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16. Abstract

The Highway Economic Requirements System-State Version (or the HERS-ST) is a software package which was developed by the Federal Highway Administration as a tool for evaluating the performance of state highway systems. HERS-ST has the capabilities of estimating highway system performance and system needs. It also has the capability of providing investment strategies required to attain a certain level of system performance. Some states such as Indiana, North Dakota, New Mexico and Oregon have been able to make extensive use of the software. New Mexico, for example has used the software to provide an assessment for the state's long term highway needs by running and evaluating various investment scenarios. The state of Indiana has used the software package in their Long Range Transportation Plan for assessing future system needs and budget planning. Texas has expressed interest in the HERS-ST software package, but it has been pointed out that the pavement deterioration model used by the HERS-ST software package to estimate pavement wear is inaccurate. This study focused on disaggregating the pavement deterioration model used by the HERS-ST to better understand its process with particular emphasis on traffic characteristics. This report presents a methodology that can be used to calibrate the model for state specific conditions.

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CALIBRATION OF HERS-ST FOR ESTIMATING TRAFFIC IMPACT ON PAVEMENT DETERIORATION IN TEXAS

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ABSTRACT

The Highway Economic Requirements System-State Version (or the HERS-ST) is a software package which was developed by the Federal Highway Administration as a tool for evaluating the performance of state highway systems. HERS-ST has the capabilities of estimating highway system performance and system needs. It also has the capability of providing investment strategies required to attain a certain level of system performance. Some states such as Indiana, North Dakota, New Mexico and Oregon have been able to make extensive use of the software. New Mexico, for example has used the software to provide an assessment for the state's long term highway needs by running and evaluating various investment scenarios. The state of Indiana has used the software package in their Long Range Transportation Plan for assessing future system needs and budget planning. Texas has expressed interest in the HERS-ST software package, but it has been pointed out that the pavement deterioration model used by the HERS-ST software package to estimate pavement wear is inaccurate. This study focused on disaggregating the pavement deterioration model used by the HERS-ST to better understand its process with particular emphasis on traffic characteristics. This report presents a methodology that can be used to calibrate the model for state specific conditions.

EXECUTIVE SUMMARY

The Highway Economic Requirements System-State Version (HERS-ST) software package is a robust tool that can be used for evaluating future transportation needs. State Departments of Transportation (DOTs) have used the HERS-ST for the following projects:

1) Long-range system planning (construction, maintenance budgeting, etc.)
2) Program evaluation (establishing performance objectives and setting goals)
3) Highway needs assessments (identification of system deficiencies)
4) Budgeting scenarios and evaluation
5) Corridor planning
6) Congestion Management

These are just some of the ways the HERS-ST software has been used in the past. New Mexico, for example used the software to furnish a 20 year needs assessment plan for the state's infrastructure. Also in New Mexico, the system was used to estimate funds required to maintain the state's infrastructure at its current level of performance. In North Dakota, the software package was used to estimate the benefits of highway infrastructure investments, while in Oregon a modified version of the software package was used to identify highway deficiencies and prioritize funds amongst candidate highway projects (Prozzi, 2009).

The pavement deterioration models applied by the HERS-ST system to evaluate pavement performance are based on the 1986 AASHTO Guide for Design of Pavement Structures (FHWA, 2005). The AASHTO Design Guide is based on the serviceability concept developed as a result of the AASHO Road Test and it uses the present serviceability rating (PSR) to evaluate the ride quality of a pavement. The ride quality can also be correlated with the International Roughness Index (IRI) which is measured from the longitudinal pavement surface profile in the wheel path (Huang, 2004). A surface profile with a significant amount of undulations for example, would be considered to have poor ride quality and would receive a high IRI score (i.e. high roughness).

Based on the evaluation of the HERS-ST pavement deterioration model, some preliminary conclusions can be drawn about its accuracy and its effectiveness: while the pavement deterioration model embedded in the HERS-ST model is an effective tool for predicting pavement deterioration on a system-wide level, certain improvements should be incorporated before it can be considered for state-wide implementation in Texas. Some of the recommended improvements are listed below:

1) Consideration of updated correlation equations for converting field measured IRI to PSR. In Texas, Ride Score is used, so a direct conversion between ride score and serviceability would be beneficial.
2) Consideration of updated load equivalency factors for converting truck traffic into equivalent single axle loads. This factors should be based on mechanistic concepts and depend on project-specific and local condition.
3) Addition of a directional distribution factor which accounts for the split of the vehicles by their direction of travel. This is a significant problem in the current system.

Specific attention should be paid to updating the load equivalency factors because, as it is explained in the report, the degree of variability and uncertainty introduced is unacceptably high.

It is unclear how current values were derived; documentation of their derivations could not be found. It is also unclear if these values are accurate, because as is demonstrated in the analyses there are several notable inconsistencies within the data. Besides, while accurate for one location, they may be inaccurate for other locations.

The most urgent and simple improvement that should be made to the HERS-ST pavement deterioration model is the addition of a directional distribution factor. This factor is currently missing from the conversion equation which allows future traffic to be converted into future equivalent single axle loads. The directional distribution factor is an important parameter when calculating pavement deterioration and without it deterioration can be largely over-predicted. This introduces an error of 50 percent. This can cause significantly different improvement scenarios and it can jeopardize the effectiveness of the HERS-ST software for assessing system needs.

In order for HERS-ST to become an effective tool in assessing transportation system needs in Texas, it was determined that the embedded pavement deterioration models need to be calibrated to better represent actual state-wide pavement performance. However, in the calibration effort it was noticed that the preventive maintenance program applied by the state of Texas and its effects on state-wide pavement performance was not readily accounted for by the HPMS dataset. This led to a calibration effort which excluded this important factor and, because of this, the calibrated pavement deterioration rate adjustment factors cannot be merited as representative of the state's pavement deterioration conditions.

This can become a significant issue for other states that will attempt in the future to calibrate the HERS-ST pavement deterioration model to state-representative conditions. In order to mitigate this issue the following measures are proposed:

1) Include surface treatments and seal coats as an entry field into the HPMS dataset. The field should specify the type of surface treatment and the month and year the surface treatment was performed.
2) Include a Preventive Maintenance option in the HERS-ST model that will allow the analyst to specify the amount of funding spent on preventive maintenance per funding period, and the percentage of the network in lane-miles this preventive maintenance program will cover for every funding period. This will lead to identifying the costs and benefits associated with a preventive maintenance program and its appropriate effects on pavement performance.

The final recommendation of this report aims at highlighting the importance of collecting quality data. In 2007, standard sample data was collected for 9,048 roadway sections throughout the state of Texas. Collecting road data for this many sections can become an overwhelming procedure for any state DOT, and as a result it was noticed that there were many inconsistencies in the data collected, particularly for the lower functional classes. Therefore, it is the recommendation of this report to decrease the number of sections for which data are collected and, instead, rely on higher expansion factors to represent the Texas transportation network. This in turn, would allow the DOT to collect data which are of higher quality. Having accurate data is important because our ability to plan for our future transportation needs heavily relies upon the state of our current transportation system.

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CHAPTER 1. INTRODUCTION

The Highway Economic Requirements System-State Version (HERS-ST) software package is a robust tool that can be used for evaluating future transportation needs. State Departments of Transportation (DOTs) have used the HERS-ST for the following projects:

1) Long-range system planning (construction, maintenance budgeting, etc.)
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These are just some of the ways the HERS-ST software has been used in the past. New Mexico, for example used the software to furnish a 20 year needs assessment plan for the state's infrastructure. Also in New Mexico, the system was used to estimate funds required to maintain the state's infrastructure at its current level of performance. In North Dakota, the software package was used to estimate the benefits of highway infrastructure investments, while in Oregon a modified version of the software package was used to identify highway deficiencies and prioritize funds amongst candidate highway projects (Prozzi, 2009).

The methodology behind the inner workings of the HERS-ST software can be simplified into the five steps shown in Figure 1.

Figure 1. HERS-ST System Evaluation Process.

The HERS-ST software begins with evaluating the current conditions of the state highway system from data provided by the analyst. The data used for the evaluation of the current conditions are supplied by the Highway Performance Monitoring System (HPMS) database. The HPMS database is an ongoing effort sponsored by the federal government to collect data pertaining to highway performance (Prozzi, 2009). These data, which attempt to capture relevant performance indicators such as roadway geometry, traffic characteristics, and pavement performance, are collected for individual highway sections throughout the states. Overall, there are 98 roadway characteristics collected for each highway section. The sections for which data are collected are supposed to be a representative sample for the entire state.

Depending on the type of application the HERS-ST software is used for, the length of the analysis period can be divided into smaller time lengths called "funding" periods. This is done to simulate the type of prioritizing procedure an agency goes through when allocating its funds to different highway projects. The HERS-ST software then proceeds to forecast future traffic at the beginning and end of each funding period. Traffic forecasts are derived from future average annual daily traffic (AADT) projections obtained from the HPMS dataset.

Once the current system conditions and the analysis period are known, the HERS-ST software analyzes the dataset for any system deficiencies. Deficiencies can include inadequate vertical or horizontal alignment, demand-to-capacity issues, and pavement deterioration. Deficiencies can occur throughout the analysis period. For example, a highway section may have an adequate pavement serviceability rating after the first funding period of the analysis, but after the second funding period, due to heavy traffic, the serviceability rating might have dropped below adequate levels. The objective of the HERS-ST software is to identify these deficiencies as they appear during the life of the system, and to propose a series of improvements to fix them.

To fix section deficiencies, the software identifies potential improvement options. For the example above, HERS-ST may recommend resurfacing the pavement after the second funding period, or reconstructing the pavement some time later down the line. Based on the calculated present value of the costs and benefits associated with each improvement, HERS-ST selects the "best" alternative (Prozzi, 2009). The selection process of the "best" alternative is based upon an incremental benefits-to-costs approach, and is calculated by the HERS-ST software in the following way:

$$IBCR = \frac{(TotCost_B) - (TotCost_I) + RV}{impCost_I - impCost_B} \tag{1}$$

where:

IBCR	:	incremental benefit cost-ratio;
TotCost	:	UCost+ACost+ECost for either base case (B) or improved case (I)
UCost	:	user costs (travel time costs, operating costs and safety costs)
ACost	:	agency costs (maintenance costs)
ECost	:	external costs (emissions costs)
RV	:	residual value of improvement relative to the base case
ImpCost	:	capital cost of either the base case (B) or the improved case (I) or zero when the base case is unimproved

The software then proceeds to sum up all of the proposed section improvements within each funding period, and the costs and benefits associated with them. For each section improvement the software tool calculates the following:

1) Operating costs
2) Travel time costs
3) Safety costs
4) Agency costs
5) Capital improvement costs
6) Maintenance costs
7) Costs associated with vehicle emissions, and
8) Residual value of the improvement (salvage value)

Based on these statistics the software provides the analyst with a way to evaluate the state highway system by various performance indicators. If for example, highway funding is a constraint, then the HERS-ST software can be used to evaluate system performance based on available funds. If some level of performance is desired from the system, then the software can identify the measures which need to be taken to achieve that level of performance. The HERS-ST software package can also evaluate system performance in terms of user delay costs, system emissions costs, or pavement serviceability.

The calculation of these performance indicators requires the use of complex models which are imbedded within the HERS-ST software package. The discussion presented in the following chapter will focus on the pavement deterioration model used by the software.

