Maintenance and Rehabilitation

TURKEY PAVEMENT MANAGEMENT SYSTEM SOFTWARE DEVELOPMENT WORKS

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Abstract

Pavement Management Systems (PMS) is a system that detects optimum solutions after determination current condition of the road pavements, by the forecasting future conditions of the pavement, determination Maintenance and Rehabilitation method alternatives and choosing the best alternatives through the calculation of the Benefit/Cost ratios. With this system, guidance is provided to decision makers by the way coordination of the all activities aimed that operation of road pavements with spending budget which belongs to the community, with the most affordable cost, as safe and economical. Pavement Management System development works has been started since 2009 with the countrywide road pavement performance tests. Hot Mix Asphalt roads in the road network all over the country have tested and analyzed with the Profilometer, Deflectometer and Pavement Friction Tester which have been provided to the Turkish Directorate of Highways. Within the scope of these analyses, required maintenance and rehabilitation alternatives and benefit/cost ratios have been determined. In accordance with obtained results and data, development of a cost effective Pavement Management System and software have been decided with considering the national conditions. This system has been developed based on world bank HDM4 models according to Turkish local conditions. In this system which have been designed as a web based over the all highways intranet network, inventory database, performance test analyses, maintenance and rehabilitation determining, cost/benefit analyses, network level priority analyses modules have been created. In this study, importance and properties of “Turkey Pavement Management System” that have been developed since 2009 until today, are presented with sample PMS analysis and evaluations of different road sections in Turkey in project and network level details.

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1. INTRODUCTION

Highway is the most common transportation network in our country. The most important factor providing is the pavement. The developments in recent years in our country increased the need of new highways and to meet that need highway construction has been scaled up. The current highway network as of 2019 in Turkey is total 67333 km, of which 39333 km section is surface treatment and 24082 km section is hot bituminous mixture. Consideration has been given to hot bituminous mixture road construction during recent years because of the enhanced importance of safety in traveling, in driving comfort and decrease in vehicle operating costs. As a result of increase in road construction during recent years, Turkey is in the first place in Europe considering the asphalt production amount. Even, General Directorate of Highways' (GDH) 2023 goal is to continue the road construction all over the country hence the production of hot bituminous mixture is going to increase more and more in coming years. [1]

Considering the existing highway length and area of the country, setting up the Pavement Management System (PMS) for highway network on regional and country basis is a vital need to define, plan and realize maintenance and rehabilitation needs at the right time, right place with optimum use of the budget. In order to use allocated resources more feasible, all data which picked up from all highways on the network is being updated and analysed in regular intervals combining with periodical investigations easily and objectively by use of PMS.

Based on this fact, General Directorate of Highways (GDH) decided to start PMS Development Programme in 2009 to manage Hot Mix Asphalt Highways which are getting a big amount of share from the budget and continues to progress decisively at the present time. As a general principle, PMS need analysis and considerations that are specific for each country. In this context, in order to constitute a data base for PMS, IRI (International Roughness Index), Rutting, Pavement Distress and Macrotexture measurements have been realized for hot mix asphalt highways in every part of Turkey. The data obtained have been utilized, analysed and solutions have been defined for required sections of the existing road network. Based on the results in hand within the GDH's PMS the optimum solutions are being provided by means of cost-benefit analysis.

In addition, by the help of developed PMS, maintenance and rehabilitation priorities and periods are being determined by evaluation of achieved results from the analysis for related sections. At this stage, investments are being planned through the future periods are going to be determined and it is going to be used as parameter in budget distribution by adding the progress in distresses on the road.

2. PAVEMENT MANAGEMENT SYSTEM (PMS)

In the past years, maintenance and rehabilitations have been realised without using a PMS or similar approach. Maintenance and rehabilitation methods and priorities have been determined by priority calculations based on pavement engineers' experiences. Optimum management have been tried to be achieved by comparing the needs and priorities of the subject highway sections with other parts.

But in this age, more systematic maintenance and rehabilitation determination and decision approach have to be used due to increase in highway kilometres together with the increase in traffic, safety and user needs, development of computer technologies and limited budgets. The need is not the maintenance and rehabilitation of a section of a road; but the network level management is required.

PMS is a computer-aided management system that provides the highest earnings available to a limited budget, ensures an objective and ~~a~~ systematic approach to find the most convenient decision, to develop the best strategies and to create the programs of optimum maintenance and rehabilitation priority for helping pavements to serve at a certain level of service and to keep its current position. [2]

Briefly, PMS provides highway network execution with minimum cost has been realized to correct road, at correct time, and for correct distress. [5]

Setting of a PMS has 5 stages as follows:

1. Pavement Network Identification,
2. Pavement Situation Measurements,
3. Pavement Situation Modelling,
4. Network Level Management, and
5. Project Level Management.

