted by NHA within the study area was also done. In recent NHA project of Malakand Tunnel (located within the study area), growth rate of 4% was used. In our final year project, we assumed the 4% growth rate for the prediction of traffic of next ten years. Through future traffic we can calculate the ESALs of the next ten year that will pass over the M-1 motorway. For the most accurate assumption, there is a need of sensitivity analysis, for the forward and backward prediction of traffic.

5.3.3.1 Forward Prediction of Traffic

Frist, we compute the daily traffic of 6 months (1 June 2019 to 31 Dec. 2019), calculate the ESALs of every day and then by adding, we get the ESALs of 6 months. By multiply these ESAls by 2, we get the 12 month or ESALs of a Year. After calculating the year ESALs we just multiply with growth factor (4%) to calculate the year ESALs of next year. Then add both to get the cumulative amount of ESALs that will pass over the M-1 by the end of two years. Similarly, we estimate the amount of ESALs that will pass in next ten years.

Table 28 ESALs calculation of the next 10 years using 4% growth rate.

Vehicle Type	Total ESAL (2020)	Total ESAL (2021)	Total ESAL (2022)	Total ESAL (2023)	Total ESAL (2024)	Total ESAL (2025)
Cars/ Jeeps	1,014.86	1,055.45	1,097.67	1,141.58	1,187.24	1,234.73
Vans /HiAce	24,598.62	25,582.56	26,605.87	27,670.10	28,776.91	29,927.98
Coaches	745,188.52	774,996.06	805,995.91	838,235.74	871,765.17	906,635.78
Passenger Bus	110,116.53	114,521.19	119,102.04	123,866.12	128,820.77	133,973.60

2 – Axle Truck	644,939.95	670,737.55	697,567.05	725,469.73	754,488.52	784,668.06
4 – Axle Trailer	962,383.87	1,000,879.23	1,040,914.40	1,082,550.97	1,125,853.01	1,170,887.13
Total ESALs at the end of each year	2,488,242.35	2,587,772.04	2,691,282.93	2,798,934.24	2,910,891.61	3,027,327.28
Cumulative ESALs at the end of each year	2,488,242.35	5,076,014.39	7,767,297.32	10,566,231.56	13,477,123.18	16,504,450.45

Vehicle type	**Total ESALs 2026**	**Total ESALs 2027**	**Total ESALs 2028**	**Total ESALs 2029**	**Total ESALs 2030**
Cars/ Jeeps	1,284.12	1,335.49	1,388.90	1,444.46	1,502.24
Vans /HiAce	31,125.10	32,370.11	33,664.91	35,011.51	36,411.97
Coaches	942,901.21	980,617.26	1,019,841.95	1,060,635.63	1,103,061.05
Passenger Bus	139,332.54	144,905.84	150,702.07	156,730.16	162,999.36
2 – Axle Truck	816,054.78	848,696.97	882,644.85	917,950.65	954,668.67
4 – Axle Trailer	1,217,722.62	1,266,431.52	1,317,088.78	1,369,772.33	1,424,563.23
Total ESALs at	3,148,420.37	3,274,357.18	3,405,331.47	3,541,544.73	3,683,206.52

the end of each year					
Cumulative ESALs at the end of each year	19,652,870.82	22,927,228.01	26,332,559.48	29,874,104.21	33,557,310.73

To check the other method for estimation of ESALs by the 40% of total vehicular traffic of M-1. With the 4% growth rate we estimate the ESAL for next 10 years, but this is less appropriate than the first one.

Table 29 No. of ESALs of the 40% total vehicular count of a day, M-1. Estimated ESALs of a year, 2020

vehicle type	No. of vehicles per day	40% Traffic	Equivalent factor	Equivalent single axle (40% Traffic x E factor)	Total ESALs per year per (ESAL x 12 x30) (2020)
cars	50,566.0000	20,226.4000	0.0002	4.0453	1,456.3008
wagons/ Hiaces	3,093.0000	1,237.2000	0.0900	111.3480	40,085.2800
coaches	6,913.0000	2,765.2000	0.9390	2,596.5228	934,748.2080
busses	612.0000	244.8000	0.9390	229.8672	82,752.1920
2 axle truck	2,636.0000	1,054.4000	3.7446	3,948.3062	1,421,390.2464
4 axle truck	735.0000	294.0000	10.4064	3,059.4816	1,101,413.3760

Table 30 ESALs calculation of the next 10 years using 4% growth rate.