CHAPTER 2. PAVEMENT DETERIORATION MODEL

The pavement deterioration model applied by the HERS-ST system to evaluate pavement performance is based on the 1986 AASHTO Guide for Design of Pavement Structures (FHWA, 2005). The AASHTO Design Guide is based on the serviceability concept developed as a result of the 1958 AASHO road test and it uses the present serviceability rating (PSR) to evaluate the ride quality of a pavement. The ride quality can also be correlated with the International Roughness Index (IRI) which is measured from the longitudinal pavement surface profile in the wheel path (Huang, 2004). A surface profile with a significant amount of undulations for example, would be considered to have poor ride quality and would receive a high IRI score. Table 1 below, shows how the present serviceability rating is correlated with IRI (in in./mile) and how the pavement condition is described for each rating system.

Table 1. Pavement condition ratings (FHWA, 2005).

PSR and Verbal Rating	IRI Value (Rigid)	Description
5.0	0	
Very Good		Only new (or nearly new) pavements are likely to be smooth enough and sufficiently free of cracks and patches to qualify for this category. All pavements constructed or resurfaced during the data year would normally be rated very good.
4.0	52	
Good		Pavement in this category, although not quite as smooth as those described above, give a first class ride and exhibit few, if any visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavement may be beginning to show evidence of slight surface deterioration, such as minor cracks and spalling.
3.0	119	
Fair		The riding qualities of pavements in this category are noticeably inferior to those of new pavements and may be barely tolerable for high speed traffic. Surface defects of flexible pavements may include rutting, map cracking, and extensive patching. Rigid pavements in this group may have a few joint failures, faulting, cracking, and some pumping.
2.0	213	
Poor		Pavements that have deteriorated to such an extent that they affect the speed of free-flow traffic. Flexible pavement may have large potholes and deep cracks. Distress includes ravelling, cracking, rutting, and occurs over 50 percent or more of the surface. Rigid pavement distress includes joint spalling, faulting, patching, cracking, scaling, and many include pumping and faulting.
1.0	374	
Very Poor		Pavements that are in an extremely deteriorated condition. The facility is passable only at reduced speeds and with considerable ride discomfort. Large potholes and deep cracks exist. Distress occurs over 75 percent or more of the surface.
0.086	999	

In order to correlate the road roughness with the present serviceability rating, the HERS-ST system employs the following conversion equations.

Table 2. IRI to PSR conversion equations (FHWA, 2005).

Surface Type	Equation
Flexible	PSR = 5.0*exp(-0.0038*IRI)
Composite	PSR = 5.0*exp(-0.0046*IRI)
Rigid	PSR = 5.0*exp(-0.0043*IRI)

The internal workings of the HERS-ST uses PSR to represent pavement conditions when determining section deficiencies, vehicle speed, operation costs, and agency costs (Prozzi, 2009). However, agencies do not typically collect PSR data and instead focus on collecting section roughness data directly from the road profile. They can then use the IRI data to estimate the ride quality in terms of PSR. Having accurate equations which allow one to correlate an IRI value with a PSR score becomes very important. The conversion equations provided by the HERS-ST software package may not be the optimal equation to use. As pointed out by Gulen, equations that are forced to pass through a PSR = 5.0 when IRI = 0.0 are biased and not statistically correct (Gulen, 1994).

To run the pavement deterioration model, the HERS-ST requires certain information which can be obtained from the HPMS dataset. This information is grouped in 14 descriptive fields and is related to specific geometric features of the roadway, traffic characteristics, and initial pavement conditions. These items are all essential to the determination of pavement wear. Table 3 presents a summary of the fields required by the HERS-ST system to run the pavement deterioration model.

Table 3. Summary of HPMS data required by the pavement deterioration model (HPMS Field Manual)

	Field No.	Data Item	Brief Description
Traffic	1	Year of Data	Enter the four digits of the calendar year for which the data apply.
	33	AADT	Annual Average Daily Traffic provides basic existing traffic inventory information for selected sections. For two-way facilities, provide the AADT for both directions
	97	Future AADT	This item provides forecast AADT information for a sample section. Code the forecasted two-way AADT for the year coded in Item 98, Year of Future AADT.
	98	Year of Future AADT	This item provides the year for which the AADT has been forecast. Enter the four-digit year for which Future AADT (Item 97) has been forecasted.
	82	% Avg. Daily SU	This item provides information on truck use on a sample section. Code single unit truck traffic as a percentage of section AADT to the nearest whole percent.
	84	% Avg. Daily CU	This item provides information on truck use on a sample section. Code combination truck traffic as a percentage of section AADT to the nearest whole percent.
Roadway	17	Functional System Code	This item permits analysis and mapping of information by highway functional system. Definitions can be found in Highway Functional Classification, Concepts, Criteria and Procedures, FHWA, 1989.
	27	Type of Facility	This item is used to determine whether a roadway is a one- or two-way operation. 1) One-Way Roadway, 2) Two-Way Roadway, 3) One-Way Structure), and 4) Two-Way Structure.
	34	Number of Through Lanes	Item provides basic inventory information on the amount of public road supply. Code the number of through lanes according to the striping or according to traffic use.
Pavement	50	Surface Pavement Type	Item details type of pavement surface on sample roadway sections. Enter 1) for unpaved, 2) low type, 3) intermediate type, 4) high type flexible, 5) high type rigid, 6) high type composite
	51	SN or D	Provides information about the pavement section structural number [SN] for flexible pavement or thickness (depth) [D] for rigid pavement.
	53	Year of Surface Improvement	Item is used to identify the year in which the sample section roadway surface was last improved. Improvement is considered to be 25 mm (one inch) or more of compacted pavement material.
	35	Measured (IRI)	This item provides information on pavement surface roughness on selected sections.
	36	PSR	This item provides information on pavement condition on selected roadway sections.

The pavement deterioration model embedded within HERS-ST predicts pavement deterioration as a function of traffic and the environment. The model first calculates pavement wear due to traffic. Then, it calculates the minimum and maximum pavement deterioration rates. The minimum rate is designed to reflect a condition in which no traffic is applied and all deterioration is directly related to environmental effects. The maximum rate is designed to place a practical limit on the amount of deterioration a roadway can experience. The maximum pavement deterioration rate is only applied to *lighter* pavement sections (or sections with a structural number between 1.0 and 3.0). HERS-ST applies these limits to the calculated PSR value to arrive at a *forecast* pavement condition (FHWA, 2005). The steps taken by the HERS-ST software to arrive at this forecast pavement condition are presented in Figure 2.

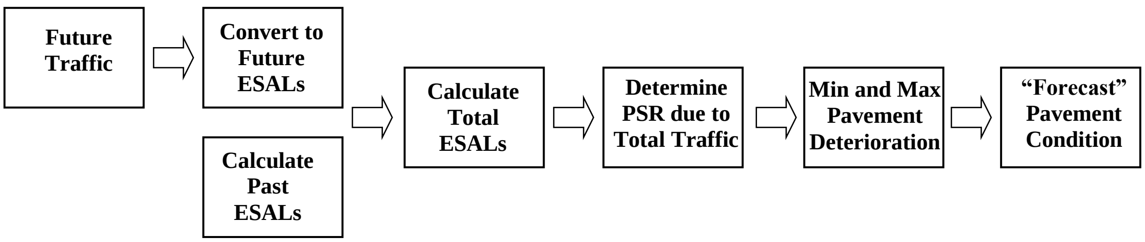

Figure 2. HERS-ST Process for Determining Future Pavement Condition.

2.1 FUTURE TRAFFIC DEMAND

The first step of the forecast process consists of the determination of future traffic demand. HERS-ST utilizes four fields from the HPMS dataset to calculate future traffic demands. The fields used by the software are 1) Year of Data, 2) AADT, 3) Year of Future Traffic, and 4) Future AADT. HERS-ST uses these fields to determine the overall traffic growth (as a percentage) and then it uses the overall growth to predict traffic demand at the start and end of each funding period for the duration of the analysis (FHWA, 2005).

The general equation for calculating future average traffic demand between any two time periods during the analysis period is as follows:

$$Traffic_{Tot.} = \frac{AADT_f + AADT_i}{2} * 365 days * (t_f - t_i) \quad (2)$$

where:

$Traffic_{Tot}$	:	total average traffic between two time periods,
$AADT_f$	:	average annual daily traffic at the end of period,
$AADT_i$	:	average annual daily traffic at the start of period,
t_f	:	year of the end period, and
t_i	:	year of the start period

2.2 CONVERTING FUTURE TRAFFICE DEMAND INTO ESALS

The second step in the process deals with the conversion of future traffic demand into equivalent 18-kip single axle loads. The method for converting traffic into equivalent single axle loads is presented by the following equation:

$$ESAL_{future} = Traffic_{Tot.}[(SU_{Avg} * LEF_{SU} * LF) + (CU_{Avg} * LEF_{CU} * LF)] \quad (3)$$

where:

$ESAL_{future}$	:	equivalent single axle loads converted from future traffic,
SU_{Avg}	:	% average daily single unit truck traffic (HPMS Item 82),
CU_{Avg}	:	% average daily combination unit truck traffic (HPMS Item 84),
LEF_{SU}	:	load equivalency factor for single unit trucks,
LEF_{CU}	:	load equivalency factor for combination unit trucks, and
LF	:	lane distribution factor

From this equation, it can be seen that the HERS-ST model adopts the widely accepted practice that passenger cars do not contribute to pavement deterioration, and so it only accounts for the heavy vehicles in its estimation of equivalent single axle loads. HERS-ST has a unique way of classifying its heavy vehicles. From Table 4 it can be seen that there are only two classes of heavy vehicles: 1) single unit trucks and 2) combination unit trucks.

Table 4. Vehicle categories prorated from HPMS vehicle classification study (FHWA, 2005).

Category	Vehicle Type
Combination Trucks	5 or More Axle Combination Trucks
	3/4 Axle Combination Trucks
Single Unit Trucks	3 or More Axle Single Unit Trucks
	6-Tire Vehicles
4-Tire Vehicles	Pickups & Vans, Automobiles

The load equivalency factors used to compare damage caused by a vehicle category to the damage caused by an 18-kip equivalent single axle load are presented in Table 5. It was initially assumed that the load equivalency factors produced for this table were derived from an analysis of Truck Weight Study data from weigh-in-motion (WIM) sites around the U.S. (email correspondence: FHWA). However, after some analysis, it is unclear how these values were actually derived. Through email correspondence with FHWA's Office of Asset Management, it was determined that the LEFs were last updated in 1996, probably in accordance with the *Axle Load Equivalency Factor*" tables which can be found in the 1993 AASHTO Guide for Design of Pavement Structures; however, the relevance of these values determined half-century ago is under debate. Through email correspondence, it was also noted by the developer that they had *"identified a few inconsistencies in the values, but implemented them into HERS as being the official FHWA values."*

Looking at the table, some observations can be made. For example, looking at the equivalent load factors for single unit trucks from the table, we could assess that under heavy loads rigid pavements would deteriorate at a faster rate than flexible pavements due to the higher load equivalency factors, everything else being equal. However, under certain distress mechanisms (e.g. rutting), rigid pavements typically outlast flexible pavements, and so, perhaps in actuality the LEFs for rigid pavements should be smaller than LEFs for flexible pavements. The main problem is that LEF should be distress dependent too. These types of disparities are seen throughout the table and that is why the question about the accuracy of these values is raised.

Table 5. Load Equivalency Factors used by HERS-ST (FHWA, 2005).

Load Equivalency Factors		SU Trucks		CU Trucks	
		Flexible	Rigid	Flexible	Rigid
Rural	Interstate	0.2898	0.4056	1.0504	1.6278
	Principal Arterials	0.3141	0.4230	1.1034	1.7651
	Minor Arterials	0.2291	0.3139	1.0205	1.0819
	Collectors	0.2535	0.3485	0.7922	1.3265
Urban	Inter/Free/Express-Ways	0.6047	0.8543	2.3517	3.7146
	Principal Arterials	0.5726	0.8123	0.8584	1.3047
	Minor Arterials	0.3344	0.4109	1.0433	1.5276
	Collectors	0.8126	1.1595	0.6417	0.9968

The last variable in the equation pertains to truck traffic distribution along a single direction of travel. If there is more than one lane in a single direction of travel, it is assumed that truck traffic will not be spread equally amongst the lanes of the travel-way, and that the bulk of the traffic will be carried by the design lane. Table 6 presents a lane distribution factors (LF) used by the HERS-ST to account for the spread of traffic along a travel-way.