At the beginning, an analysis program should have been developed to collect road performance data regularly and initially; then database establishment, determination of maintenance and rehabilitation strategies for highway maintenance, and determination of the project suggestions which has top optimum advantages have to be set up. [3]

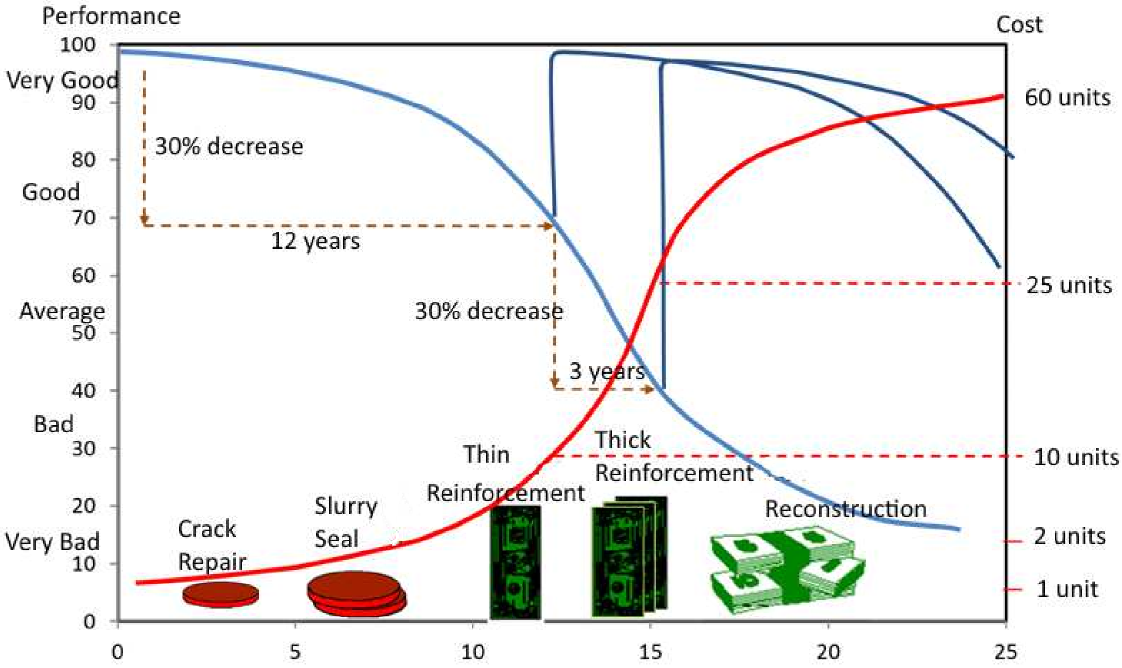


Figure 1: Pavement Performance Versus Maintenance and Rehabilitation Cost

Deciding priority of the sections of a highway regarding maintenance and rehabilitation on highway, considering when and what kind of works should be done and execution of lifetime-cost analyses all together defined as “Network Level Pavement Management”. Determination of the detailed maintenance and rehabilitation on independent parts after Network Level is named as “Project Level Pavement Management”. [3]

3. PAVEMENT MANAGEMENT SYSTEM IN TURKEY

The starting point to develop a PMS for Turkey was to inspect similar systems used in other countries that can be considered as examples for Turkey. For this purpose, many systems actually used in various parts of the world were inspected and compared in order to decide the methods to be used, content and details of the proposed PMS for the needs of Turkey.

As an example, a similar system was developed in Spain for use of Spanish Ministry of Public Works and Transport to cover 20000 km of highways. The system was developed based on the experiences of other authorities and the system used in North America. [4]. The step-by-step decisions during selection of system to be used, like, content (if it should be a very detailed one or a rather simple one at the beginning), selection of analysis methods, deficiencies, indexes, etc. were studied for Spanish PMS system.

Another reference study was the World Bank's Highway Design and Maintenance (HDM) model which was studied in detail with all aspects including the experiences of other authorities and users including academic literature.

After intensive explorations and comparisons, it was decided to follow World Bank's HDM IV model for PMS system to be developed for Turkey.

PMS Database for Turkey contains 4 main elements as:

1. Inventory Data,
2. Visual Distress Evaluations,
3. Functional Condition Data and
4. Structural Condition Data.

To start with the PMS set up, pavement condition tests have been completed by GDH and Komsa in the Hot Mix Asphalt highway sections in order to obtain road condition data. During field data collection program, world class measuring devices owned by Turkish GDH were used.

Vehicles and equipment owned by GDH as of 2019 are:

1. Dynatest RSP Mk-III Profilometer – OBSI Pavement Surface Noise Testing Device (17 Laser, 2 ea. Accelerometers, 1 Inertial Motion Sensor, GPS, Distance Meter, OBSI System, Ambient and Pavement Temperature Meter) - 1 complete set

2. Dynatest RSP Mk-IV Profilometers (2 Lasers, 2 Accelerometers, GPS, Distance Meter) - 15 complete sets
3. Dynatest 1295 Pavement Friction Tester (1000 L Water Tank, 2 Full Brake Systems, GPS, Distance Meter, Ambient and Pavement Temperature Meter) – 1 complete set
4. KUAB Falling Weight Deflectometer (9 Geophones, Distance Meter, Pavement Temperature Meter) – 1 complete set

Figure 2: Turkish General Directorate of Highways-Pavement Condition Test Vehicles

A program named as "Development of Pavement Management System" has been realized between 2009 and 2014 to collect performance data on the existing highways. Total 8362,69 km long hot-mix asphalt paved highways all over the country have been measured and collected data have been evaluated.

All collected data were analysed by experienced pavement engineers to determine the current structural and functional conditions of the inspected roads.

After this data collection program, another program has been started to develop and set up a PMS in GDH by increasing the number of parameters to be utilized during analysis and decision phases.

4. DEVELOPMENT OF ENHANCED PMS FOR USE IN TURKISH GDH

At the beginning of enhanced PMS development program, most appropriate and efficient pavement management parameters and methods have been determined considering the characteristics of Turkish highways network and conditions of the country. In addition, it was decided to develop a PMS software capable to handle both PMS methods; namely, network and project level pavement management methods.