Vehicle Type	Total ESALs 2020	Total ESALs 2021	Total ESALs 2022	Total ESALs 2023	Total ESALs 2024	Total ESALs 2025
cars	1456.30	1514.55	1575.13	1638.14	1703.67	1771.81
wagons/ Hiaces	40085.28	41688.69	43356.24	45090.49	46894.11	48769.87
coaches	934748.21	972138.14	1011023.66	1051464.61	1093523.19	1137264.12
busses	82752.19	86062.28	89504.77	93084.96	96808.36	100680.69
2 axle truck	1421390.25	1478245.86	1537375.69	1598870.72	1662825.55	1729338.57
4 axle truck	1101413.38	1145469.91	1191288.71	1238940.26	1288497.87	1340037.78
Total ESALs at the end of each year	3581845.60	3725119.43	3874124.20	4029089.17	4190252.74	4357862.85
Cumulative ESALs at the end of each year	3581845.60	7306965.03	11181089.23	15210178.41	19400431.15	23758294.00

Vehicle Type	Total ESALs 2026	Total ESALs 2027	Total ESALs 2028	Total ESALs 2029	Total ESALs 2030

cars	1842.69	1916.39	1993.05	2072.77	2155.68
wagons/ Hiaces	50720.67	52749.49	54859.47	57053.85	59336.01
coaches	1182754.69	1230064.87	1279267.47	1330438.17	1383655.69
busses	104707.92	108896.24	113252.09	117782.17	122493.46
2 axle truck	1798512.11	1870452.60	1945270.70	2023081.53	2104004.79
4 axle truck	1393639.29	1449384.86	1507360.26	1567654.67	1630360.86
Total ESALs at the end of each year	4532177.36	4713464.46	4902003.04	5098083.16	5302006.48
Cumulative ESALs at the end of each year	28290471.36	33003935.82	37905938.85	43004022.01	48306028.49

5.3.3.2 Backward Prediction of Traffic

Calculation of pervious year ESALs, is done by the reducing the ESALs of the year 2020 by 2.5%. Design year of M-1 was 2007. So, as reducing the ESALs we calculate the no. of ESALs that passed over M-1 during its first operational year.

Table 31 No. of ESALs estimation in the previous operational years of M-1.

Vehicle Type	Total ESALs 2020	Total ESALs 2019	Total ESALs 2018	Total ESALs 2017	Total ESALs 2016	Total ESALs 2015
cars	1456.30	1419.89	1384.40	1349.79	1316.04	1283.14
wagons/	40085.28	39083.15	38106.07	37153.42	36224.58	35318.97

Hiaces						
coaches	934748.21	911379.50	888595.02	866380.14	844720.64	823602.62
busses	82752.19	80683.39	78666.30	76699.64	74782.15	72912.60
2 axle truck	1421390.25	1385855.49	1351209.10	1317428.88	1284493.15	1252380.82
4 axle truck	1101413.38	1073878.04	1047031.09	1020855.31	995333.93	970450.58
Total ESALs at the end of each year	3581845.60	3492299.46	3404991.98	3319867.18	3236870.50	3155948.74
Cumulative ESALs at the end of each year	42758686.28	39176840.68	35684541.21	32279549.24	28959682.06	25722811.56

Vehicle Type	**Total ESALs 2014**	**Total ESALs 2013**	**Total ESALs 2012**	**Total ESALs 2011**	**Total ESALs 2010**
cars	1251.06	1219.79	1189.29	1159.56	1130.57
wagons/ Hiaces	34435.99	33575.09	32735.72	31917.32	31119.39
coaches	803012.55	782937.24	763363.81	744279.71	725672.72
busses	71089.78	69312.54	67579.73	65890.23	64242.98

2 axle truck	1221071.30	1190544.52	1160780.91	1131761.39	1103467.35
4 axle truck	946189.32	922534.58	899471.22	876984.44	855059.83
Total ESALs at the end of each year	3077050.02	3000123.77	2925120.67	2851992.66	2780692.84
Cumulative ESALs at the end of each year	22566862.83	19489812.81	16489689.04	13564568.37	10712575.71