Table 6. Lane distribution factors (FHWA, 2005).

No. of Lanes (One direction)	Lane Factor
1	1.00
2	0.90
3	0.70
4 or more	0.60

In the process of converting future traffic demands into equivalent single axle loads, one apparent flaw was observed in the calculation. If studied carefully, it can be noticed that the calculation is missing a directional distribution factor which accounts for the split of the vehicles by their direction of travel. This is an important factor because in most cases, where the directional distribution factor is assumed to be 50% of the AADT, this could reduce the future ESALs by half and hence, reduce pavement deterioration substantially.

The HERS-ST process and the HPMS dataset were carefully studied, and it was observed that the HPMS does include a directional split factor in the dataset, and it is used by the HERS-ST in the calculation of its capacity model, but it is not used in the calculation of its pavement deterioration model. This apparent shortcoming should be corrected in the future versions of HERS-ST and the technical report should be updated accordingly.

2.3 CALCULATING SUBSEQUENT EQUIVALENT 18-KIP SINGLE AXLE LOADS

The third step in the process calls for calculating the amount of ESALs it takes to degrade the pavement section from a PSR of 5.0 to its current base year value. So, if the current PSR value obtained from the HPMS dataset is 3.5, the HERS-ST calculates the amount of ESALs it would take to degrade the pavement from a PSR of 5.0 to a PSR of 3.5. For flexible pavements, this process is accomplished by applying the following equation:

$$ESAL_{subsequent} = 10^{LOGELA} \tag{4}$$

$$LOGELA = XA + \frac{XG}{XB} + XO + XM$$

$$XA = 9.36 * \log(SNA) - 0.2$$

$$XB = 0.4 + \frac{1094}{SNA^{5.19}}$$

$$XG = \log(\frac{(5 - PSRI)}{3.5})$$

$$SNA = SN + \sqrt{\frac{6}{SN}}$$

$$XO = ZR * S_O$$

$$XM = 2.32 * \log(M_R) - 8.07$$

$$ZR = INV_{strdev}(\mathrm{Re}\,l)$$

where:

SN	:	structural number indicative of total pavement thickness (HPMS Item 51),
PSRI	:	base year PSR (HPMS Item 36, or convert from Item 35 which is IRI),
Rel	:	reliability factor (dependent on functional class of roadway section),
M_R	:	resilient modulus of roadbed soil, and
SO	:	prediction error (depends on pavement type).

As it can be seen, this equation disaggregates the fundamental regression equation derived from the AASHO Road Test into several different parts. The base year PSR value is typically obtained from pavement roughness by applying the conversion equations discussed in Table 2. The structural number used in the equation is also obtained from the HPMS dataset. If for some reason the HPMS dataset does not provide a structural number for the pavement section, then the HERS-ST pre-processor system calculates a section structural number (or depth) based upon annual traffic demand. Furthermore it classifies the sections as being, light, medium, or heavy (Table 7) depending on the calculated structural number (or the thickness of the PCC slab).

Table 7: HERS-ST estimates structural number if none is provided (FHWA, 2005)

Rigid Pavements	Flexible Pavement	Pavement Section
$D \leq 7$	$SN \leq 3$	Light
$7 < D \leq 9$	$3 < SN \leq 4.5$	Medium
$9 < D$	$4.5 < SN$	Heavy

Depending on the pavement type and the functional classification of the roadway section, the pavement deterioration model also applies a reliability factor and prediction error factor to the calculation of equivalent single axle loads. The following input parameters are shown in Table 8.

Table 8. Input parameters for the flexible pavement model (FHWA, 2005).

Input Parameter	Description	Varies By	Default Values	
So	Prediction Error	Pavement Type	0.49	Flexible
			0.39	Rigid
Rel	Reliability Factor	Functional Class	90%	Interstate
			85%	Other
			80%	Collector
M_R	Modulus	Functional Class	4,000 for all FC's	

To calculate the amount of ESALs it takes to deteriorate the pavement section from a PSR of 5.0 to its current base year value for a rigid pavement, a different model is applied. The rigid pavement deterioration model is also based on the 1986 AASHTO Guide for Design of Pavement Structures and is presented below.

$$ESAL_{subsequent} = 10^{LOGELA} \qquad (5)$$

$$LOGELA = XO + XA + \frac{XG}{XB} + XN * XC$$

$$XA = 7.35 * \log(D + 1) - 0.06$$

$$XB = 1 + \frac{16.24 * 10^6}{(D + 1)^{8.46}}$$

$$XN = 4.22 - 0.32 * PT$$

$$XC = \log[\frac{SCP * CD * (D^{0.75} - 1.132)}{215.63 * J * (D^{0.75} - \frac{18.42}{(EC / K)^{0.25}})}]$$

where:

D	:	thickness (inches) of pavement slab (HPMS Item 51),
PT	:	design terminal serviceability index (2.5),
SCP	:	Portland cement concrete modulus of rupture (600 psi),
CD	:	load transfer coefficient (1.0),
J	:	drainage coefficient (3.0),
EC	:	Modulus of elasticity for portland cement concrete (3.5 x 106 psi), and
K	:	Modulus of subgrade reaction (200 pci)

From the equation, it can be seen that some assumptions are made about the material characterization of the concrete slab and the strength of the subgrade soils. These materials are assumed to be universal to all rigid pavement designs; however, in reality this is not the case and pavement response and deterioration will be affected by such assumptions. These input parameters should be changed to more accurately represent state conditions. This is discussed later in the report.

2.4 CALCULATING FUTURE PSR DUE TO TRAFFIC

Before calculating a future PSR value for the roadway section, the first step is to calculate the amount of ESALs it took to degrade the pavement from a PSR of 5.0 to its current base year value and then from its current base year to the future analysis year. This is done by summing up the future ESALs calculated from future traffic demand in step 2 and the subsequent ESALs calculated using the AASHTO regression equations in step 3.

$$ESAL_{Total} = ESAL_{future} + ESAL_{subsequent} \quad (6)$$

Once the total number of ESALs is known, the initial (PSRI) value in the AASHTO regression equation can be substituted with the unknown future PSR value, and solved.

$$PSRF = 5 - 3.5PDRAF_{pt} * 10^{XG} \quad (7)$$

$$XG_{flex.} = XB * [\log(ESAL_{Total}) - XA - XO - XM]$$

$$XG_{rigid} = XB * [\log(ESAL_{Total}) - XA - XO - XN * XC]$$

where:

PSRF	:	future year (or final) PSR due to traffic,
XG_{flex}	:	XG calculated for flexible pavements,
XG_{rigid}	:	XG calculated for rigid pavements, and
$PDRAF_{pt}$	:	pavement deterioration rate adjustment factor.

From Equation 7, it can be observed that the final PSR calculated for the future analysis year is adjusted by a factor called PDRAF. The technical report which accompanies the HERS-ST software package, gives guidance to the use of the PDRAF. It states that the PDRAF can be used to reflect the effects of the state's environment since it is not readily accounted for in the regression equations (FHWA, 2005). It can also be used to reflect the differences between various construction materials used throughout the state. In other words, the pavement deterioration rate adjustment factor can be used by the analyst to more accurately calibrate the model to fit state-specific conditions.

This factor becomes an important parameter when attempting to capture the performance of a network of roadways for an entire state. A pavement's structural integrity usually varies by functional class. For example, an urban freeway is typically built to the highest standards with the best available aggregates, increased load transfer through dowel bars, a subbase layer for drainage, and strict quality control. A local collector street, on the other hand, may rely on aggregate interlock for load transfer, may have a weaker subbase and use local aggregates. If exposed to the same traffic conditions, the freeway would perform significantly better than the local road. To account for these disparities, a pavement deterioration rate adjustment factor is applied to the equation. It adjusts the performance of a pavement section based on pavement type (flexible or rigid) and the roadway's functional class. The PDRF can be thought of as a global calibration factor which sums up all the disparities amongst various roadway sections into one parameter. It is presented in Table 9.

Table 9. Pavement deterioration rate adjustment factors (FHWA, 2005).

PDRAFs	HERST-ST Functional Classification	
	Code	Description
1.0	1	Rural Principal Arterial
1.0	2	Rural Other Principal Arterial
1.0	6	Rural Minor Arterial
1.0	7	Rural Major Collector
1.0	11	Urban Principal Arterial-Interstate
1.0	12	Urban Principal Arterial-Other Freeways and Expressways
1.0	14	Urban Other Principal Arterial
1.0	16	Urban Minor Arterial
1.0	17	Urban Collector

2.5 CALCULATING MINIMUM PAVEMENT DETERIORATION

It is assumed that a pavement that will not undergo any kind of traffic will experience some minimum amount of deterioration. This deterioration will be the result of environmental effects (such as freeze-thaw cycles, aging, erosion, thermally induced stresses, etc.) To account for these effects, the HERS-ST model applies a minimum deterioration rate to the pavement, and it makes sure that the deterioration experienced by the pavement due to traffic is greater than the deterioration experienced by the pavement if it were just exposed to the environment. This concept can be described mathematically by Equation 8.

$$PSRF < PSR_{MAX} \tag{8}$$

where:

PSRF	:	future year (or final) PSR due to traffic, and
PSR_{MAX}	:	maximum allowable PSR (associated with min. deterioration rate)

If for some reason the future year PSR due to traffic is higher than the maximum allowable PSR, then HERS-ST uses the maximum allowable PSR as the future year (or final) PSR. The maximum allowable PSR which is associated with the minimum pavement deterioration rate is calculated by the model using the following equation:

$$PSR_{MAX(t)} = PSR_{t0} * \left(\frac{PDL}{NPSRAI}\right)^{\frac{t-t0}{ML}} \tag{9}$$

where:

t	:	any time of interest,
t0	:	time at which section was last improved (HPMS Item 53), or six months before the beginning of the HERS run,
PSR_{t0}	:	PSR at time t0 (can be assumed as a base-year PSR if information on the section is limited),
PDL	:	pavement deficiency level (PSR at which the pavement section is determined to be deficient and needs either reconstruction or resurfacing),
NPSRAI	:	“normal” PSR after improvement, and
ML	:	maximum life of a pavement section in years.

There are certain parameters here that need to be understood. A pavement section is identified to be deficient by the HERS-ST model when its PSR value reaches some specified minimum criterion. This criterion can be a user-specified threshold or it can be a threshold specified by the HERS-ST. If it is a HERS-ST specified threshold, then it can be split up into two categories 1) Deficiency level (DL) which is the PSR at which a pavement needs to be resurfaced, and 2) Reconstruction level (RL) which is the PSR at which a pavement needs to be reconstructed. These values are presented in Table 10 for rural and urban sections, respectively.

Table 10. PSR deficiency levels which trigger an improvement (FHWA, 2005, HERS-ST Software V4.3).