The developed enhanced PMS software containing:

1. Inventory Management System
2. Network Level Management (Calculation, Analysis and Budget Management)
3. Project Level Management (Calculation, Analysis and Project Design)

And, consisting of three main divisions:

1. Creating Database
2. Project Level Pavement Management
3. Network Level Pavement Management

4.1. Creating Database

Turkish GDH PMS server containing full data base is located at GDH Headquarter Building in Ankara. In addition, there are 17 regional offices of GDH throughout Turkey and it is possible to access this server from all these regions directly through access code system.

Data bade have been set up by pavement engineers assigned (2 engineers from each region) at regional offices. These engineers pick up actual data on the highways in field and inputs to the specified units within the main server for the highways within the responsibility of their region. The PMS Software has a user access code system for authorisation to use the software such that each user (each region) can only access, view and edit the data of their region. Users and authorization of the software are managed by the administrator in GDH Headquarters in Ankara.

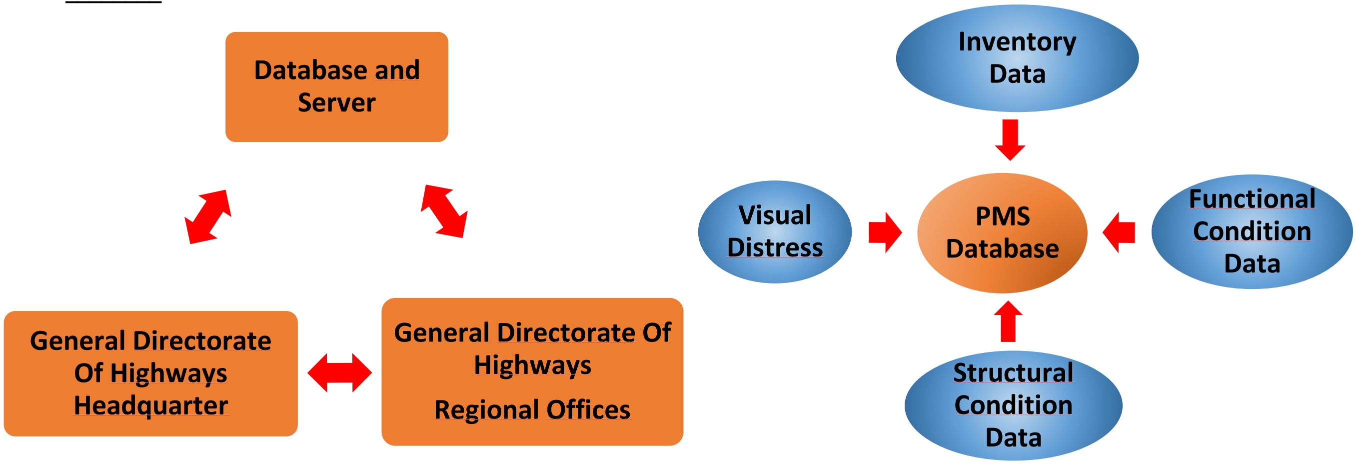


Figure 4: Database and Server Scheme

4.1.1. Inventory Data

Inventory data contains geometrical and physical information of road pavement sections. This information is compulsory for current pavement condition calculations and future modelling.

An interface within the software for data input and editing has been developed. The inventory data obtained have been input by pavement engineers of the region offices for each hot mix asphalt surfaced road sections of Turkey covering all inventory details including pavement section numbers of lanes, lane widths, layer thicknesses etc.

Figure 5: PMS Software Inventory Data Input/Edit Interface

4.1.2. Pavement Performance Tests and Measurements

IRI, Rutting, Macrotexture, Deflection data for hot-mix asphalt surfaced highways all over the country have been being obtained by GDH region pavement engineers starting from 2009 by means of Dynatest Mark IV Profilometers available at 17 different Region Offices. The data obtained have been input to PMS Database through PMS Software Performance Test Data Input Interface.

In general, structural data can be obtained through borehole samples, visual evaluations and non-destructive testing methods.

The borehole sampling is destructive and very slow method compared to non-destructive methods; and collection of sufficient number of representative samples is not physically possible over thousands of kilometres of roads with this method.