Vehicle Type	**Total ESALs 2009**	**Total ESALs 2008**	**Total ESALs 2007**
cars	1102.31	1074.75	1047.88
wagons/ Hiaces	30341.41	29582.87	28843.30
coaches	707530.90	689842.63	672596.57
busses	62636.90	61070.98	59544.21
2 axle truck	1075880.67	1048983.65	1022759.06
4 axle truck	833683.33	812841.25	792520.22
Total ESALs at the end of each year	2711175.52	2643396.13	2577311.23
Cumulative ESALs at the end of each year	7931882.88	5220707.36	2577311.23

5.3.3 Estimation of the Remaining Life of M-1

The calculation of the predicted ESALs for the next ten years and last 13 years is done by the above-mentioned procedure. When we put the design thickness of the M-1 in the PaveXpress, it gives the load to failures, these load to failures help us to estimate the remaining life of the pavement. These load to failure can be explain as when such amount of load axels will pass on the pavement it will start deteriorating and this will the end period of the pavement. So, the loads to failure from the PaveXpress are the 7.4 M. By comparing it with annual ESALs, this amount will reach by the end of the 2022, as shown in above table. So, the remaining design life of pavement is 2 years.

5.4 Conclusions

The current conditions at the segregate Fateh Jang interchange, also called M-1 interchange Islamabad, is facing dire situations at present. Due to queue formation and the LOS criteria at the mentioned interchange being below D. Drivers especially commuter traffic face long queues during peak hours of traffic. The current infrastructure present does not accommodate the arrival rate during the Peak hours. Also, the M-tag lanes are not being followed strictly and this causes lengthy delays in M-tag lanes also. The current conditions need some toll optimization protocols to be set forward that should be strictly followed.

The operational characteristics such as queue and queue lengths were modelled using PTV VISSIM-9. Modelling of the existing infrastructure was done which gave us results that the LOS at the interchange was not acceptable. Also, modelling of traffic 5 and 10 years from now was performed and it resulted that the conditions grew gruesome in time and delays of up-to 300 seconds per vehicle was predicted.

The immediate solution put forward for reducing queue delays and the queue stoppages was to implement strict policies for the M-Tag lanes, restricting all M-tag traffic to only three lanes and increasing the traffic percentage of M-tag vehicles to 34%. The LOS criteria are significantly reduced to C and better and idle fuel burning saving P. RUPEES 14,082,224.6 for the first year. Since this is an immediate response the effects of it are for the near future and after 3 to four years the situation will again require for the enhancement of the interchange that will last for the next 10 years or more. The proposal to further increase the number of M-Tag lanes to 4 and 20 lanes in total at the interchange with 35% M-Tag vehicular traffic is best suited for the LOS criteria to be C and better. The achievement of LOS A was only possible if most of the traffic flowing on the motorway was M-tag equipped and no manual payments were done on the interchanges. Since the service times at the interchanges for manual passage is not acceptable. The other proposed scenario for the improvement was the increasing of lanes on M-1 to four and the toll plaza lanes to 16 with 4 M-tag lanes and 52.5% traffic on M-tag lanes is both hard to achieve and un-economical which is why it is not proposed.

With the increased in the number of vehicles moving on motorway 1 due to SWAT and HAZARA Expressway the functional characteristics of Motorway 1 that is the pavement has undergone deflections and a decrease in potential life of the pavement. The remaining life of the under-lying structure needs evaluation and the calculation of remaining life to be estimated.

The PaveXpress software was used for analyzing the pavement structure of the M-1. The results yielded the fact that the pavement can withstand the load repetitions of a standard axle for 7 million times before it fails due to fatigue, the rutting of the pavement required the passages to be in the range of quarter of a billion to be exact 643 million before rutting failure would occur. Because the rehabilitation of the pavement was done in 2020 and the pavement is as rehabilitated the next rehab of the pavement should occur in 2022 when the design ESALs and the accumulated ESALs are equal. For rehab in 2023 the pavement would have already failed in fatigue and the conditions will be far worsened.

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