RL	**DL**	**Rural**	
2.3	3.2		Flat
2.3	3.2	Interstate	Rolling
2.3	3.2		Mountainous
2.3	3.2		Flat
2.3	3.2	Other Principal Arterial ADT>6,000	Rolling
2.3	3.2		Mountainous
2.3	3.0		Flat
2.3	3.0	Other Principal Arterial ADT≤6,000	Rolling
2.3	3.0		Mountainous
2.0	2.6		Flat
2.0	2.6	Minor Arterial ADT>2,000	Rolling
2.0	2.6		Mountainous
2.0	2.6		Flat
2.0	2.6	Minor Arterial ADT≤2,000	Rolling
2.0	2.6		Mountainous
1.5	2.4		Flat
1.5	2.4	Collectors ADT>1,000	Rolling
1.5	2.4		Mountainous
1.5	2.4		Flat
1.5	2.4	Collectors ADT=400-1,000	Rolling
1.5	2.4		Mountainous
1.5	2.2		Flat
1.5	2.2	Collectors ADT<400	Rolling
1.5	2.2		Mountainous
RL	**DL**	**Urban**	
2.3	3.4		Interstate
2.3	3.2		Other Freeway
2.3	3		Other Primary Arterials
2.0	2.6		Minor Arterials
1.5	2.4		Collectors

It should be noted that the HERS-ST model does not always recommend pavement resurfacing as an improvement to the section. If it is more beneficial to allow the section's PSR to decrease to reconstruction levels and then reconstruct the pavement, HERS-ST will select the most beneficial scenario. That being said, it is important to understand the effects of the two improvements associated with pavement deterioration.

2.5.1 Pavement Resurfacing and Reconstruction

Pavement resurfacing occurs when the PSR value reaches a deficiency level (DL) specified by Table 10. Pavement resurfacing can be defined as an application of a flexible pavement overlay to the current pavement structure. The thickness of the overlay is determined based upon the forecast ESALs over the pavement's remaining design life. The thicknesses of the overlays are presented in Table 11.

Table 11. Pavement thickness after improvement (FHWA, 2005).

Forecast ESALs over Design Life	Pavement Type	
	Flexible	Rigid
≤ 50,000	1.5	6.5
50,001 - 150,000	2.5	6.5
150,001 - 500,000	3.0	6.5
500,001 - 2,000,000	4.0	8
2,000,001 - 7,000,000	5.0	9.5
> 7,000,000	5.5	10.5

Pavement overlays improve serviceability by adding a boost to the current PSR value. Table 12 shows how much a resurfacing activity adds to the PSR of a pavement section. Table 13 presents the maximum thresholds to how much a pavement with an overlay can be improved.

Table 12: Increase in PSR after resurfacing (FHWA, 2005).

Pavement Type	High Flexible	High Rigid	Medium Surface	Low Surface
Rural	1.8	1.8	1.8	1.8
Urban	1.8	1.8	1.8	1.8

Table 13. Maximum value of PSR after resurfacing (FHWA, 2005).

Pavement Type	High Flexible	High Rigid	Medium Surface	Low Surface
Rural	4.3	4.3	4.2	4
Urban	4.3	4.3	4.2	4

If the HERS-ST model proposes a reconstruction of the pavement, then the pavement is reconstructed according to characteristics of the previous structure. So, if the previous pavement structure was a flexible pavement, then the new reconstructed structure will also have a flexible pavement design. The thickness of the new reconstructed pavement structure will depend upon the forecast ESALs over the pavement's remaining design life and can be determined from Table 11. The reconstructed pavement will bear all the qualities of a new pavement. The PSR after reconstruction is presented in Table 14.

Table 14. PSR after reconstruction (FHWA, 2005).

Pavement Type	High Flexible	High Rigid	Medium Surface	Low Surface
Rural	4.6	4.6	4.4	4.2
Urban	4.6	4.6	4.4	4.2

2.5.2 Maximum pavement life

Another aspect of the minimum pavement deterioration rate which needs to be understood is the maximum pavement life parameter. The maximum life of a pavement is presented in Table 15. As it can be seen, the maximum pavement life is dependent upon the type of pavement and structural number or the thickness of the pavement.

Table 15. Maximum Pavement Life (FHWA, 2005).

Pavement Type	Flexible	Rigid
Heavy	25	30
Medium	20	25
Light	15	20

2.6 CALCULATING MAXIMUM PAVEMENT DETERIORATION

The HERS-ST model also applies a maximum deterioration rate to light pavements, or pavements with a structural number less than 3.0 or a slab thickness less than 7 inches. This factor is there to ensure that the deterioration experienced by the pavement section will not exceed some practical limit. Equation 10 describes this process mathematically:

$$PSRF > PSR_{\min} \qquad (10)$$

where:

PSRF : future year (or final) PSR due to traffic, and

PSR_{min} : minimum allowable PSR (associated with max. deterioration rate).

If for some reason the future year PSR due to traffic on a light pavement is lower than the minimum allowable PSR, then the HERS-ST model uses the minimum allowable PSR as the future year (or final) PSR. The minimum allowable PSR is calculated using a linear relationship which is described by Equation 11:

$$PSR_{\min.} = PSR_{t0} - PDR_{\max} * (t - t_0) \qquad (11)$$

where:

t : any time of interest,

t0 : time at which section was last improved (HPMS Item 53), or six months before the beginning of the HERS run,

PSR_{t0}	:	PSR at time t0, and
PDR_{max}	:	user specified maximum pavement deterioration rate (set to 0.3)

2.7 CALCULATING THE "FORECAST" PAVEMENT CONDITION

From the analysis conducted in the previous six steps, a forecast pavement condition can be obtained. The forecast pavement condition is dependent upon the future year PSR due to traffic (PSRF) and the two maximum and minimum serviceability boundaries. Equations 12 through 14 present this relationship.

$$PSR_{forecast} = PSRF \quad if, \quad PSR_{\min.} < PSRF < PSR_{\max} \tag{12}$$

$$PSR_{forecast} = PSR_{\max.} \quad if, \quad PSRF > PSR_{\max.} \tag{13}$$

$$PSR_{forecast} = PSR_{\min.} \quad if, \quad PSRF_{light\_pavements} < PSR_{\min.} \tag{14}$$

2.8 VALIDATING THE HERS-ST PAVEMENT DETERIORATION MODEL

To check the adequacy of the HERS-ST pavement deterioration model and to see if the principles discussed in the HERS-ST Technical Report (FHWA, 2005) were congruent with the actual behavior of the software, seven sections were selected from the 2007 Texas HPMS data file, tested with the HERS-ST software and validated with hand calculations conducted in a MS Excel spreadsheet. The trial sections chosen for this validation process are presented in Table 16.

Table 16. Trial sections chosen for validation process.

Section ID	000101M0 1057	000207M3 7201	000211M0 3661	000307M3 8801	000307M 46471	002201M1 3050	002202M2 5378
AADT	8,400	14,100	13,800	7,736	8,409	1,997	1,200
Future AADT	11,761	42,300	19,321	10,833	14,460	2,797	1,680
Future Year	2027	2027	2027	2027	2027	2027	2027
%Avg. SUT	5	4	4	3	3	3	4
%Avg. CUT	4	5	6	6	6	4	4
Fun. Class	14	1	1	1	11	2	2
Facility Type	2	2	2	2	2	2	2
Through Lanes	4	4	4	4	4	2	2
Surface Type	4	5	4	6	6	4	4
SN or D	4	10	5.9	4.7	5.2	3.4	3.4
Year of Improve.	0	0	0	2006	2006	0	0
Base IRI	109	97	64	60	73	95	88
Base PSR	3.30	3.46	3.92	3.98	3.79	3.48	3.58
PDRAF	1.0	1.0	1.0	1.0	1.0	1.0	1.0

From the table, it can be seen that the trial runs covered a number of facilities and a number of surface types. There were four high-type flexible pavement sections, two composite pavement sections which underwent an improvement in 2006 and one rigid pavement section selected for the analysis.

The HPMS data for these seven sections were entered into the HERS-ST software and a 20 year analysis with five four-year long funding periods was simulated. The present serviceability rating after two funding periods or eight years of analysis was recorded and compared to computations conducted in a MS Excel spreadsheet. These findings are presented in Table 17.

Table 17. Validation of the HERS-ST pavement deterioration model.

SECID	PSR0	IRI0	AADT0	Analysis	AADTf	PSRf (HERS-ST)	PSRf (MS Excel)
000101M01057	3.19	118.5	8,400	8 years	9,742	3.07	3.07
000207M37201	3.24	100.9	14,100	8 years	25,840	4.2	3.16
000211M03661	3.9	65.7	13,800	8 years	16,002	3.87	3.87
000307M38801	3.75	62.8	7,736	8 years	8,964	3.7	3.7
000307M46471	3.52	76.3	8,409	8 years	10,785	3.46	3.46
002201M13050	3.42	100.2	1,997	8 years	2,305	3.34	3.34
002202M25378	3.53	91.3	1,200	8 years	1,387	3.49	3.49

From the table it can be seen that the PSR calculations conducted by the HERS-ST software were almost identical to those calculated in the MS Excel spreadsheet when applying the principals discussed in the previous sections of this report. One disparity exists for the second section in the Table 17. This was a section whose serviceability rating decreased below the deficiency level of 3.2 PSR and warranted a resurfacing job which HERS-ST implemented at the end of the first funding period.

From this analysis it can be concluded with high confidence that the pavement deterioration model imbedded in the HERS-ST software package works and it is consistent with the principals discussed in the Technical Report (FHWA, 2005).

2.9 PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

From the discussion of the HERS-ST pavement deterioration model, some preliminary conclusions can be drawn about its accuracy and its effectiveness: The pavement deterioration model embedded in the HERS-ST model is an effective tool for predicting pavement deterioration on a system-wide level; however, certain improvements should be incorporated before it can be considered for state-wide implementation in Texas. These recommended improvements are listed below:

4) Consideration of updated correlation equations for converting field measured IRI to PSR. In Texas, we use Ride Score, so a direct conversion between ride score and serviceability would be beneficial.
5) Consideration of updated load equivalency factors for converting truck traffic into equivalent single axle loads. This factors should be based on mechanistic concepts and depend on project-specific and local condition.

6) Addition of a directional distribution factor which accounts for the split of the vehicles by their direction of travel.

Specific attention should be paid to updating the load equivalency factors because, as was mentioned earlier in the report the degree of variability and uncertainty introduced is quite high. It is unclear how current values were derived, and it is unclear if any documentation of their derivations exists. It is also unclear if these values are accurate, because as was mentioned earlier there are several notable inconsistencies within the data. Besides, while accurate for one location, they may be inaccurate for other location.

The most urgent and simple improvement that should be made to the HERS-ST pavement deterioration model is the addition of a directional distribution factor. This factor is currently missing from the conversion equation which allows future traffic to be converted into future equivalent single axle loads. The directional distribution factor is an important parameter when calculating pavement deterioration and without it deterioration can be largely over-predicted. This can cause significantly different improvement scenarios and it can jeopardize the effectiveness of the HERS-ST software for assessing system needs.

CHAPTER 3. CALIBRATING THE PAVEMENT DETERIORATION MODEL

The HERS-ST software package comes with two data files which allow for the calibration of the pavement deterioration model. These two data files are imbedded within the *Default* folder of the HERS-ST application and they are labeled as **Params.dat** and **Dltbls.dat**.

The Dltbls.dat file is a data-tables file which allows for the calibration of certain pavement deficiency and pavement reconstruction levels (FHWA, 2005). For example, if a specific state does not reconstruct its urban interstates at a PSR of 2.4, but instead reconstructs them at a PSR of 2.6, this type of change can be made within the Dltbls.dat file to reflect state-specific scenario.