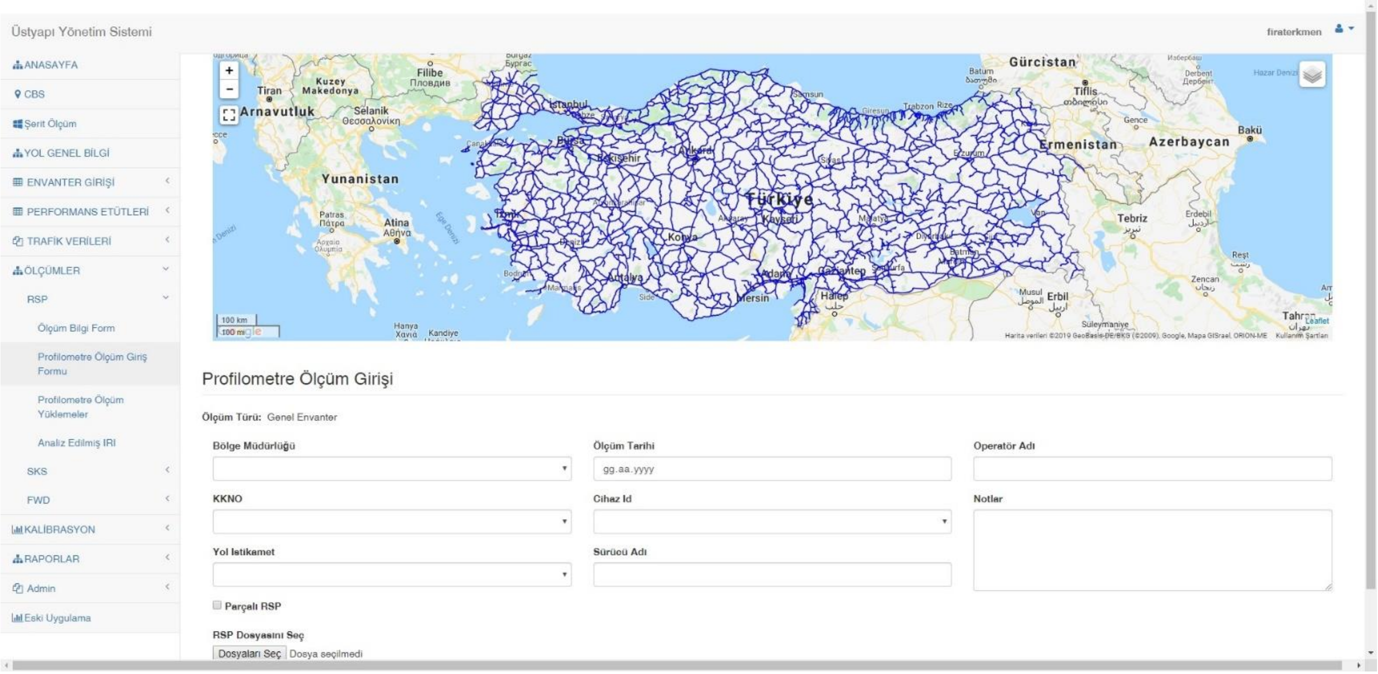


Figure 6: PMS Software Performance Data Input Interface

Structural condition of a pavement can also be evaluated through visual inspections by means of walking along the pavement and taking notes and images, or by means of images obtained by a Profilometer. However, visual inspection is not as accurate as the other methods and inspection/evaluation depends mainly on the interpretations and comments of the inspecting/analysing engineer and it may change according to the personnel; consequently, it is subjective.

On the other hand, use of non-destructive testing systems (deflection method) are more feasible, very quick (the average test period of about 1 minute per point) and testing sufficient number of points representing overall highway section is possible. In addition, non-destructive deflection test can provide elasticity modulus for each layer, remaining life and required overlay thickness of the pavement.

Therefore, deflection method has been chosen as the primary method for determination of structural condition of the pavements for use with PMS software. In some cases, if deflection cannot be measured due to unexpected conditions, it is also possible to input data for PMS software obtained through visual distress evaluations or borehole sampling.

As an example; highway 010-20 Tirebolu - Trabzon section has been tested on October 23, 2015 by using images collected by Profilometer and on September 29, 2010 with Deflectometer.

4.2. Analysis and Evaluation

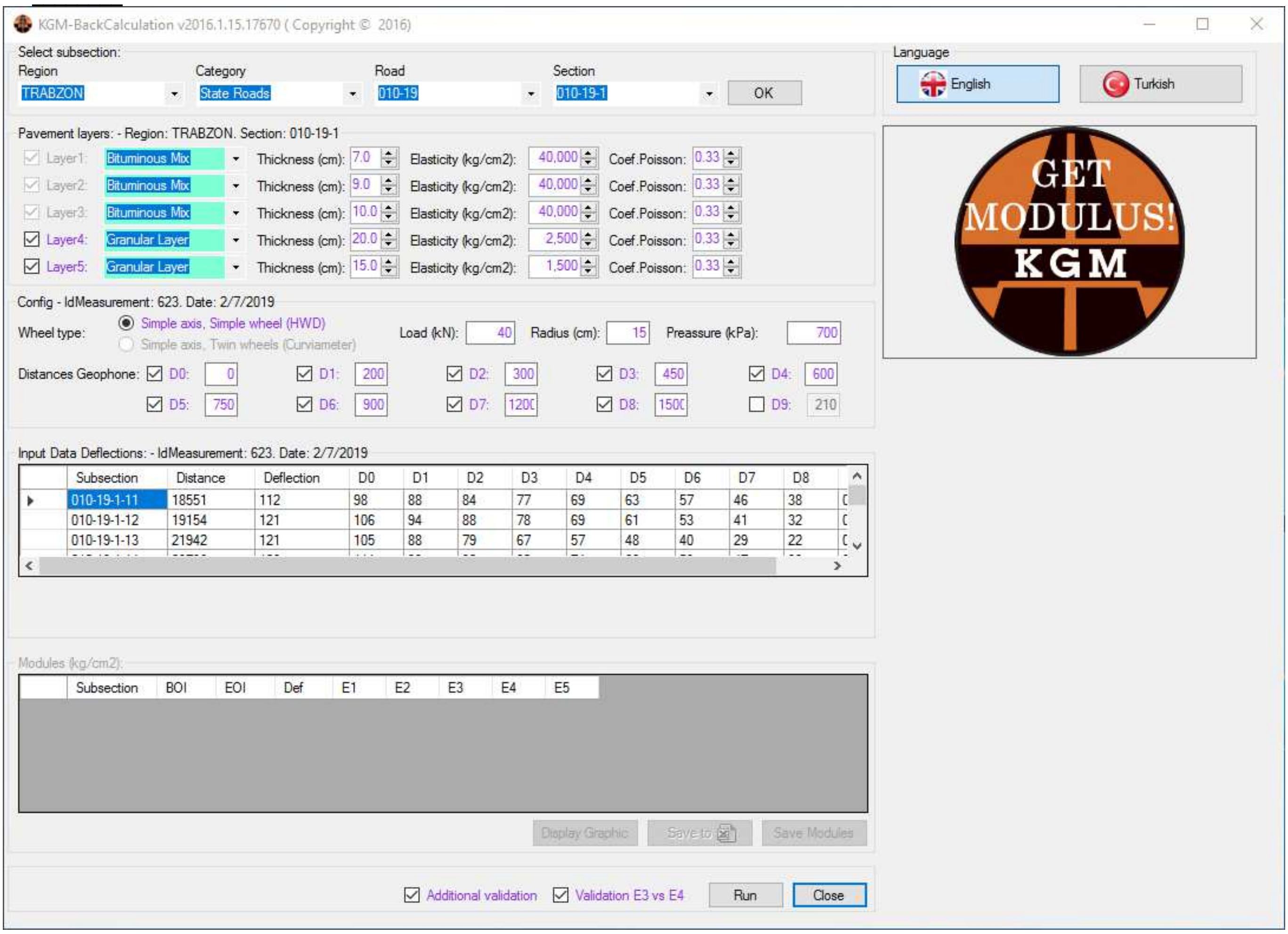
The enhanced PMS software is capable to analyse the input data and to evaluate current structural and functional condition of the pavement automatically.

