ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

CE 454

Pavement Maintenance and Rehabilitation Term Project

Erman Toraman - 1737261

Melih Tatar - 1737204

Mert Demir - 1736388

Osman Taştekin - 1670371

Uğurcan Özdemir - 1737691

Table of Contents

INTRODUCTION

The road section between Migros and Çankaya University, 100.Yıl, Çankaya is selected to perform maintenance and rehabilitation study.

Figure 1 – Selected Road Section

The road is made of hot mixed asphalt and two-way road with four lanes. However, the right lanes of both directions are out of use due to parked cars along the whole road. Section's length is approximately 850 m. There is a refuge between two directions that contain greenery. The road suffers from several distresses and does not provide a comfortable driving. Moreover, it has some deformations related to infrastructure works. The region containing the road section, has continental climate and high temperature difference between day and night as well as between summer and winter.

Average temperature ranges								
season	day-time temperature range				night-time temperature range			
	Maximum		Minimum		Maximum		Minimum	
	°F	°C	°F	°C	°F	°C	°F	°C
summer	90	32	70	21	65	18	50	10
winter	45	7	10	−12	25	−4	−10	−23

Figure 2 - Continental Climate Statistics

The road is one of the main connections between 100.Yıl and Eskişehir Road. Moreover, it is widely used by METU students and personnel for entrance to and exit from the school. In Thursday and Sunday days, there is a traffic jam due to the local bazaar near the road. In addition to these, the traffic volume of the road will inevitably increase after the construction of "1074 Malazgirt Boulevard". Because of all above reasons, the rehabilitation and maintenance of the road is an important issue for both residents and drivers.

Figure 3 - Çankaya University - Migros Direction

CONDITION SURVEY ACTIVITIES

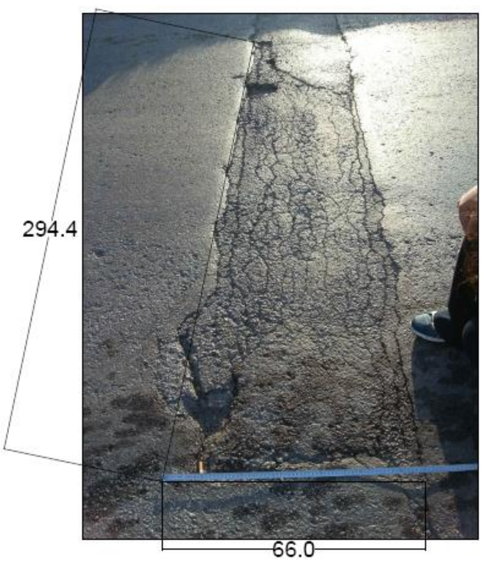
Distress Survey

For the condition survey, we went to the road section in the early time of day in order to be able to identify and measure the distresses and defects better. We measured the width of cracks when it is possible. In the observations we specified several distresses with different severity levels.

The type of the distresses can be determined by visual assessment; however, in order to assess severity of the distresses, different measurement types are determined for different distresses type by the Distress Identification Manuel.

According to Distress Identification Manuel,

- For fatigue cracking: measuring the area of the affected area
- For rutting: recording the maximum depth.
- For longitudinal cracking: measuring length in meters of longitudinal cracking within the wheel path or not wheel path.
- For transverse cracking: recording and measuring width of the transverse cracking.
- For patch deterioration: recording number of patches and measuring rutting length
- For potholes: recording number of potholes and measuring depth of the pothole.
- For edge cracking: measuring affected area of the cracking and observing loss of material



First of all, the picture is inserted at the AutoCAD2014 and then scale property is adjusted. In other words, the distance measured at the road is same as the dimension of the AutoCAD. After this procedure the area function of the AutoCAD is used in order to obtain affected area. Other dimensions can be determined like these procedure.

Identified distress types and possible causes are as follows:

Transverse Cracks: In the observation, we specified high severity (30 mm spacing) transverse cracks. This type of distress is generally temperature-related and when we take the region climate into consideration, high temperature difference is a possible cause. Therefore, we can also call these cracks as thermal cracks.

Figure 4 - Transverse Cracks

Rutting: In the observation, we specified some low severity (around 3 cm) rutting examples from place to place. Generally, this type of distress is load-related. However, the selected road section is rarely used by heavy vehicles like trucks and this changes our prediction to other possible causes like consolidation of sub-layers or subgrade, insufficient design thickness, lack of compaction during construction or weak asphalt mixtures. A detailed survey including tests may give us the correct cause but due to lack of equipment and the fact that it is not observed along the whole road, we assume that it is caused by local settlement of sub-layers or subgrade.

Figure 5 - Rutting

Edge Cracking: In the observation, we specified edge cracks along almost whole road section. The widths of cracks are changing from space to space. In the current circumstance, edge cracks are not disturbing the driving comfort since they are limited in a narrow area. However, if necessary rehabilitation is not applied, they may propagate through the mid-sections of lanes. There are several possible causes of edge cracks like lack of lateral support, settlement of underlying material, weak base or subgrade, frost heave and heavy traffic etc. However, when we consider both condition and usage of the road, poor drainage system is the most likely cause of those cracks.

Figure 6 - Edge Cracks

Fatigue Cracking: In the observation, we specified fatigue cracking in longitudinal direction with low to moderate severity. Possible and most likely causes are excessive loading, weak or thin surface or base and poor drainage. These cracks are generally observed along the parking lanes and sections where patching is applied.

Figure 7 – Low Severity Fatigue Cracks

Figure 8 – Moderate Severity Fatigue Cracks

Patch Deterioration / Utility Cuts: In the observation, we specified plenty of these kinds of distresses at moderate severity. The most likely cause is poor installation techniques like inadequate compaction, inferior or improper material usage. Since there are a number of high severity level these distresses, they are one of the major breakdowns along the road section that decreases the driving quality.

Figure 9 - Moderate Severity Patch Deterioration

Figure 10 –Distress Locations

There are 18 important distresses that can be perceived by windshield survey technic and there are certain properties that creates the distress which are type, severity and amount