The other file (Params.dat) allows for direct calibration of many of the parameters discussed in the previous chapter. The parameters which the HERS-ST model allows the analyst to calibrate through the Params.dat file are as follows:

1) Pavement deterioration rate adjustment factors (currently set to 1.0)
2) Load equivalency factors for single unit and combination trucks (refer to table 5)
3) Maximum pavement deterioration rate (currently set to 0.3 PSR/year)
4) Maximum pavement life which governs the minimum pavement deterioration rate
5) Flexible pavement input parameters (refer to table 8)
6) Rigid pavement input parameters (refer to equation 5)
7) Truck growth factors

In the previous chapter, it was described how and when these parameters are used. It was also described how changing some of these parameters would change the predicted outcome. This is important to understand because we need to know how we can adjust these parameters to more accurately represent real life pavement conditions. This, in turn, will yield better results and a more comprehensive way of estimating system-wide pavement performance and assessing system-wide pavement needs.

In the following sections, we discuss the calibrating one of the parameters employed in the HERS-ST pavement deterioration model and the efforts that went into its calibration. Furthermore, the following sections will discuss the robustness of the calibrated parameter and the conclusions derived from the calibration effort. The parameter under scrutiny is the pavement deterioration rate adjustment factors (PDRAFs) for the nine functional classification systems employed by the HERS-ST model.

3.1 CALIBRATING PAVEMENT DETERIORATION ADJUSTMENT FACTORS

The pavement deterioration rate adjustment factors can be thought of as global calibration factors which have the ability to adjust for any inconsistencies within the pavement deterioration model by directly influencing the final PSR due to traffic. To reacquaint the reader with the pavement deterioration model, Equation 7 is once again presented below.

$$PSRF = 5 - 3.5PDRAF_{pt} * 10^{XG} \tag{7}$$

$$XG_{flex.} = XB*[\log(ESAL_{Total}) - XA - XO - XM]$$
$$XG_{rigid} = XB*[\log(ESAL_{Total}) - XA - XO - XN*XC]$$

where:

$PSRF$	:	future year (or final) PSR due to traffic,
$XG_{flex.}$	:	XG calculated for flexible pavements,
XG_{rigid}	:	XG calculated for rigid pavements, and
$PDRAF_{pt}$	:	pavement deterioration rate adjustment factor.

From the equation it can be seen that the PDRAF has a significant influence on a pavement section's final PSR. It can be seen that values of PDRAF which are greater than 1.0 will increase the rate of pavement deterioration, while values of PDRAF which are less than 1.0 will do the opposite. Currently, all PDRAF values are set to 1.0 for all functional classes (refer to Table 9). However, different roadways are built for different functions with different materials. For example, an urban concrete pavement collector road will not only have a different slab thickness than an urban concrete pavement freeway, but it may also be constructed with different materials. The concrete may not have the same flexural strength on the collector as it does on the freeway, the aggregates may be a locally available and not as durable, the compaction effort that goes into strengthening the subgrade soils may not be as intensive, and the load transfer between slabs may rely solely on aggregate interlocks in the case of the collector road while dowel bars are used for the urban freeway. These are all internal parameters which cannot be readily accounted for on an individual level, but with a pavement deterioration rate adjustment factor they can be grouped into categories according to their functional classification. In the example presented above, the PDRAF for the urban freeway facility may be expected to have a value of less than 1.0 to represent the better mix of materials and the extra quality control that went into its construction.

The PDRAF can also be used to reflect the effects of the state's environment (FHWA, 2005). For example, if it is seen that because of extra freeze-thaw cycles pavement sections are deteriorating faster than what is predicted by the HERS-ST pavement deterioration model, than the PDRAFs can be adjusted accordingly to account for the disparity between predicted performance and field observations.

Because this factor is so influential over the pavement deterioration model, it was decided that calibrating the PDRAF to state-specific conditions would be the best option. In order to calibrate the PDRAFs, a simple question had to be asked: *What PDRAF value do we need to attain so that the predicted pavement performance matches actual pavement performance over some analysis period?* To answer this question a procedure was developed and it is presented in Figure 3.

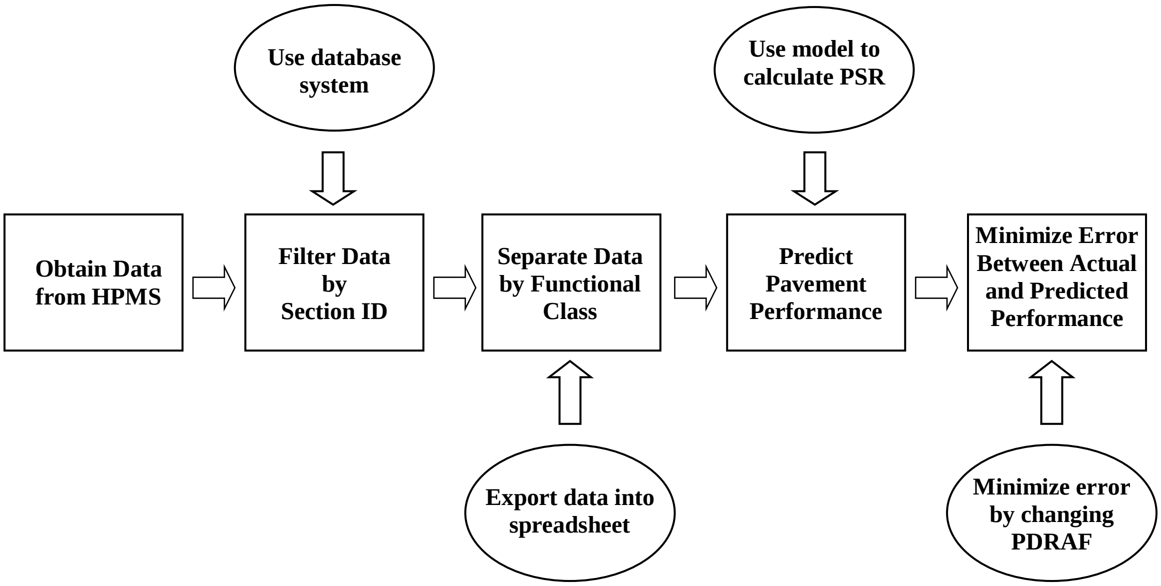

Figure 3. Procedure for Calibrating the PDRAFs.

From Figure 3, it can be seen that the calibration effort attempts to study a sample of data. Then based on that sample, it attempts to calibrate the pavement deterioration model so it replicates real-life pavement performance by minimizing the error between actual and predicted PSR values over a span of several years. This effort can be broken down into the following five steps:

1) ***Step 1: Obtain HPMS data.*** HPMS data for the state of Texas was obtained from year 1993 to year 2007 in two-year time intervals (i.e. data was received for the following years: 1993, 1995, 1997, 1999, 2001, 2003, 2005, and 2007). Out of the received data, it was determined that only data from years 2001-2007 can be used for the calibration of the pavement deterioration rate adjustment factors. HPMS data which ranged from years 1993-1998 used an older format of the HPMS coding and was not compatible with the 1999-2007 data and could not be used by the HERS-ST. The 1999 year data was also found to be incompatible with the 2001-2007 data because of the disparities between section IDs. If calibration of the pavement deterioration rate adjustment factors is to be conducted for a specific state, the analyst should refer to the HPMS Field Manual to gain a better understanding of how the old format differs from the new one.

2) ***Step 2: Filter data for similar sections.*** In order to monitor the rate at which the pavement network deteriorates in the state of Texas, individual sections have to be observed separately. To do so, a database was created with HPMS data ranging from year 2001-2007 and the database was filtered by section ID. In total, there were 4,997 roadway sections which had the same section ID from year 2001 to year 2007. This allowed us to monitor how recorded IRI changed during the six-year analysis period for each individual section. Furthermore, it was reasoned that, if a pavement section did not receive any improvements from year 2001-2007 then, theoretically, its roughness index should be consistently increasing and the serviceability rating should be consistently decreasing during the six-year analysis period. Therefore, the dataset was further queried for sections that did not receive a section improvement from years 2001-2007. In total there were 3,594 usable pavement sections split amongst the nine functional classes.

3) **Step 3: Separate sections by functional class**. In this step the 3,594 sections were exported out of the database into an excel spreadsheet and separated according to their functional class. Table 18 presents how this data was split amongst the various functional classes:

Table 18. HPMS sections used for the analysis.

Class Description	Functional Code	No. of Flexible Pavement Sections	No. of Rigid Pavement Sections
Rural Interstate	1	53	18
Rural Principal Arterial	2	149	6
Rural Minor Arterial	6	135	4
Rural Major Collector	7	279	2
Urban Interstate	11	90	79
Urban Freeway	12	122	120
Urban Principal Arterial	14	755	189
Urban Minor Arterial	16	677	135
Urban Collector	17	679	102

4) ***Step 4: Predict pavement performance.*** Pavement performance can be predicted by applying the HERS-ST pavement deterioration model discussed in the previous section. In this calibration effort, pavement performance was predicted for all 3,594 sections on a two-year, four-year, and six-year analysis basis. To do so, an extensive MS Excel spreadsheet was created and coded in accordance with the equations used by the pavement deterioration model. The HERS-ST software itself was not used in this calibration effort because of complications involving various improvement scenarios the software implements during the analysis. However, since the software was validated with the technical report (Chapter 2), it was decided that there was no need to involve a complicated system when a simple spreadsheet can be used. An example of the calculated data for one section ID is presented in Table 19 below.

Table 19. Example of calculated data for calibration.

Functional Code	1	Lane Dist. Factor	0.9
Section ID	001704M10000	ESALSfuture	1,963,022
Type of Facility	2	XA	7.2067
No of Through Lanes in Both Directions	4	XB	0.4855
Surf./Pavement Type	4	XG	-0.4085
StrNumorDepth	5.1	SNA (or XN)	6.1847
Year of Last Surface Improvement	1998	XO	0.6280
qry2001.Year	2001	XM (or XC)	0.2868
qry2001.AADT	23,832	ZR	1.2816
qry2001.IRI	84	So	0.49
qry2001.BasePSR	3.63	Reliability	90%
qry2001.%ADSUTrucks	6	MR	4,000
qry2001.%ADCUTrucks	21	LOGELA	7.2801
qry2003.%ADSUTrucks	6	ESALsubsequent	19,058,090
qry2003.%ADCUTrucks	22	ESALTotal	23,070,782
qry2001.Directional Factor	63	XG	-0.3682
qry2003.Year	2003	PDRF	1.00000
qry2003.AADT	26,390	PSRPredicted-2003	3.50
Total Traffic (2001-2003)	18,331,030	PSRActual -2003	3.59
LEFSUTrucks	0.2898	Error2	0.0084
LEFCUTrucks	1.0504	Pavement Type	Flex

From this data table, it can be seen that with a PDRAF of 1.0, the HERS-ST pavement deterioration model predicted a PSR of 3.50 after a two-year analysis. However, from field data acquired from the HPMS, it was seen that actual PSR was determined to be 3.59 (or IRI of 87 in/mi). This led to an error of 2.55% between the actual and the predicted value. This is a small error, which implies that in this single case the pavement deterioration model did an adequate job at predicting pavement deterioration. But, *how accurate would the model become if the analysis period was extended to 4 years or 6 years, and the number of pavement sections was increased from 1 to 100 or even 1,000? How much consistency would there be between predicted values and actual values? And, what kind of trends, if any would emerge?* These are all questions that need to be answered after further calibration.

5) **Step 5: Calibrate model by adjusting PDRAFs .** The last step in the calibration process involves minimizing the square error between actual and predicted performance by adjusting the PDRAF for each individual section. This was done through the use of the MS Solver tool. For the example above, the PDRAF which minimized the error

between the actual PSR and predicted PSR was determined to be 0.9389 (with a square error term of 1.97E-31). A more generalized solution is presented by Equation 15.

$$Find \quad PDRAF \quad so \quad that \quad (PSRF - PSR_{Actual})^2 = 0 \tag{15}$$

If this sort of calibration is done for all 3,594 pavement sections in the sample dataset, then one would develop a range of PDRAFs for each one of the functional classes. This range could then be analyzed and used to develop a common PDRAF for each one of the functional classes.