4.2.1. IRI Analysis

Raw longitudinal profile data is filtered through 250 mm moving average filtering method and Filtered IRI values are obtained.

4.2.2. Deflection Analysis

Deflection values are being back calculated in accordance with Linear Elastic Method by using Back Calculation Module of Turkish PMS Software to gather with the required pavement thicknesses by using Pavement Mechanistic Empirical Model. [5]



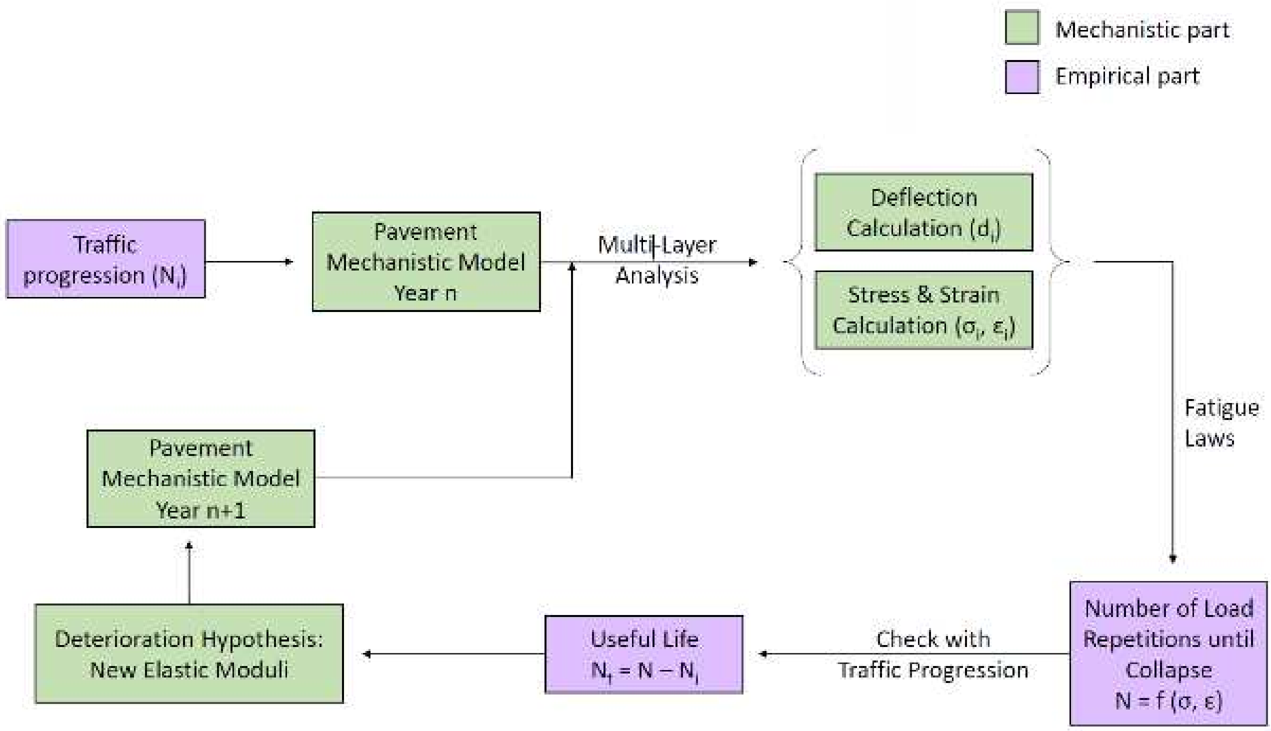


Figure 7: Turkish PMS Software Multi-Layer Analysis

4.2.3. Homogeneity Analysis

The enhanced PMS Software separates the data collected by test vehicles and equipment. Afterwards, Homogenous Sectioning Module of the software divides the road section under study in to homogenous sections for each data parameter as IRI, Rutting and Deflection concurrently or separately to obtain homogeneous sections (sub-sections). All calculations and evaluations after this stage are being performed based on these homogenous sections.