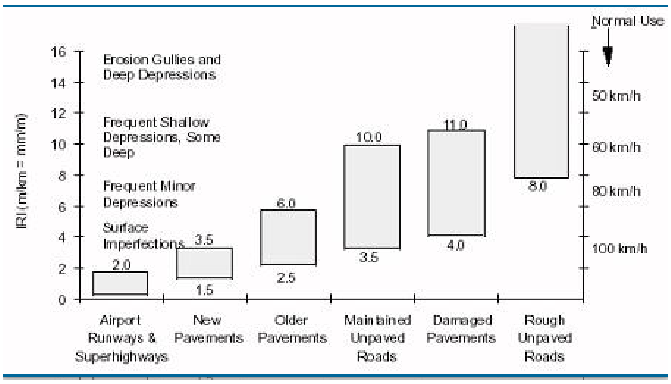
Distress No	Distress Type	Distress Amount	Distress Severity	Probable Reason(s)
1	Fatigue Cracking	9 m^2	High	Traffic (Dynamic) loading
2	Rutting	7 cm	NA	Foundation failure
3	Transverse Cracking	3 cm rutting	High	Temperature problems
4	Longitudinal Cracking	1 cm rutting	Moderate	Drainage problems Parking Car (Static) Loading
5	Patch Deterioration	1 cm rutting	Moderate	Drainage problems
6	Edge Cracking	8 cm rutting	High	Drainage (slope) problems
7	Transverse Cracking	3.5 cm rutting	High	Temperature Load related problems
8	Pothole	6.5 cm	High	Weather effect Load related problems
9	Fatigue	5.3 m^2	High	Traffic (Dynamic) loading
10	Edge Cracking	5 cm rutting	High	Bad installation (cover)
11	Fatigue Cracking	5.8 m^2	High	Traffic (Dynamic) loading
12	Fatigue Cracking	4.7 m^2	High	Traffic (Dynamic) loading
13	Patch Deterioration	1 m^2	Moderate	Bad installation of manhole
14	Patch Deterioration	1.3 m^2	Moderate	Bad installation of manhole
15	Fatigue Cracking	3.8 m^2	Moderate	Traffic (Dynamic) loading Weather effect
16	Longitudinal Cracking	2.3 cm rutting	High	Parking Car (Static) Loading Weather effect
17	Pothole	3.8 cm rutting	High	Load related problems Weather effect
18	Patch Deterioration	1.0 cm rutting	Moderate	Drainage problems

Roughness Survey

Pavement roughness is generally defined as an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle and so affects user. Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs.

Windshield survey which can be adequate for obtaining a qualitative assessment was conducted in order to assess pavement roughness. During the survey, in both directions, the entire project was driven at posted speed limits to get an overall idea for pavement roughness. During the survey, due to the surface stresses such as raveling, shoving, rutting, potholes and differential elevations such as swells, depressions can be perceived for evaluating the roughness of the pavement by the user perspective.

The AASHO Road Test (Highway Research Board, 1972[2]) developed a definition of pavement serviceability, the present serviceability rating (PSR), that is based on individual observation. PSR is defined as "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve" .International Roughness Index (IRI) is used to define a characteristic of the longitudinal profile of a traveled wheel track and constitutes a standardized roughness measurement.



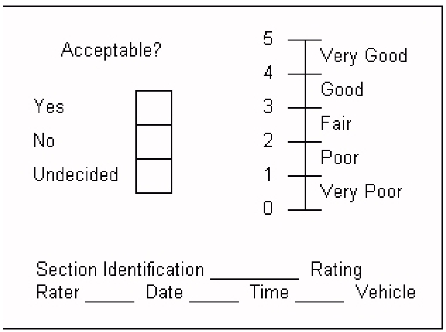


Figure 11 – IRI Roughness Scale **Figure 12 – Serviceability Rating Form**

There is a correlation between IRI and PSI which is: $PSI = 5\ x\ e^{(-0.0041\ x\ IRI)}$

Based on the user response, the following values of PSI are generally considered critical levels triggering a need for rehabilitation:

Friction Survey

Pavement surface friction is the force that resists the relative motion between a tire and pavement structure. The water on the pavement which is to reduce the direct contact between the pavement surface and the tire.

Surface friction is influenced by the three factors: micro texture, macro texture and surface drainage.

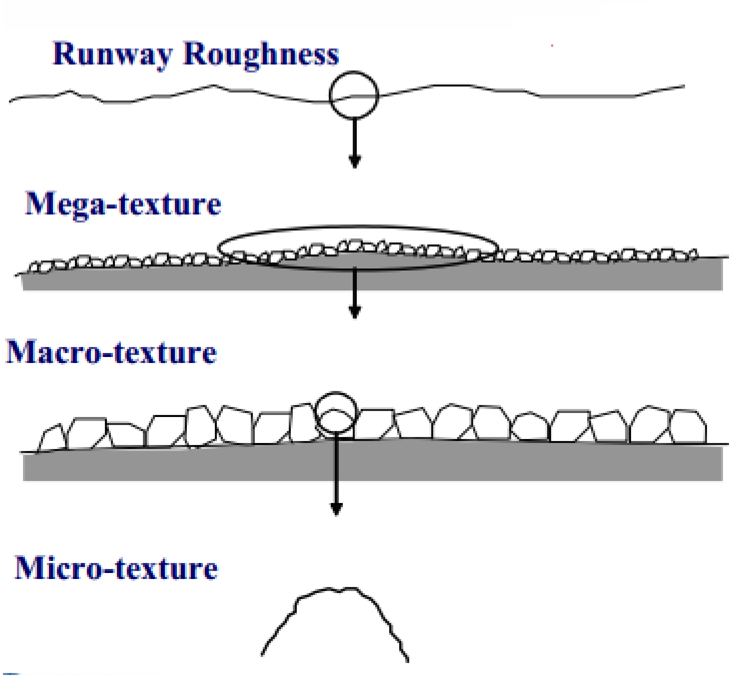


Figure 13 – Pavement Texture

Macro texture is the overall texture of the pavement which is intended to serve as escape channels for the surface water at the pavement - tire interface.

Along the way that is studied on it has a lot of deterioration and therefore, macro and micro texture is assumed to be corrupted.

Drainage Survey

The visual evaluation was conducted in order to evaluate drainage-related items and there are some questions to be answered for evaluating drainage condition of the pavement.

Questions	Condition – Y / N
Are the ditch lines clear of standing water?	Yes
Are the ditch lines and pavement edge free from weed growth?	No
After a rain, is there moisture standing in the joints or cracks?	Yes
Is there evidence of pumping?	No
Is there water standing at the outer edge of the shoulder?	Yes
Are joint sealants or crack sealants in good condition, and do they prevent water from entering the pavement?	No

Beyond these questions, if the slope of the pavement discussed, along the slope of the road (longitudinal direction) is 2.9% as average and 5% as maximum. These values is not too bad to direct water path. For transverse direction, it is observed that the water in the middle of the pavement is delivered to edges.