3.2 RESULTS FROM THE CALIBRATION EFFORT FOR THE STATE OF TEXAS

The calibration effort for the state of Texas was conducted on a two-year, four-year, and six-year analysis basis. Actual PSR after two years, four years, and six years was compared against the PSR predicted by the pavement deterioration model. Afterwards the PDRAFs were adjusted for each pavement section to yield a minimum square error between the predicted and actual values. This yielded a range of PDRAFs, which for some functional classes ranged from 0.001 to 11.5. To obtain a representative idea of where the bulk of the values lied for each functional class, frequency plots were created. For each functional class PDRAFs were split by pavement type (flexible and rigid) and the frequency plots for the PDRAFs were split respectively. The analyses were conducted on a two-year, four-year, and six year basis to monitor how the PDRAF's shifted with longer analysis periods.

The results of the calibration effort are presented in Figures 4 through 22. It is worth mentioning at this time that, although the procedure which was developed for this calibration effort is believed to be logical and sound, the accuracy of these results is believed to be undermined by the quality of data obtained from the HPMS database. These issues will be discussed further at the end of this chapter.

3.2.1 Results for Rural Interstates

From Figures 4 and 5 and the statistics presented in Table 20, it can be seen that for rural interstates the range of PDRAFs varies from about 0.4 to 1.4 with a significant concentration of PDRAFs from between 0.9 to 1.1. This would imply that based on the HPMS data the model does an adequate job of predicting performance with a PDRAF of 1.0. Of course discrepancy in pavement deterioration will exist because the state of Texas spans over several climatic regions and pavement deterioration is expected to fluctuate from region to region. For example, some pavement sections are in regions of East Texas where they have expansive soils and receive a significant amount of rain, while other sections are in regions of West Texas where they have hard caliche subgrade soils and experience ideal pavement weather conditions, so pavement deterioration and hence pavement deterioration factors will vary respectively.

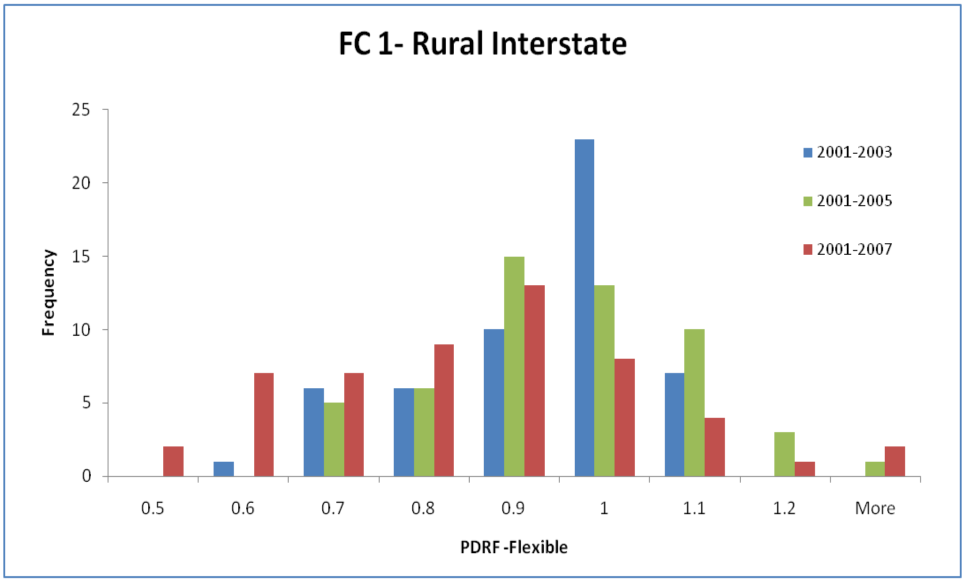

Figure 4. PDRAFs for Rural Interstates (Flexible Pavements).

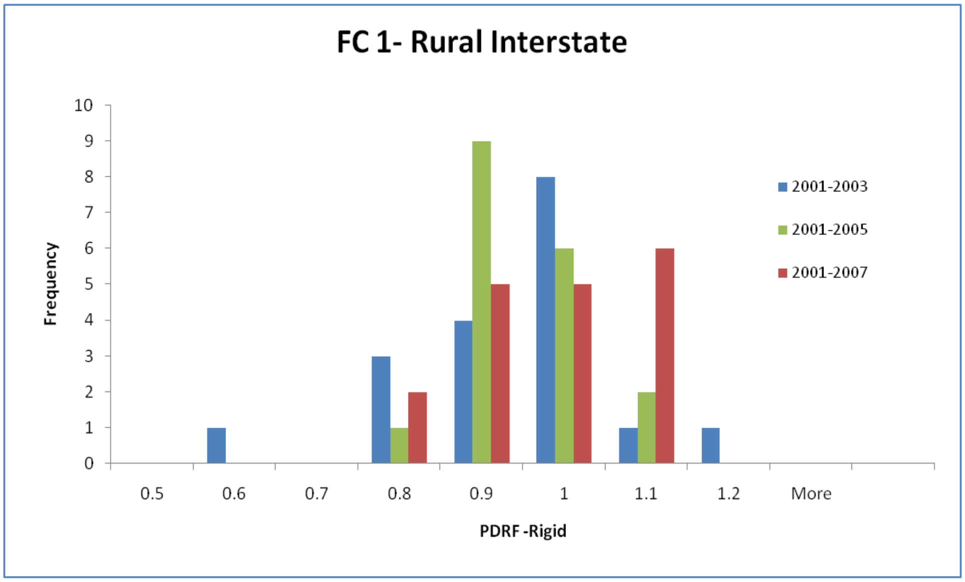

Figure 5. PDRAFs for Rural Interstates (Rigid Pavements).

Table 20: Statistics from calibration effort for rural interstates

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.878	0.909	0.805	0.892	0.904	0.827
Max	1.069	1.210	1.385	1.136	1.048	0.954
Min	0.513	0.621	0.443	0.595	0.701	0.644

3.2.2 Results for Rural Principal Arterials

From Figures 6 and 7 and the statistics presented in Table 21, it can be seen that for rural principal arterials the range of PDRAFs varies from about 0.2 to 1.7 with a significant concentration of PDRAFs in the range of 0.9 to 1.1. From the flexible principal arterial pavement network it can be observed that the range of the PDRAFs shifted to the left.

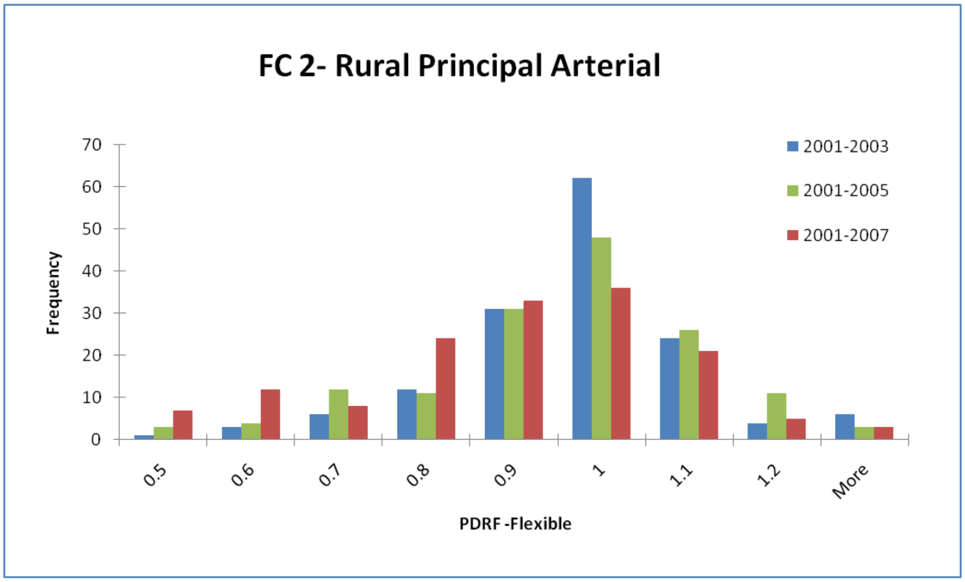

Figure 6. PDRAFs for Rural Principal Arterials (Flexible Pavements).

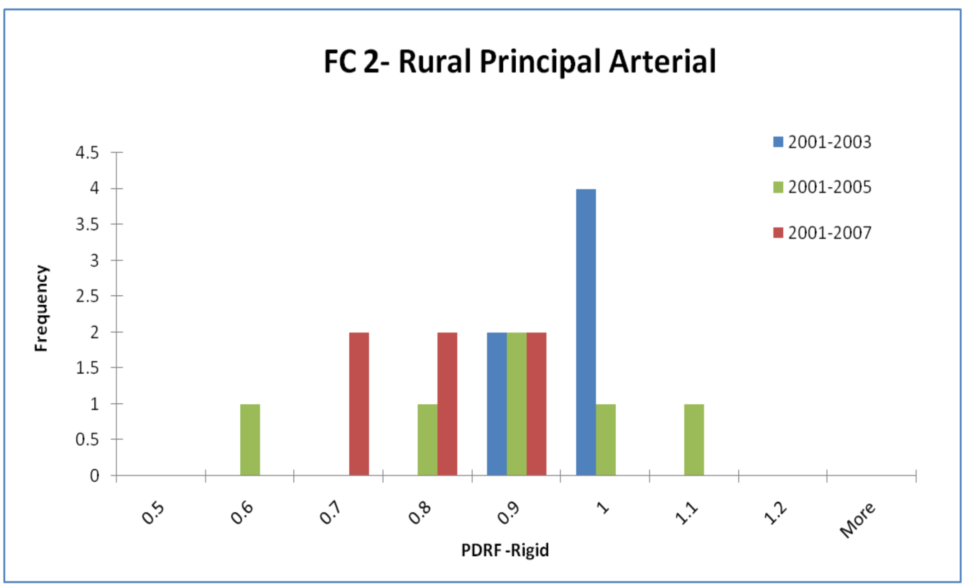

Figure 7. PDRAFs for Rural Principal Arterials (Rigid Pavements)/

Table 21. Statistics from calibration effort for rural principal arterials.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.935	0.905	0.849	0.923	0.827	0.753
Max	1.688	1.296	1.277	0.984	1.063	0.877
Min	0.453	0.412	0.244	0.853	0.529	0.629

3.2.3 Results for Rural Minor Arterials

From Figures 8 and 9 and the statistics presented in Table 22, it can be seen that for rural minor arterials the range of PDRAFs varies from about 0.4 to 2.2 with a significant concentration of PDRAFs from between 0.9 to 1.0. From the flexible pavement network it can also be seen that the highest concentration of PDRAFs shifted from a value of 1.0 to a value of 0.9 with a longer analysis period.