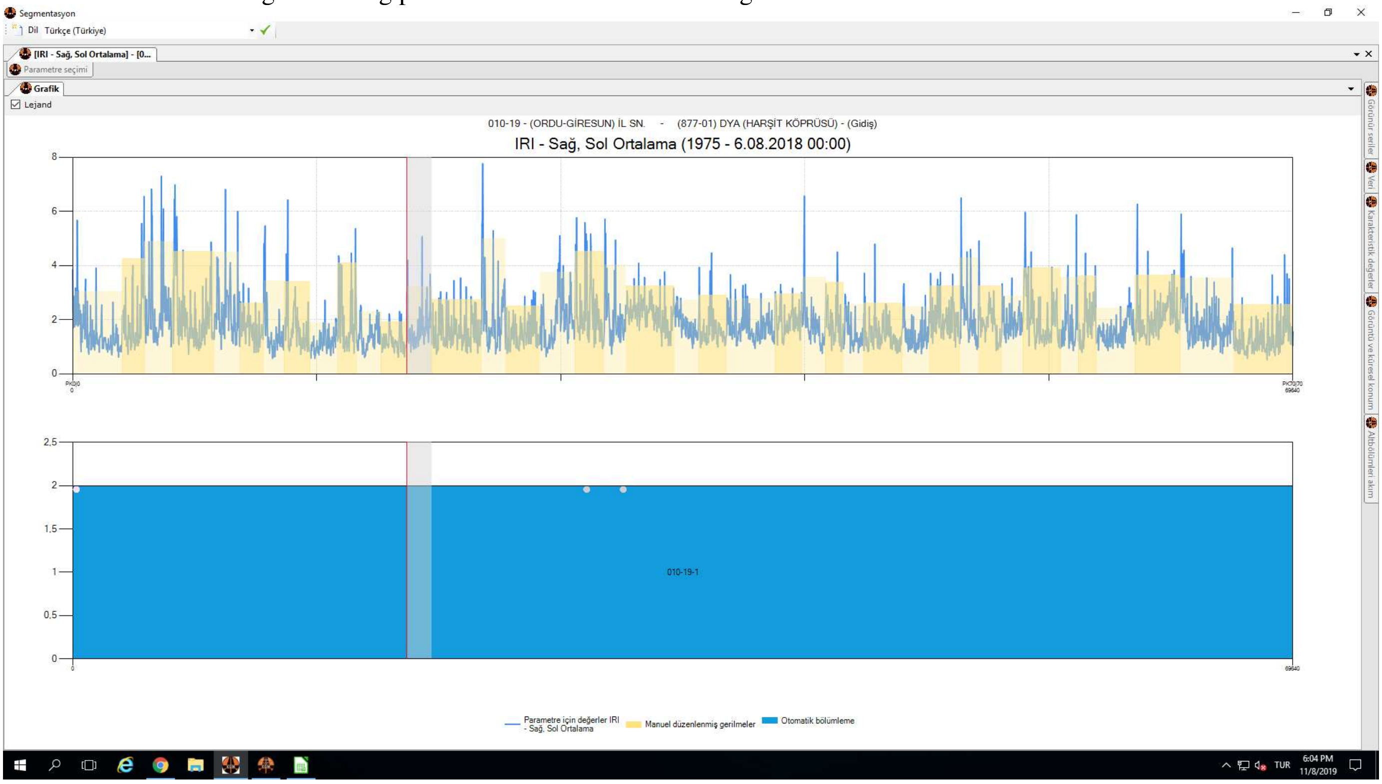


Figure 8: Homogenous Sectioning Software Output

Table 1: 010-20 Highway Homogenous Sections (3600 mt long Sample Section, as an example)

Homogenous Section Number	From (km)	To (km)	Homogenous Section Number	From (km)	To (km)
010-20-1-00	0+000	0+860	010-20-1-19	15+000	15+300
010-20-1-01	0+860	1+060	010-20-1-20	15+300	15+600
010-20-1-02	1+060	1+420	010-20-1-21	15+600	15+840
010-20-1-03	1+420	2+740	010-20-1-22	15+840	17+520
010-20-1-04	2+740	3+600	010-20-1-23	17+520	18+440
010-20-1-05	3+600	4+420	010-20-1-24	18+440	19+660

4.3. Future Modelling and Decision Making for Maintenance – Rehabilitation

After determining current condition of the road sections, required optimum maintenance and rehabilitation time and types are determined by the software. In this phase, maintenance & rehabilitation times are determined in accordance with the maximum values (limit values) defined by the user for each parameter.

4.3.1. Future Condition Prediction and Modelling

Modelling methods have been investigated by pavement engineers and the most appropriate methods have been selected for Turkey.

The parameters considered for model selection are age of pavement, cracks, maintenance quality and climatic conditions. Especially, climatic conditions parameter is the governing factor, because Turkey has different climatic characteristics in different regions. Based on these criteria, Mechanistic – Empirical Pavement Design Guide (2001) Appendix OO-1 principals is decided to be used for IRI modelling of PMS software without any modifications in the method. [7]

Considering its adaptability feature for regional conditions, The World Bank Highway Development & Management HDM-4 modelling principals are used for modelling of Rutting, Macro Texture and Cracking on Turkey PMS Software. [8]

IRI, Deflection and Pavement Point values are being modelled and optimum rehabilitation and maintenance plan are being determined by the software for the road under study.

4.3.2. Future Condition Prediction and Modelling

After evaluation of models, the following actions (maintenance types) are recommended by the software for the flexible pavements:

Table 2: PMS Software Maintenance Types

Code	Maintenance Type
D	Micro milling (average thickness of 1 cm) [m2]
E	Micro surfacing of 3cm (including watering pp) [m2]
I	Pothole repair (units)
J	Milling of existing AC mix [cm/m2]
K	Overlay with new AC mix [cm/m2]
O	Inlay replacement with new AC mix [cm/m2]
X	Fixed actions (predefined user assigned actions)
Z	Crack sealing

Optimum maintenance and rehabilitation types are determined by decision tree of the software. Limit values of this decision tree can be adjusted by the administrator of PMS software.