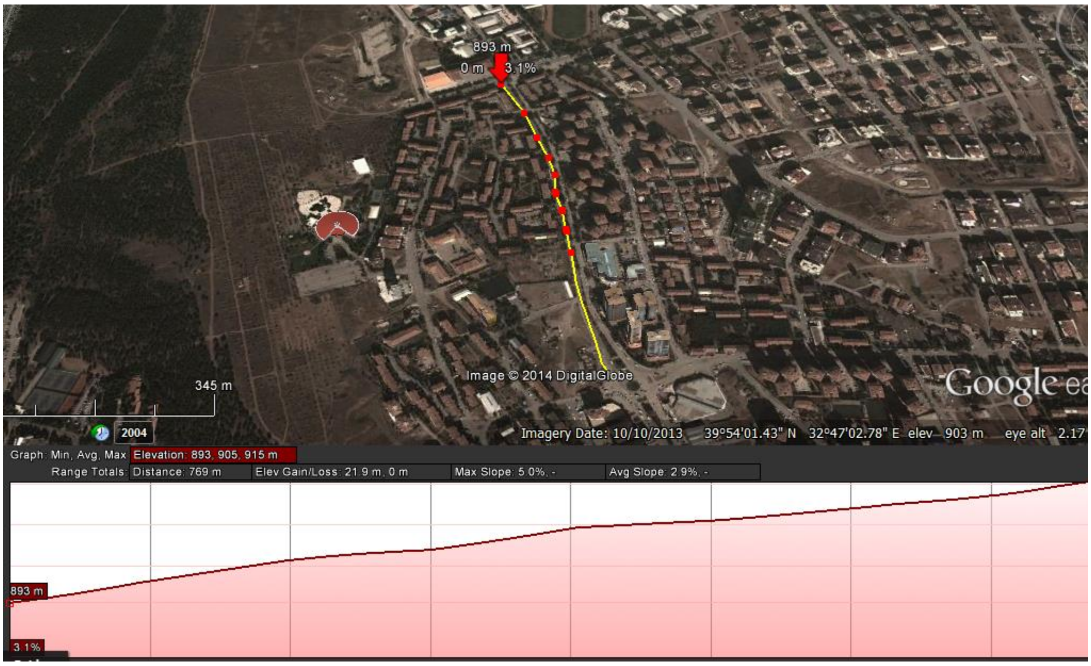


Figure 14 – Pavement Slope

Traffic Survey

Traffic data collection is conducted in order to estimate past traffic and forecast future traffic. Conventional in-situ technology is used for road traffic data collection. Specifically in more detailed, conventional in-situ technologies can be categorized into two: the intrusive and non-intrusive methods. The intrusive methods includes data recorder and a sensor placing on or in the road. The most important instruments can be described as: pneumatic road tubes, piezoelectric sensors, magnetic loops. They have been employed for many years. On the other hand, non-intrusive techniques are mainly based on remote observations. These techniques can be manual counts, passive and active infra-red, passive magnetic and microwave radar. Manual counts which is the most traditional method is used in order to estimate traffic.

Figure 15 – Traffic Count Place

- **Traffic Data Collection**
  - **Selection of Counting Sites**

A specific location for counting site must be determined on site. For this specific route, the location just before the intersection is determined and manual counting process is conducted at this point. The counting process is done at the two side of the road, face to face. This points are selected for:

- The road section is enough away from the junction and the prediction is that due to the end of the road location, this path is frequently used by the drivers.
- Road section is to meet safety requirements.
- Location is on a horizontal (flat) and geometrically straight road section.
- Section of the road does not have the interrupted traffic flow.

- **Vehicle Classification and Configuration**

Manual Count Classification:

This type of traffic flow count is divided by a visual assessment of the vehicle size and configuration of axles. Vehicles are categorized into the Federal Highway Administration's vehicle classification.

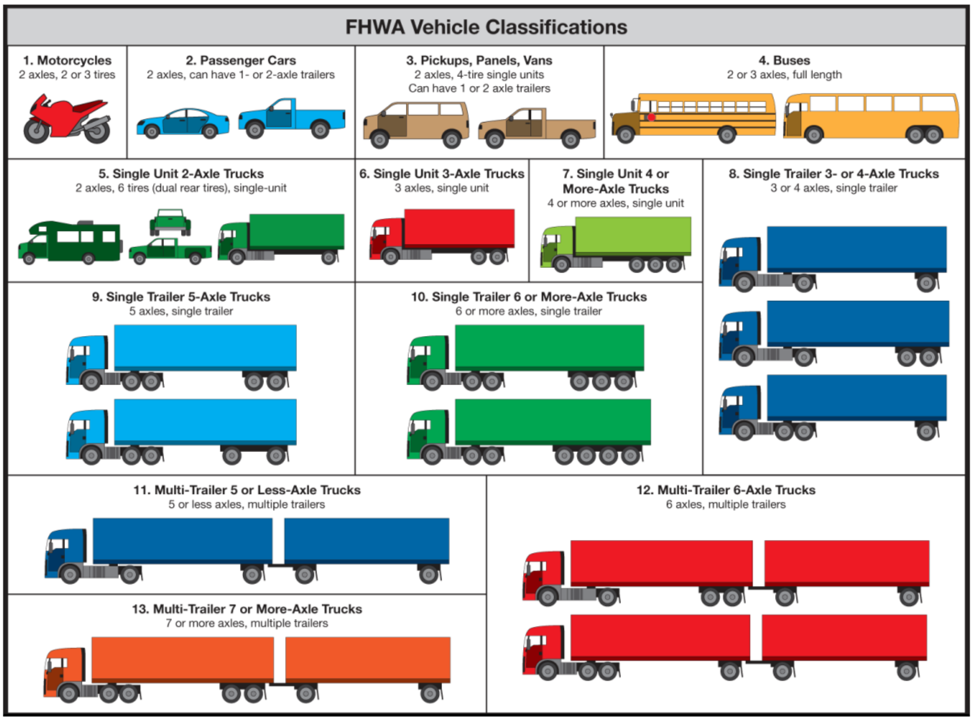


Figure 16 – FHWA Vehicle Classification

In Turkey, we assume that school shuttle buses, passenger minibuses refers to class 3 of FHWA vehicle classification. Passenger coaches are linked with class 4 and at last refuse collection vehicle with two single axle refers to class 5.