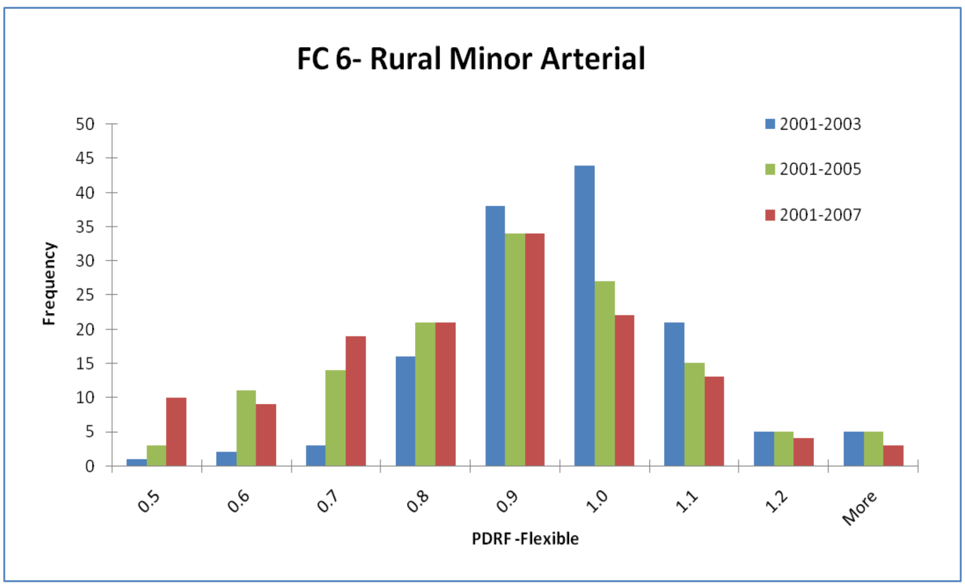

Figure 8. PDRAFs for Rural Minor Arterials (Flexible Pavements).

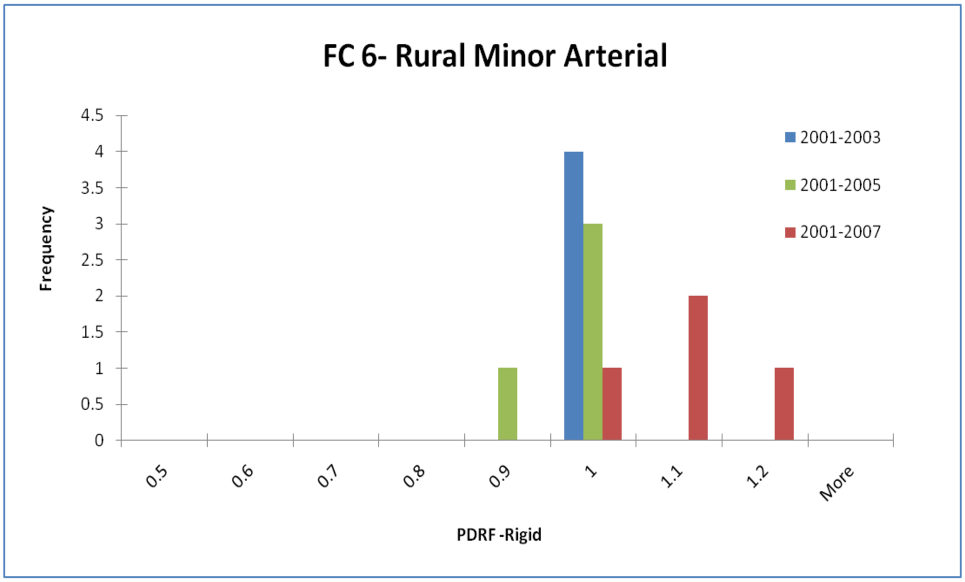

Figure 9. PDRAFs for Rural Minor Arterials (Rigid Pavements).

Table 22. Statistics from calibration effort for rural minor arterials.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.918	0.849	0.822	0.979	0.944	1.036
Max	1.637	1.323	2.236	0.988	0.999	1.105
Min	0.412	0.457	0.292	0.973	0.824	0.970

3.2.4 Results for Rural Major Collectors

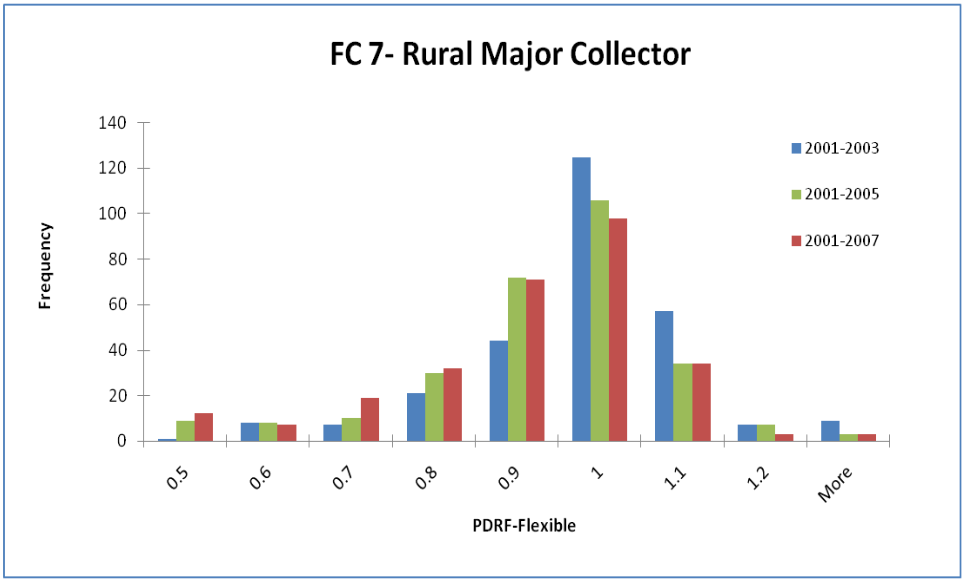

Figure 10. PDRAFs for Rural Major Collectors (Flexible Pavements).

Table 23: Statistics from calibration effort for rural major collectors

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.933	0.885	0.863	1.004	0.974	0.780
Max	1.895	1.368	1.314	1.013	0.979	0.917
Min	0.335	0.239	0.137	0.995	0.969	0.643

From Figure 10 and the statistics presented in Table 23, it can be seen that for rural major collectors the range of PDRAFs varies from about 0.1 to 1.9 with a significant concentration of PDRAFs in the range of 0.9 to 1.0. The chart for the rigid pavement network is not shown as there were only two observations and their statistics are presented in Table 23.

3.2.5 Results for Urban Interstates

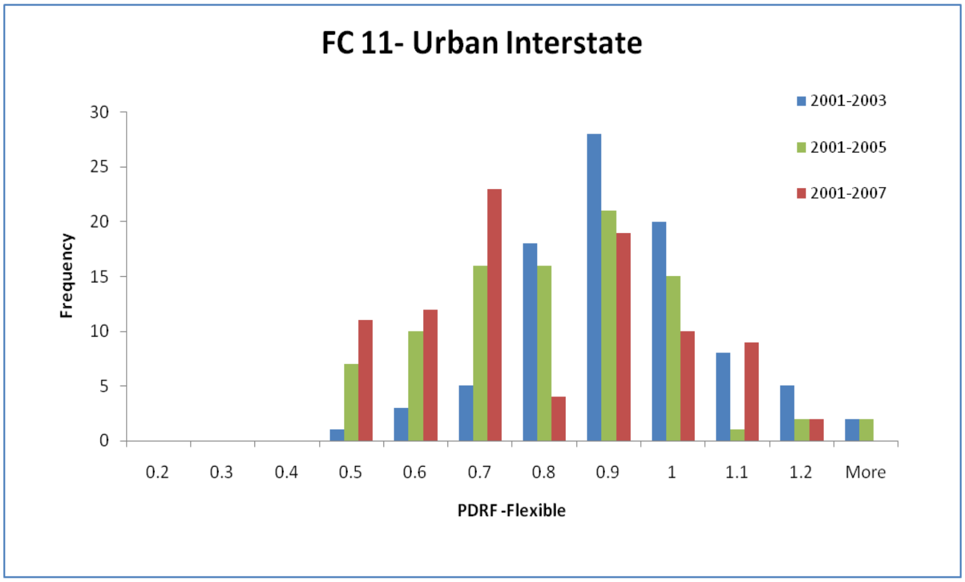

Figure 11. PDRAFs for Urban Interstates (Flexible Pavements).

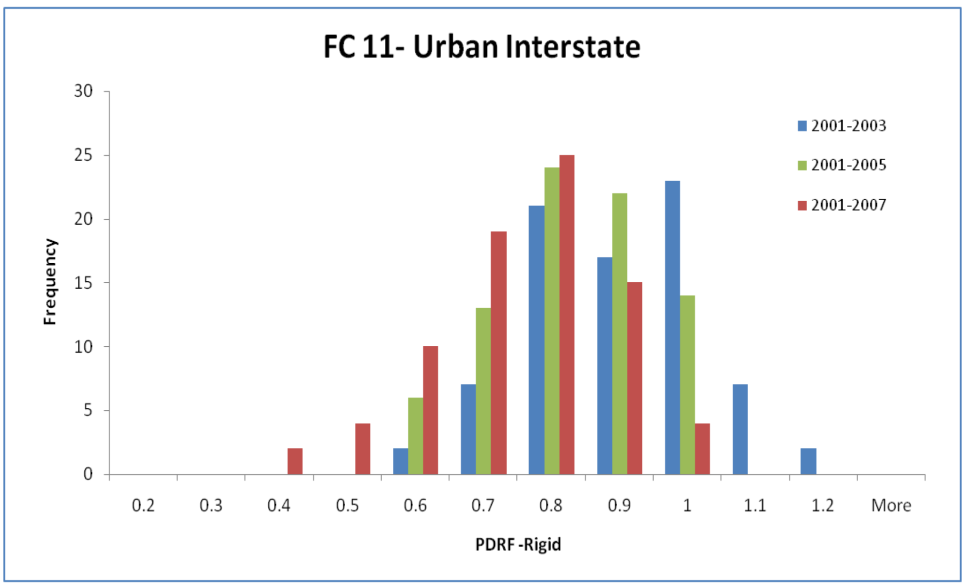

Figure 12. PDRAFs for Urban Interstates (Rigid Pavements).

From Figures 10 and 11 and the statistics presented in Table 24, it can be seen that for urban interstates the range of PDRAFs varies from about 0.4 to 1.4 with a significant concentration of PDRAFs in the range of 0.7 to 0.9. The smaller range of PDRAFs may imply that there is more quality control that goes into the design of urban interstates and hence pavement deterioration is more predictable on that facility throughout the state of Texas.

Table 24. Statistics from calibration effort for urban interstates.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.874	0.768	0.744	0.860	0.789	0.707
Max	1.433	1.350	1.154	1.158	1.000	0.969
Min	0.439	0.403	0.460	0.582	0.547	0.343

3.2.6 Results for Urban Freeways

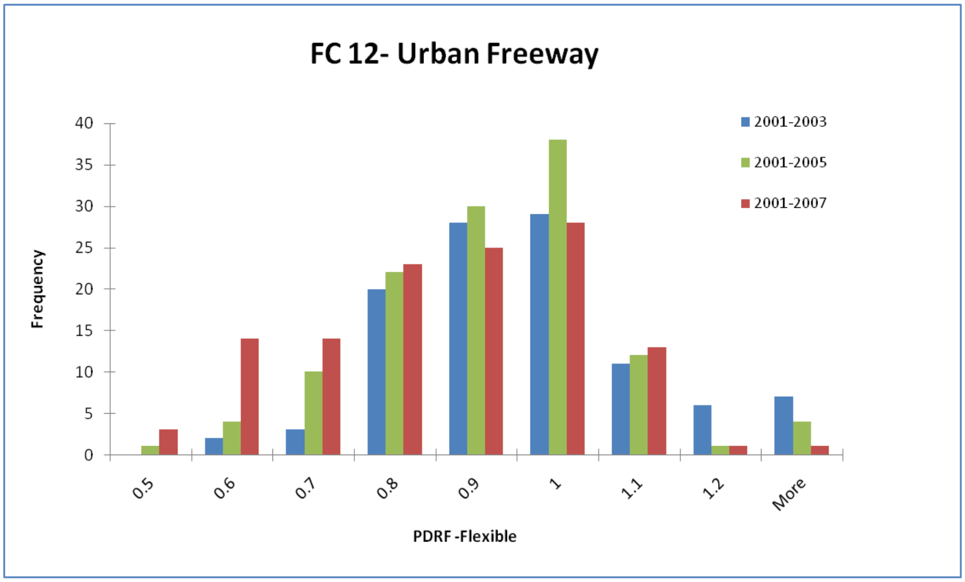

Figure 13. PDRAFs for Urban Freeway (Flexible Pavements).