The resulting Maintenance and Rehabilitation plan outputs are given for first five sections of the studied highway as follows:

Table 3: 010-20 Road Maintenance and Rehabilitation Plan for Subsections (ForFive Homogeneous Sections)

<table>
<tr><th>Homogenous Section Number</th><th>From (km)</th><th>To (km)</th><th>Maintenance Type</th><th>Maintenance Year</th></tr>
<tr><td>010-20-1-00</td><td>0+000</td><td>0+860</td><td>Micro Milling
Crack Sealing
Crack Sealing
Crack Sealing
8.5 cm Overlay
12.5 cm Overlay
4 cm Overlay</td><td>2022
2022
2023
2024
2025
2030
2038</td></tr>
<tr><td>010-20-1-01</td><td>0+860</td><td>1+060</td><td>Crack Sealing
7.5 cm Overlay
11.5 cm Overlay
8 cm Overlay</td><td>2022
2023
2028
2036</td></tr>
<tr><td>010-20-1-02</td><td>1+060</td><td>1+420</td><td>10 cm Overlay
14 cm Overlay
Crack Sealing
Micro Milling</td><td>2022
2030
2038
2038</td></tr>
<tr><td>010-20-1-03</td><td>1+420</td><td>2+760</td><td>Micro Milling
Crack Sealing
Crack Sealing
Crack Sealing
Crack Sealing
Crack Sealing
Micro Milling
Crack Sealing
11.5 cm Overlay</td><td>2020
2022
2023
2024
2025
2026
2026
2027
2034</td></tr>
<tr><td>010-20-1-04</td><td>2+760</td><td>3+600</td><td>5 cm Overlay
8 cm Overlay
8 cm Overlay</td><td>2022
2026
2032</td></tr>
</table>

According to these maintenance plans, pavement condition parameters have been predicted for future by modelling.

Table 4: 010-20 Road Deflection Future Modelling Results (for Five Homogenous Sections)

Subsection No	**010-20-01-00**	**010-20-01-01**	**010-20-01-02**	**010-20-01-03**	**010-20-01-04**
From (km)	0+000	0+860	1+060	1+420	2+740
To (km)	0+860	1+060	1+420	2+740	3+600
Deflection Test Result	2010/35	2010/38.3	2010/47.2	2010/27.3	2010/36.7
2019	35.5	38.8	47.6	27.5	37.2
2020	35.8	38.8	47.8	27.5	37.5
2021	37.0	41.2	51.7	28.2	41.2
2022	38.9	44.6	41.5	28.8	41.6
2023	42.0	41.7	42.5	28.8	42.2
2024	45.8	42.5	43.6	29.8	44.5
2025	41.8	44.3	45.3	30.3	47.8
2026	42.0	46.7	46.4	31.3	41.8
2027	44.2	50.6	48.8	32.6	42.0
2028	46.5	41.9	51.4	34.1	43.0
2029	50.4	42.0	54.1	35.2	45.2
2030	41.8	43.0	41.6	36.9	47.6
2031	42.0	44.1	41.8	38.8	50.8
2032	43.0	46.1	42.8	41.9	26.9
2033	44.0	47.2	43.9	45.4	26.8
2034	45.8	49.7	45.0	41.7	27.4
2035	46.9	52.3	46.0	41.8	28.1
2036	49.0	26.0	47.1	44.0	29.1
2037	51.2	25.9	48.3	46.3	29.9
2038	24.9	26.2	49.5	49.1	31.5

Table 5: 010-20 Road IRI Future Modelling Results (for Five Homogenous Sections)

Subsection No	**010-20-01-00**	**010-20-01-01**	**010-20-01-02**	**010-20-01-03**	**010-20-01-04**
From (km)	0+000	0+860	1+060	1+420	2+740
To (km)	0+860	1+060	1+420	2+740	3+600
IRI Test Results	2014/2.04	2014/1.66	2014/2.1	2014/2.41	2014/2.03
2019	2.08	1.70	2.14	1.50	2.06
2020	2.18	1.81	2.25	1.59	2.17
2021	2.29	1.92	2.37	1.69	2.28
2022	1.50	2.04	1.50	1.79	1.50
2023	1.63	1.50	1.61	1.90	1.61
2024	1.79	1.61	1.72	2.04	1.72
2025	1.50	1.72	1.83	2.25	1.83
2026	1.61	1.83	1.95	1.50	1.50
2027	1.72	1.95	2.06	1.64	1.61
2028	1.83	1.50	2.17	1.76	1.72
2029	1.95	1.61	2.28	1.88	1.83
2030	1.5	1.72	1.50	1.99	1.94
2031	1.61	1.83	1.61	2.10	2.06
2032	1.72	1.94	1.72	2.21	1.50
2033	1.83	2.06	1.83	2.32	1.61
2034	1.94	2.17	1.94	1.50	1.72
2035	2.06	2.28	2.06	1.61	1.83
2036	2.17	1.50	2.17	1.72	1.94
2037	2.28	1.61	2.28	1.83	2.05
2038	1.50	1.72	1.50	1.95	2.16

4.4. Cost Analysis and Budget Management

After determination of maintenance plans, maintenance costs and operation costs are calculated by the software for every action and for each homogenous section.