Figure 17: Class 2 Type

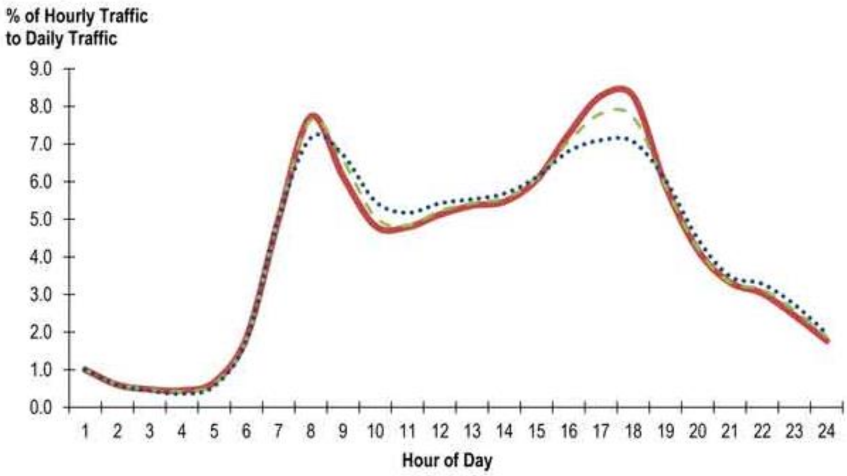
Figure 18: Class 3 Type

Figure 19: Class 5 Type

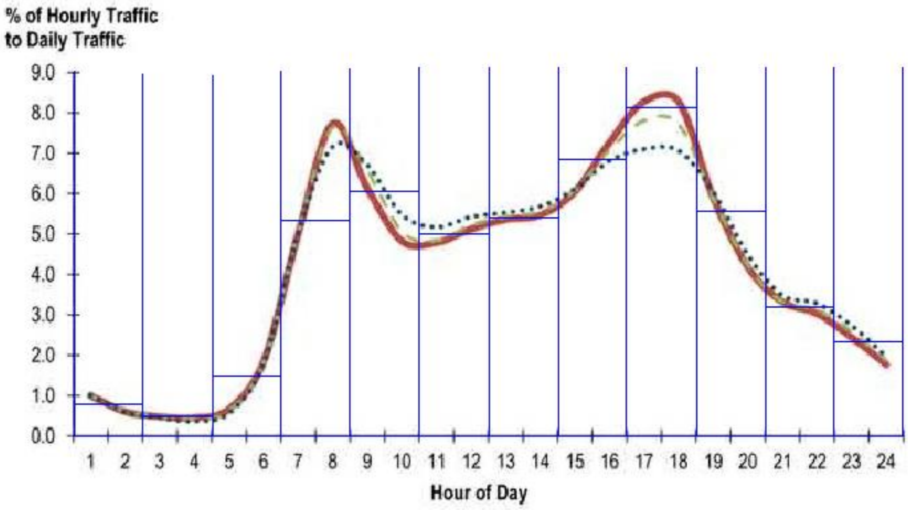
- **Counting Characteristics**
  - **Frequency of Traffic Counts**

It is very significant to consider that in order to predict traffic flow volumes that can be expected on the road during specific periods, awareness of traffic volumes changing considerably at each point in time is important. The observations are conducted with hourly pattern concern which means showing a number of distinguishable peaks. The traffic counting process lasts 4 hour at total,two session 8.00-10.00 a.m and 16.00 -18.00 p.m.

By taking the % of Hourly Traffic to Daily Traffic vs. Hour of Day table as a reference from Federal Highway Association, it can be calculated average daily traffic.



This graph can be used in order to estimate average daily traffic by giving coefficients dividing into two hour intervals like as below:



Note that the traffic data between 8.00 - 10.00 a.m and 16.00-18.00 p.m and coefficients of hourly traffic to daily traffic is corresponding to each other.

- **Interpretation of Traffic Counting**
  - **Direction: Çankaya University to 100. Year Bazaar**

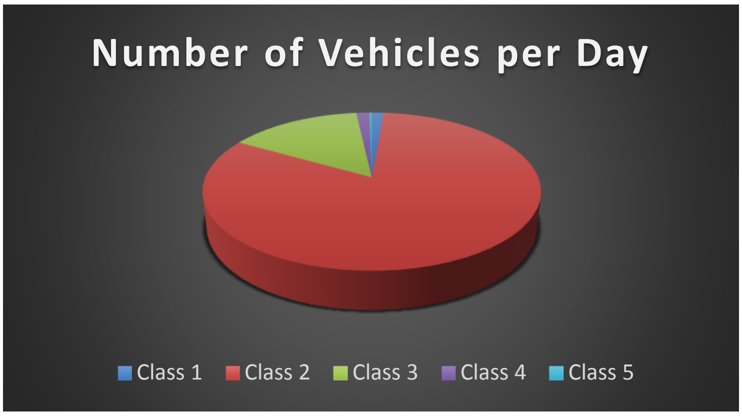
If the numbers of the vehicles is adjusted with the coefficients from the hourly traffic to daily traffic vs. hour of day graph as shown below, the table is obtained.

Vehicle Class	8.00 – 10.00 A.M	16.00 – 18.00 P.M
Class 1		26
Class 2	826	964
Class 3	154	174
Class 4	20	22
Class 5	2	4
Sum	1016	1206

*Note that there is not any different vehicle class passing during the observation

A.M	00.00-2.00	2.00-4.00	4.00-6.00	6.00 - 8.00	8.00 -10.00	10.00 - 12.00
Class 1	0	0	0	0	0	0
Class 2	106	65	198	564	826	688
Class 3	20	12	37	105	154	128
Class 4	0	0	0	10	20	17
Class 5	0	0	0	1	2	2
Sum	130	80	244	694	1016	847
P.M	**12.00-14.00**	**14.00-16.00**	**16.00-18.00**	**18.00-20.00**	**20.00-22.00**	**22.00-24.00**
Class 1	17	22	26	18	14	10
Class 2	636	810	964	657	501	363
Class 3	115	146	174	119	90	66
Class 4	15	15	22	13	3	0
Class 5	3	3	4	3	2	2
Sum	796	1013	1206	822	627	454

Sum of 24 Hour Vehicle Numbers	
Class 1	106
Class 2	6379
Class 3	1166
Class 4	115
Class 5	22
Sum	7788



- **Direction: 100 Year Bazaar to Çankaya University**

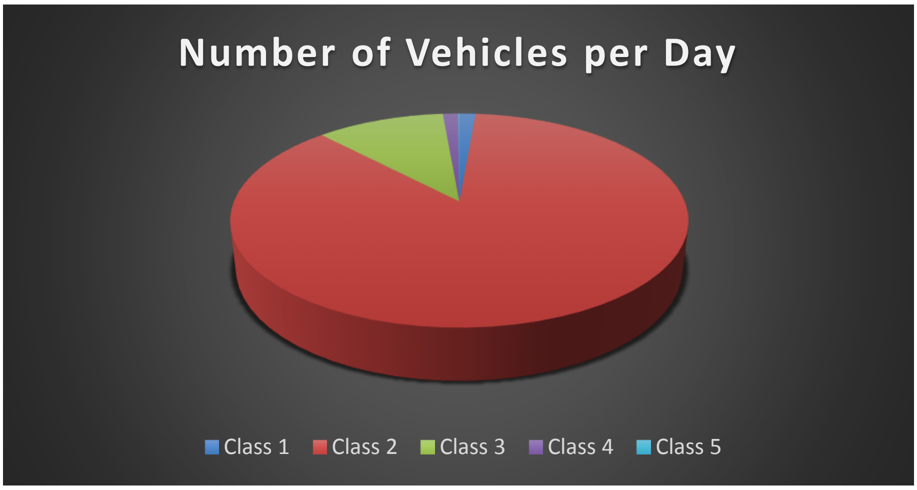
Vehicle Class	8.00 – 10.00 A.M	16.00 – 18.00 P.M
Class 1		30
Class 2	918	1224
Class 3	164	116
Class 4	18	22
Class 5		2
Sum	1108	1410

If the numbers of the vehicles is adjusted with the coefficients from the hourly traffic to daily traffic vs. hour of day graph as shown below, the table is obtained.

*Note that there is not any different vehicle class passing during the observation

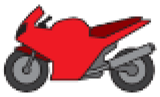
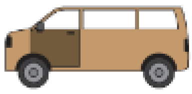
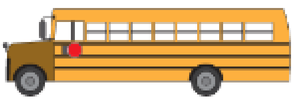
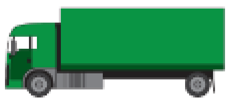
A.M	00.00-2.00	2.00-4.00	4.00-6.00	6.00 - 8.00	8.00 -10.00	10.00 - 12.00
Class 1						
Class 2	118	72	220	627	918	765
Class 3	21	13	39	112	164	137
Class 4	0	0	0	10	18	18
Class 5	0	0	0	0		0
Sum	142	87	266	757	1108	923
P.M	**12.00-14.00**	**14.00-16.00**	**16.00-18.00**	**18.00-20.00**	**20.00-22.00**	**22.00-24.00**
Class 1	20	25	30	20	16	11
Class 2	808	1028	1224	834	636	461
Class 3	77	97	116	79	60	44
Class 4	16	15	22	13	3	0
Class 5	1	2	2	1	1	1
Sum	931	1184	1410	961	733	531

Sum of 24 Hour Vehicle Numbers	
Class 1	122
Class 2	7712
Class 3	959
Class 4	115
Class 5	8
Sum	8916



Average Daily Traffic = 8916 + 7788 = **16704** vehicles per day

- **Calculation of Equivalent Single Axle Load**

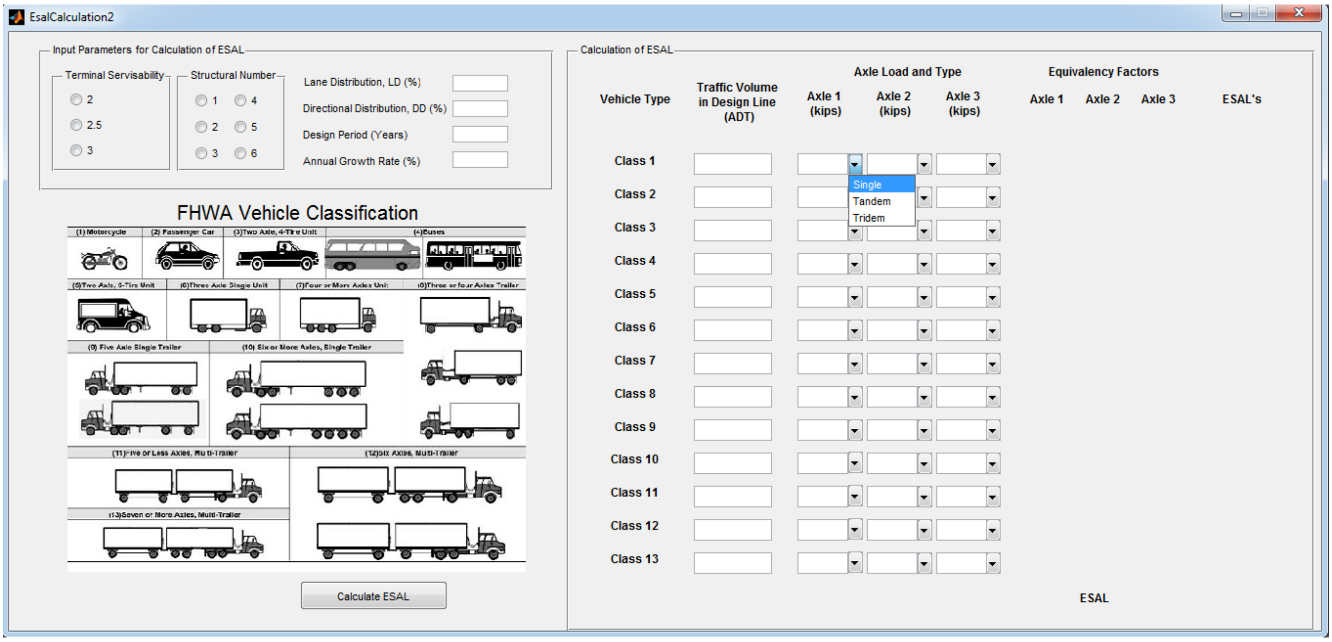
Vehicle Type	Gross Weight(kips)	Axle Configuration	Vehicle Count	LEF of Axles	Truck Factor of Vehicles	Total ESAL of Vehicles (ESAL)
Motorcycles (1) 	0.4	-	228	-	-	-
Passenger Cars (2) 	4	Single Single	14091	.0002 .0002	.0004	5.6
Panels, Vans (3) 	7	Single Single	2125	.00155 .00155	.0031	6.59
Buses (4) 	36	Single Single	230	1 1	2	460
2 Axle Trucks (5) 	18	Single Single	30	0.061 0.061	0.122	3.66
TOTAL			**16704**			**475.85**

Design Period (Years)	15
Directional Distribution (7788/16704)	0.47
Lane Distribution	0.7 (assumed)
Annual traffic growth rate	0.04 (assumed)
Growth Rate = $((1+0.04)^{20}-1)/0.04$	20.02