Table 6: 010-20 Road Annual Total Maintenance Budget

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Total Budget (k TRY)	1,536	857	292	6,010	2,969	2,563	3,200	3,855	2,826	3,665
Year	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**
Total Budget (k TRY)	6,985	4,264	875	2,315	2,630	6,699	1,481	1,771	1,453	6,985

According to these analyses, for the example road section 98,112,254.00 TRY (approx. 15,426,455.03 Euros) are calculated as required budget in order to provide that the pavement serves at the desired level. this budget includes maintenance and repair costs of all homogeneous sections on the road.

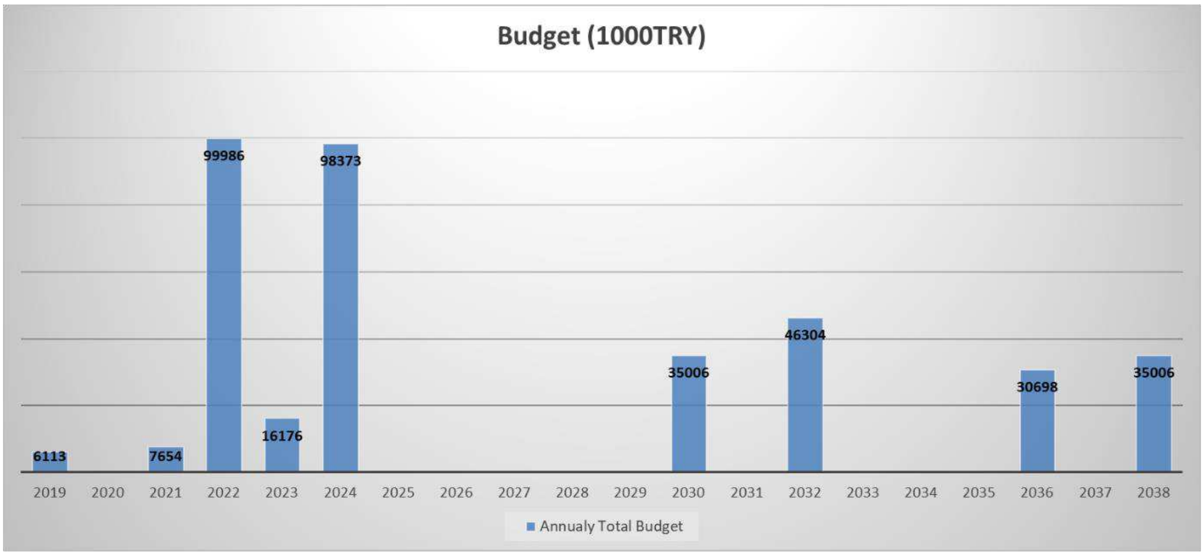


Figure 9: Annual Maintenance Budget

Maintenance construction costs which are determined by evaluating the number of lanes, lengths of the roads, the traffic values and vehicle operating expenses for each vehicle will pass from the related sections are calculated. The same costs are also calculated for the case of the required maintenance-repair is delayed by 3 years.

The "Delay Cost Ratio" is calculated by the ratio of these two calculated values and maintenance - repair priority comparison can be done with this value for all sections at network level. After all these calculations have been completed, the user can evaluate the budget according to years and can divide the budget according to priorities of the administration. Maintenance plan and cost analyses for one of the regions have been executed and maintenance priorities have been determined by the software as example for this study.

The following two graphs reflect the final report of the example analysis of one region. [9]

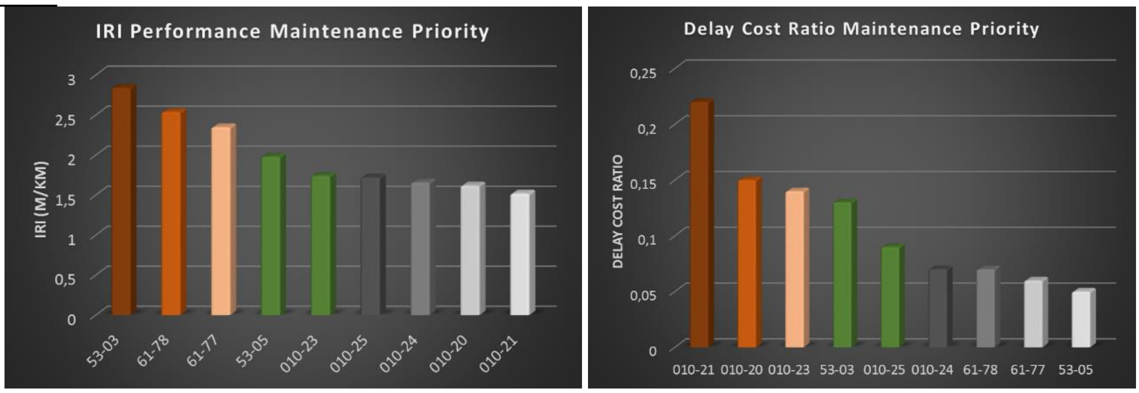


Figure 10: Network Level Maintenance Priority Graphs

According to this example, "53-03" road has the highest roughness value and it is the first section that should be maintained in case the only one parameter considered is IRI. However, the software is also evaluating based on the traffic, road geometry and existing condition of the pavement, and in case the delay cost ratios are considered; "010-21" road should be the first section to be maintained. Therefore, maintenance of "010-21" highway is going to provide more financial benefit than "53-03" highway.

5. CONCLUSION

As a result of all above summarized studies, Pavement Management System software for Turkey has been developed and 17 different Region Headquarters has been starting to use PMS Software in order to maintain road network at the right time with the right method within the available budget.

Pavement Management System software for Turkey is capable of estimating future pavement condition in different regions and in line with these estimations it is preparing maintenance – repair plans and automatically determines optimum solution that can provide the highest benefit with the lowest cost.

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