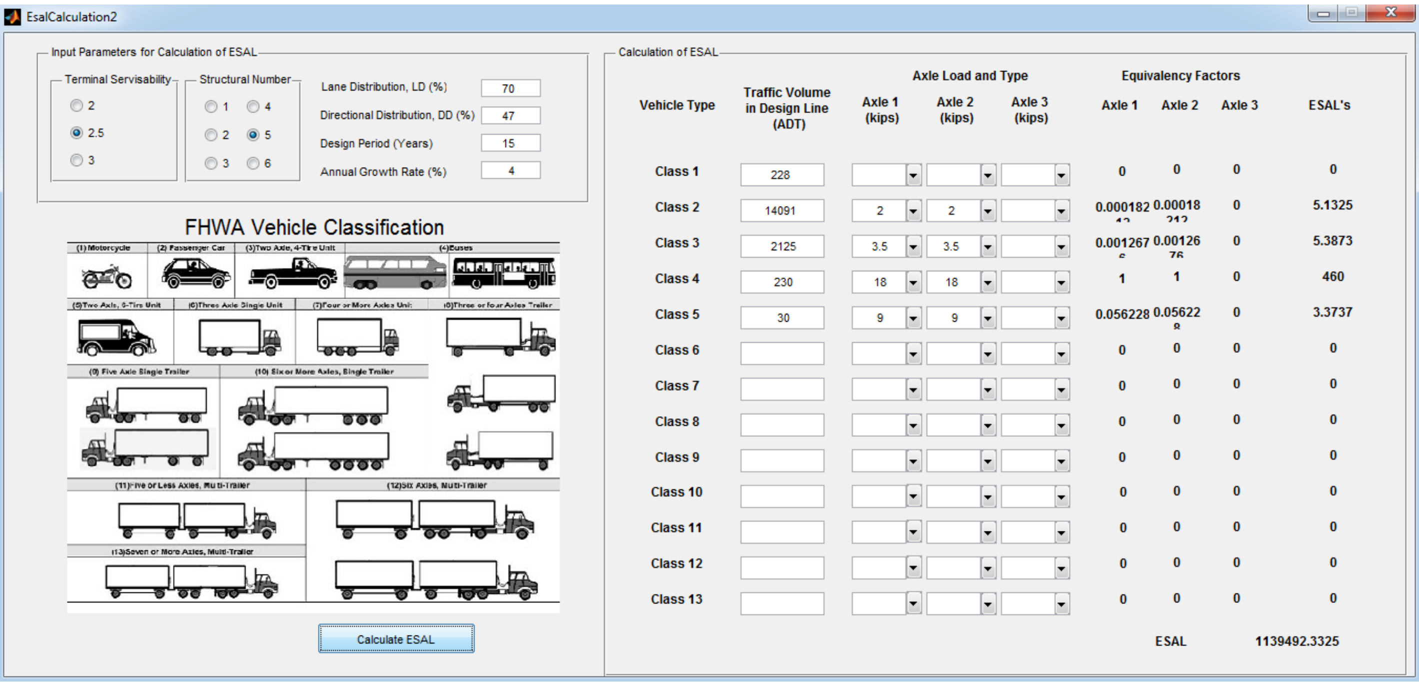
ESAL = $W_{80\ kN}$ x DD x LD x 365 x G

ESAL = 475.85x 0.47 x 0.7 x 365 x 20.02 = **1144196**

There is also Matlab Graphical User Interface is prepared for calculating Equivalent Single Axle Load.



When our traffic data is applied to the Esal Calculation program:



The slight difference occurs between hand calculation and program due to the fact that program uses AASHTO formulas in order to calculate load equivalency factors. However, hand calculation is conducted by using load equivalency factor tables.

$$LEF_{L1} = \left[\frac{(L1 + L2)^{4.79}}{(18 + 1)^{4.79}} \right] * \left[\frac{10^{G_t/\beta_{18}}}{(10^{G_t/\beta_{L1}}) * L2^{4.331}} \right]$$

$$G_t = \log_{10}\left(\frac{4.2 - p_t}{4.2 - 1.5} \right)$$

$$\beta = 0.40 + \frac{0.081 * (L1 + L2)^{3.23}}{(SN + 1)^{5.19} * L2^{3.23}}$$

These formulas are used during the calculation of load equivalency factors.

L1 = axle load

L2 = axle type (single = 1, tandem = 2, tridem = 3)

P_t = terminal servisability

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the potential loss taken to a point where pt=1.5.

β = a function of design and load variables that influence the shape of the pversus-W serviceability curve.

SELECTION of FEASIBLE ALTERNATIVES

Suggested Rehabilitations for Individual Distress Types:

Edge Cracking

Along the almost whole road edge crackings are observed. In order to rehabilitate the distress, we should first identify possible cause of problem. Edge cracking has different causes such as, lack of adequate drainage system, lack of lateral support, frost heave, weak base or subgrade soil, heavy traffic or vegetation along the edge and settlement of underlying soil. In our road section, reason is most likely combination of lack of adequate drainage and frost heave. Due to lack of drainage system, water, on the surface accumulates at the edges and it damages surface of road. In the winter time with the low temperature accumulated water freezes in cracks and it enlarges cracks in all directions.

Generally, improving drainage, removing vegetation close to edge, filling cracks with asphalt emulsion slurry or emulsified asphalt, or crack sealing. In our case, vegetation does not cause a problem. Thus removing vegetation is not an option. Crack sealing or filling cracks with asphalt emulsion slurry is not a valid rehabilitation technique to stop the distress mechanism. Final option is to improve the drainage system. Cause of distress is accumulation of water, thus improving the drainage system will prevent water accumulation at edges and stop distress mechanism.

Alternatives:

1. Improving Drainage System
2. Filling cracks with asphalt emulsion slurry
3. Crack sealing

As a result, we suggest improving drainage system as a rehabilitation technique.

Fatigue cracking

In our road section, we generally have high severity fatigue cracking. Before deciding rehabilitation technique it is appropriate to identify stress mechanism and its causes. Due to repeated traffic loading, HMA surface cracks from tension region. Possible causes of this problem are;

- Loss of base, subbase or subgrade support
- Stripping on the bottom of the HMA layer
- Increase in loading
- Inadequate structural design
- Poor construction

Possible rehabilitation alternatives are patching and HMA overlay over entire pavement surface.

In our road section, fatigue cracks are high severity, however they are not widespread to perform HMA overlay over entire pavement surface. Instead, it is logical to dig out crack section then replace the area of poor subgrade and improve drainage of that area and finally patch over the repaired subgrade.

Alternatives:

1. HMA overlay over entire road
2. Partial improvement and patching

As a result, we suggest partial improvement of subgrade of crack region and patching of improved subgrade.

Patch Deterioration

In our road section, we specied plenty of patch deterioration. There are several possible causes of this distress type. Poor intallation techniques like inadequate compaction, inferior or improper material usage and failure of the surrounding or underlying material are alternatives. In our case, the most probable cause is poor installation techniques. The reason for this is poor foundation or sub-base related distresses were not observed widely along the road. In the literature, there is only one suggested rehabilitation technique for this type of distress and it is replacement of patch with deep or full-depth patch.

Alternatives:

1. Replacement of patch with deeper patch

Transverse Cracking

Transverse cracks that are predominately perpendicular to pavement centerline and are not located over Portland cement concrete joints. High severity transverse cracking has any crack with a mean width greater than 19 mm and also our section has high severity transverse cracking.(3 cm or 30 mm) For flexible pavements with an HMA surface, transverse cracking is the primary distress concern related to temperature. In general, the best maintenance treatment for a transverse crack is crack sealing. For higher severity cracks, patching may be required.

Possible Causes:

- Shrinkage of the HMA surface due to low temperatures or asphalt binder hardening.
- Reflective crack caused by cracks beneath the surface HMA layer
- Top-down cracking
- Poorly constructed paving joint crack
- Cracks in an underlying layer that reflect up through the pavement

Alternatives:

1. Remove and replace the cracked pavement layer with an overlay.
2. Crack sealing
3. Seal Coat
4. Unusual soil properties minimize reflection cracking
5. Asphalt-rubber membrane with thin overlay
6. Heater-scarification/milling with thin overlay

Pothole

Small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course. They generally have sharp edges and vertical sides near the top of the hole. Potholes are most likely to occur on roads with thin HMA surfaces (25 to 50 mm) and seldom occur on roads with 100 mm or deeper HMA surfaces. In our section, pothole distress severity is high (6.5 cm or 65 mm). Pothole causes some problems which are roughness (serious vehicular damage can result from driving across potholes at higher speeds) and moisture infiltration.

Possible Causes:

- Continued deterioration of another type of distress, such as thawing of a frozen sub-grade, cracking, raveling, or a failed patch after pieces of the original pavement surface have been dislodged
- Poor surface mixtures
- Weak spots in the base or sub-grade
- Severity of the surrounding distress and traffic action accelerate potholes
- Generally, potholes are the end result of fatigue cracking.
- As alligator cracking becomes severe, the interconnected cracks create small chunks of pavement, which can be dislodged as vehicles drive over them.
- The remaining hole after the pavement chunk is dislodged is called a pothole.

Rehabilitation Alternatives:

1. Partial, full-depth or injection patching

Rutting

Rutting can be defined as surface depression in the wheelpath. Pavement uplift (shearing) may occur along the sides of the rut. Ruts are particularly evident after a rain when they are filled with water.

There are four types of rutting:

- Mechanical deformation or subgrade displacement of the asphalt pavement.
- Plastic deformation of the asphalt mixtures near the pavement surface.
- Consolidation or the continued compaction under the action of traffic.
- Surface wear, the actual wearing away of surface particles by traffic.

Rutting in bituminous pavement can occur due to variety of causes. Some of the common causes for rutting could be as given below:

- Inappropriate mix design
  - Incorrect grading
  - Excessive binder content
  - Excessive fines like sand or clay
  - Round aggregates with smooth texture
- Effects of hot weather temperature on pavement
- Effects of heavy traffic loads
- Inadequate initial field compaction and density
- Effects of slow speed (frequent stop and start or stationary condition)
- Effects of secondary compaction.

Rehabilitation Alternatives:

1. Cold milling including profile requirements with or without overlay
2. Heater scarification or milling with overlay
3. Replacement

Overlay Design

Effective Thickness Procedure

The effective thickness for overlay design is mainly based on the deterioration of the pavement structure. After the construction of pavement, due to the traffic loading or soil condition, pavement structure undergoes some deterioration and it needs to be rehabilitated. This method asserts that pavement has already spent some life time, and pavement is getting thicker during all time dynamic traffic loading and therefore, effective thickness becomes more important. To calculate the effective thickness of an existing pavement, some parameters which are composition, thickness and condition of the each layer, equivalent single axle load have to be known.

- **Subgrade Strength Analysis**

In order to calculate effective thickness, the properties resistance of the subgrade such as resilient modulus, CBR and must be known. Normally, these parameters can be obtained from the field tests, from NDT, or laboratory tests. However, these tests did not applied. Instead of that, subgrade soils into three general classes by overlay design criteria is used. The class of the sub grade is assumed to be between poor and medium soils. Therefore, parameters are adjusted by linearly interpolation between poor and medium soil:

Resilient Modulus (M_R): 55 MPa

California Bearing Ratio (CBR): 5

Resistance, R-Value: 13

- **Traffic Analysis**

Equivalent Single Axle Load (18 kip = 80 kN) is obtained as 1144196

- **Estimating Effective Thickness From Pavement Condition**

In order to find effective thickness of each layer, actual thickness of each layer and appropriate conversion factor are necessary parameters.

For conversion factor the pavement condition is appropriate with respect to surface for number 6 classification of material. In other words, the pavement structure indicates that conversion factor that being used at the calculation further is range between 0.5 – 0.7. In order to stay at the safe side, the conversion factor is taken as 0.5 for the surface. In addition, the conversion factor is taken as 0.5 (class 6) and 0.2 for base and sub base respectively.

The thickness of each layer is taken as 25, 15 and 10 cm for sub base, base and surface layers respectively.

T_e (HMA Surface) = 10 x 0.5 = 5 cm

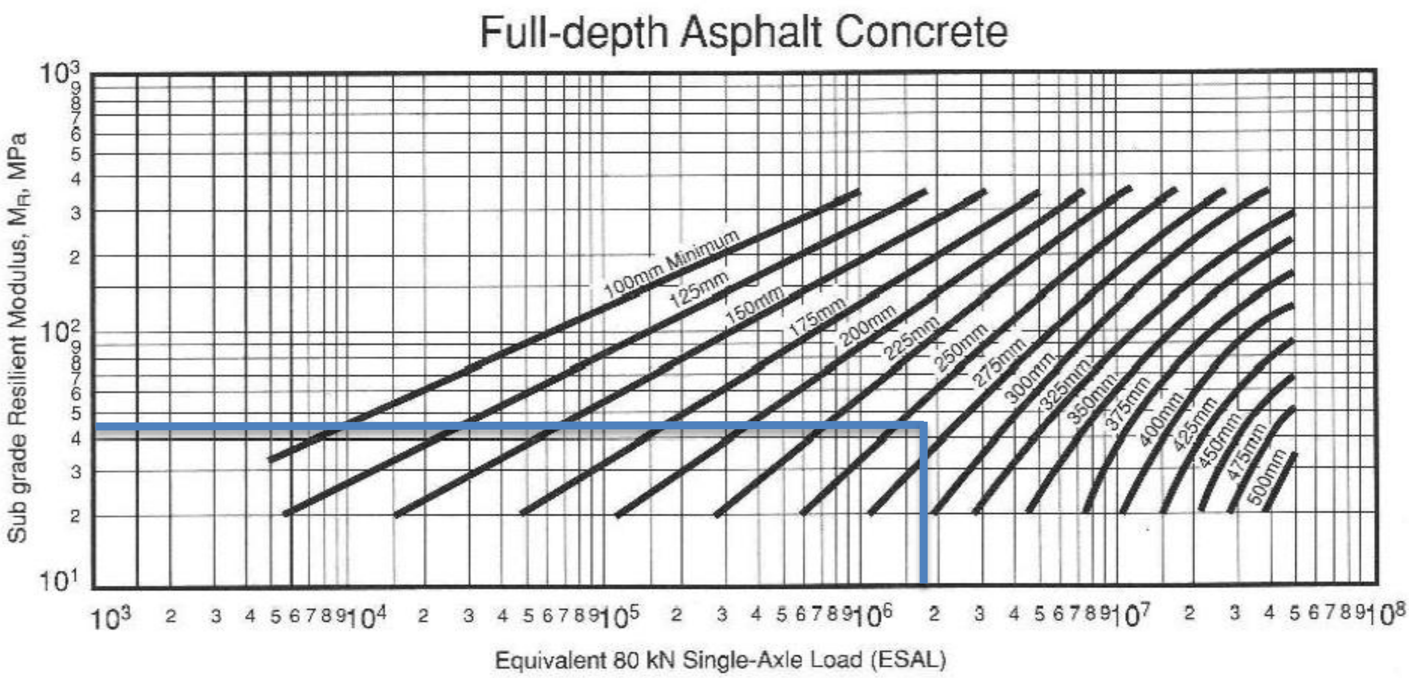
T_e (base) = 15 x 0.5 = 7.5 cm; T_e (sub base) = 25 x 0.2 = 5 cm

T_e (all layers) = 5 + 7.5 + 5 = 17.5 cm

- **Calculation of Overlay Thicknesses**

The thickness of the overlay is calculated: $T_o = T_n - T_e$ where

T_o: Thickness of the overlay; **T_n:** Thickness of the new pavement obtaining from the ESAL and M_R graph; **T_e:** Effective thickness of the existing structure



Subgrade M_R = 55 MPa; **ESAL** = 1144196; **T_e (all layers)** = 17.5 cm

From the table, T_n = 26 cm

T_o = 26 – 17.5 = 8.5 cm for overlay thickness

Alternative 1 (2 years)			
	unit price (TL)	**Amount**	**Cost (TL)**
Crack Sealing (m^2)	10,35	9	93,15
Level Up Overlay (m^2)	8,15	5	40,75
Crack Sealing (m^2)	10,35	0,58	6,003
Crack Sealing (m^2)	10,35	0,03	0,3105
Replacement (m^3)	325	0,88	286
Crack Sealing (m^2)	10,35	0,24	2,484
Crack Sealing (m^2)	10,35	0,3	3,105
Partial Patching (m^3)	180	0,065	11,7
Crack Sealing (m^2)	10,35	9,5	98,325
Crack Sealing (m^2)	10,35	0,1	1,035
Crack Sealing (m^2)	10,35	8,8	91,08
Crack Sealing (m^2)	10,35	7,5	77,625
Replacement (m^3)	325	0,127	41,275
Replacement (m^3)	325	0,127	41,275
Crack Sealing (m^2)	10,35	4	41,4
Crack Sealing (m^2)	10,35	0,2	2,07
Partial Patching (m^3)	180	0,05	9
Replacement (m^3)	325	0,03	9,75
Total			**856,338**

Alternative 2 (4 years)			
	unit price (TL)	amount	cost
Full Depth Repair (m^3)	325	0,9	292,5
Cold Milling w/o Overlay (m^3)	43,75	0,93	40,6875
Seal Coat (m^2)	0,69	0,58	0,4002
Seal Coat (m^2)	0,69	0,03	0,0207
Replacement (m^3)	325	0,88	286
Filling cracks with asphalt emulsion slurry (m^2)	1,1	0,24	0,264
Seal Coat (m^2)	0,69	0,3	0,207
Full Depth Patching (m^3)	325	0,065	21,125
Full Depth Repair (m^3)	325	0,95	308,75
Filling cracks with asphalt emulsion slurry (m^2)	1,1	0,1	0,11
Full Depth Repair (m^3)	325	0,88	286
Full Depth Repair (m^3)	325	0,75	243,75
Replacement (m^3)	325	0,127	41,275
Replacement (m^3)	325	0,127	41,275
Full Depth Repair (m^3)	325	0,4	130
Seal Coat (m^2)	0,69	0,2	0,138
Full Depth Patching (m^3)	325	0,15	48,75
Replacement (m^3)	325	0,03	9,75
Total			**1751,002**

Alternative 3 (8 years)			
	unit price (TL)	amount	cost
HMA Overlay (m^2)	37,63	9	338,67
Cold Milling w/o Overlay (m^3)	43,75	0,93	40,6875
HMA Overlay (m^2)	37,63	0,58	21,8254
HMA Overlay (m^2)	37,63	0,03	1,1289
HMA Overlay (m^2)	37,63	14,65	551,2795
HMA Overlay (m^2)	37,63	0,24	9,0312
HMA Overlay (m^2)	37,63	0,3	11,289
HMA Overlay (m^2)	37,63	1	37,63
HMA Overlay (m^2)	37,63	9,5	357,485
HMA Overlay (m^2)	37,63	0,1	3,763
HMA Overlay (m^2)	37,63	8,8	331,144
HMA Overlay (m^2)	37,63	7,5	282,225
HMA Overlay (m^2)	37,63	4,53	170,4639
HMA Overlay (m^2)	37,63	4,53	170,4639
HMA Overlay (m^2)	37,63	4	150,52
HMA Overlay (m^2)	37,63	0,2	7,526
HMA Overlay (m^2)	37,63	1	37,63
HMA Overlay (m^2)	37,63	4	150,52
Total			**2673,282**

All unit prices are found after a detailed search on internet. Moreover, all unit prices represent only row material cost. Labor, transportation cost and salvage values do not represented in unit prices above.

Life Cycle Cost Analysis

Analysis Period = 15 years (the life span over which this project is evaluated, is 15 years)

Average Annual Discount Rate i = 8 percent (assumed to be the difference between the market interest rate and construction inflation rate).

Alternative 1 Cost Analysis					
i = 0.08					
Definition	**Cash Flow Amount (TL)**	**n**	**1/(1+i)^n**	**PW of Cash Flow**	
Maintenance 1	856,4	0	1	856,40	
Maintenance 2	856,4	2	0,8573	734,22	
Maintenance 3	856,4	4	0,7350	629,48	
Maintenance 4	856,4	6	0,6302	539,68	
Maintenance 5	856,4	8	0,5403	462,69	
Maintenance 6	856,4	10	0,4632	396,68	
Maintenance 7	856,4	12	0,3971	340,09	
Maintenance 8	856,4	14	0,3405	291,57	
			PW	4250,81	TL
			EUAC	496,62	TL/year

Alternative 2 Cost Analysis					
i = 0.08					
Definition	**Cash Flow Amount (TL)**	**n**	**1/(1+i)^n**	**PW of Cash Flow**	
Maintenance 1	1751	0	1	1751,00	
Maintenance 2	1751	4	0,7350	1287,04	
Maintenance 3	1751	8	0,5403	946,01	
Maintenance 4	1751	12	0,3971	695,35	
			PW	4679,39	TL
			EUAC	546,69	TL/year

Alternative 3 Cost Analysis					
i = 0.08					
Definition	Cash Flow Amount (TL)	n	1/(1+i)^n	PW of Cash Flow	
Maintenance 1	2673,3	0	1	2673,30	
Maintenance 2	2673,3	8	0,5403	1444,30	
			PW	4117,60	TL
			EUAC	481,06	TL/year

After life cycle cost analysis, cheapest alternative is alternative 3. EUAC of alternative 3 is 481.06 TL per year. Thus we choose third of feasible alternatives which is HMA overlay with a thickness of 8.5 cm.

DISCUSSION

In the project, after all calculations we selected alternative 3 which have the least equivalent uniform annual cost.

Here, there are two things that we recommend for our selected alternative. Firstly, although we went to the road in the early time of day to have less traffic, it was difficult to measure the exact length or area of distresses. Therefore, we used approximate values. Secondly, we had difficulty to find the exact unit prices of each rehabilitation technique. We used again approximate unit prices that we were able to find after a detailed internet search.

By taking these small problems into consideration, after more sensitive measurements, a more accurate life cycle cost analysis could be made. However, the difference will not be big considerably.

CONCLUSION

In the project, first we selected an approximately 1 km road section (between Çankaya University and 100 Year bazaar) and calculated the traffic volume within specified hours and calculated total traffic volume accordingly. Then, we specified each distress along the way and measured their approximate areas. After that, we listed 3 alternative rehabilitation techniques to each type according to life span and cost and by using the numbered alternatives, we specified 3 different rehabilitation suggestion. Finally, we performed life-cycle cost analysis and selected alternative three.

REFERENCES

- *http://www.asphaltinstitute.org/public/engineering/maintenance_rehab/asphalt-pavement-distress-summary.dot*
- *http://www.pavementinteractive.org/*
- *http://www.asphaltinstitute.org/public/engineering/maintenance_rehab/asphalt-pavement-distress-summary.dot*
- *http://www.pavementinteractive.org/article/roughness/#refmark-2*
- *http://ops.fhwa.dot.gov/publications/fhwahop13015/sec6.htm*
- *Lecture Handouts*