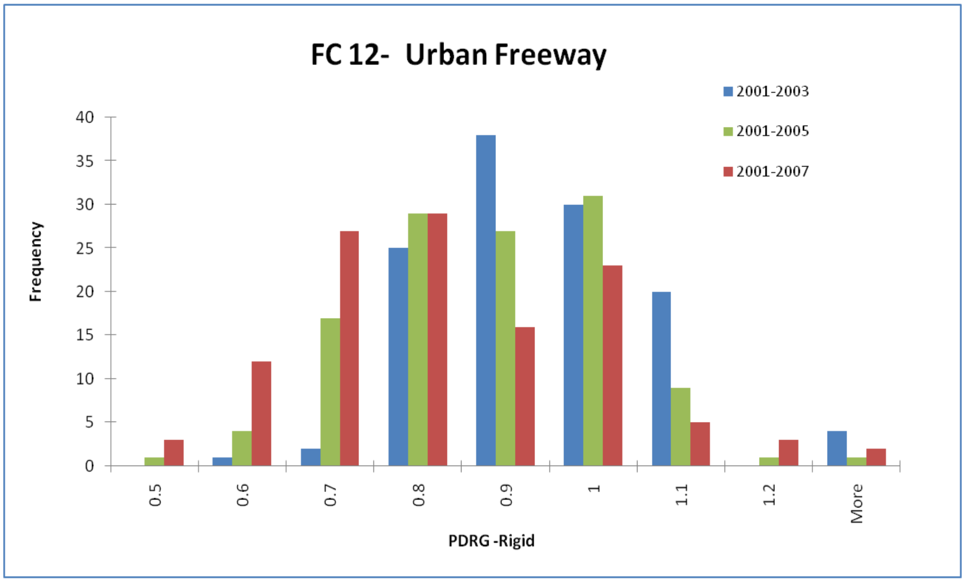

Figure 14. PDRAFs for Urban Freeway (Rigid Pavements).

Table 25. Statistics from calibration effort for urban freeways.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	0.928	0.875	0.810	0.909	0.838	0.790
Max	1.734	1.482	1.216	2.239	1.760	1.987
Min	0.560	0.483	0.450	0.586	0.468	0.436

From Figures 13 and 14 and the statistics presented in Table 25, it can be seen that for urban freeways the range of PDRAFs varies from about 0.4 to 2.2 with a significant concentration of PDRAFs in the range of 0.8 to 1.0.

3.2.7 Results for Urban Principal Arterials

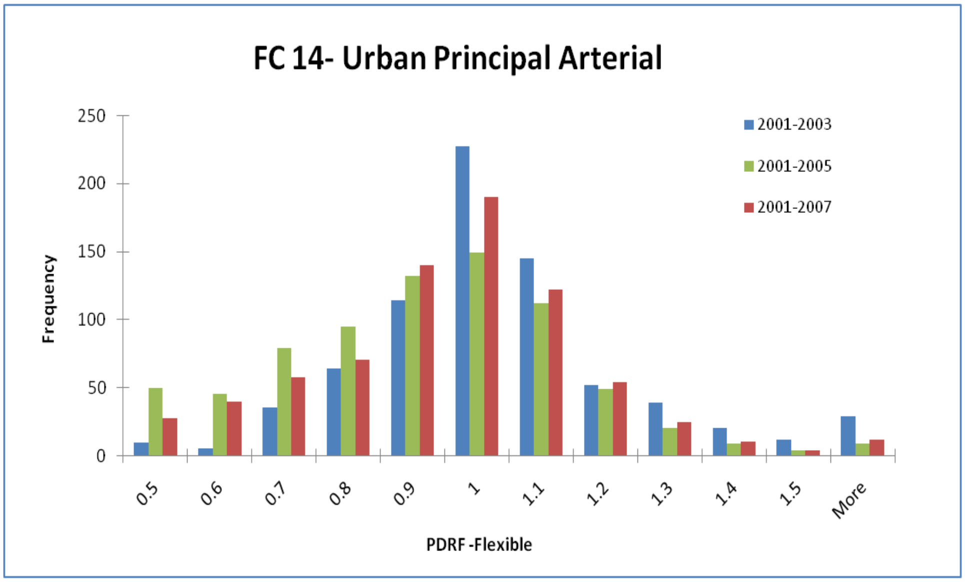

Figure 15. PDRAFs for Urban Principal Arterials (Flexible Pavements).

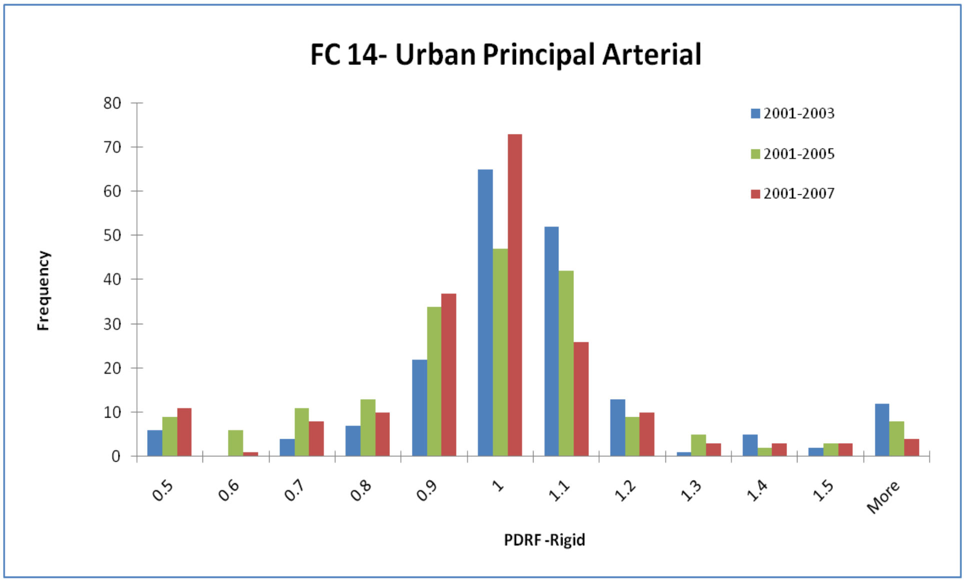

Figure 16. PDRAFs for Urban Principal Arterials (Rigid Pavements).

From Figures 15 and 16 and the statistics presented in Table 26, it can be seen that for urban principal arterials the range of PDRAFs varies from about 0.0 to 32.6 with a significant concentration of PDRAFs in the range of 0.9 to 1.1. This large range of PDRAFs and the significant number of outlying values implies that the data used for the calibration effort has a large degree of variability and should be given further scrutiny before a common PDRAF can be applied for this functional class.

Table 26. Statistics from calibration effort for urban freeways.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	1.022	0.874	0.912	1.080	1.485	0.935
Max	11.530	4.916	2.404	6.672	32.572	1.831
Min	0.000	0.190	0.235	0.000	0.233	0.373

3.2.8 Results for Urban Minor Arterials

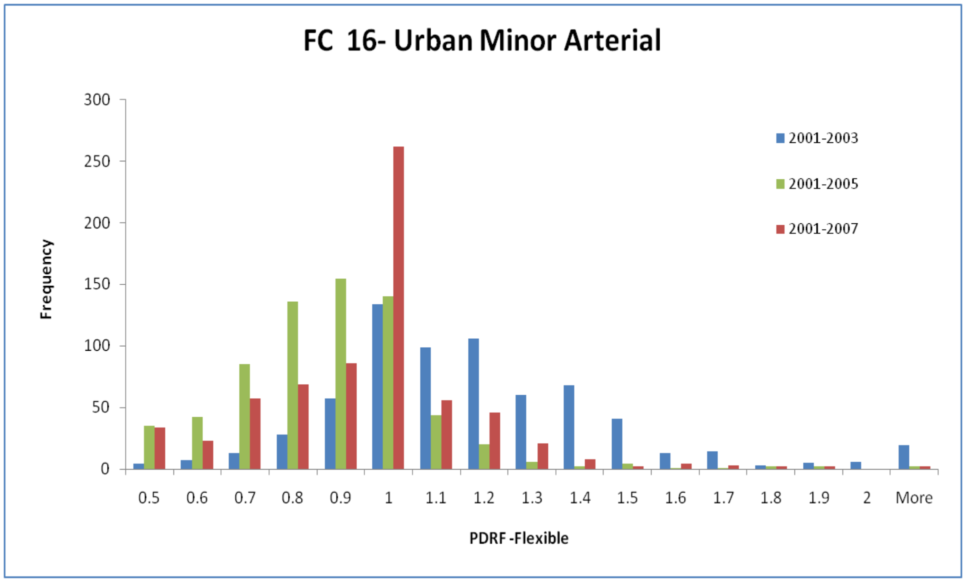

Figure 17. PDRAFs for Urban Minor Arterials (Flexible Pavements).

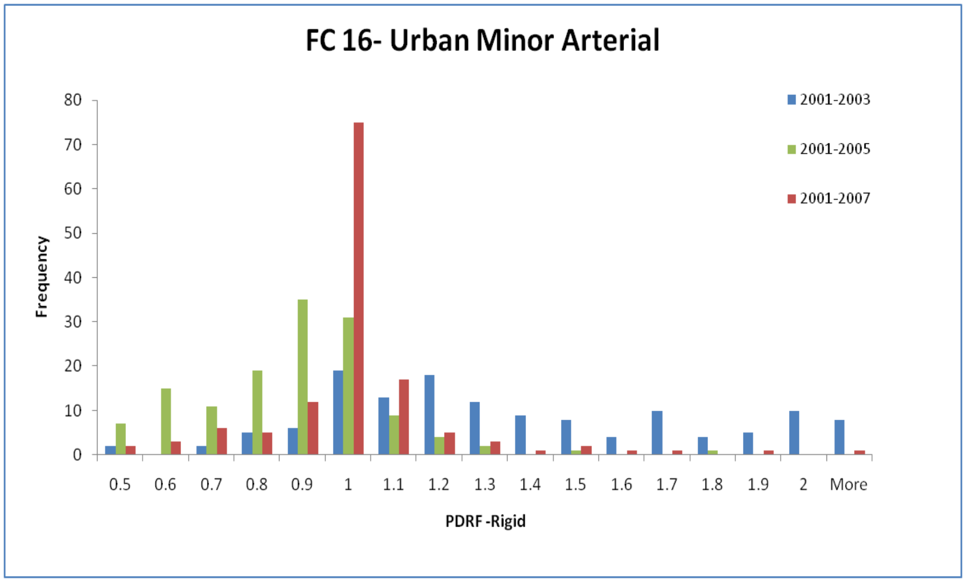

Figure 18. PDRAFs for Urban Minor Arterials (Rigid Pavements).

Table 27. Statistics from calibration effort for urban freeways.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	1.317	0.833	0.911	1.996	0.830	0.984
Max	25.901	3.041	2.966	26.858	1.715	3.842
Min	0.345	0.000	0.196	0.400	0.100	0.262

From Figures 17 and 17 and the statistics presented in Table 27, it can be seen that for urban minor arterials the range of PDRAFs varies from about 0.0 to 26.9 with a significant concentration of PDRAFs in the range of 0.8 to 1.0. This large range of PDRAFs and the significant number of outlying values once again implies that the data used for the calibration effort has a large degree of variability and should be given further scrutiny.

3.2.9 Results for Urban Collector Roads

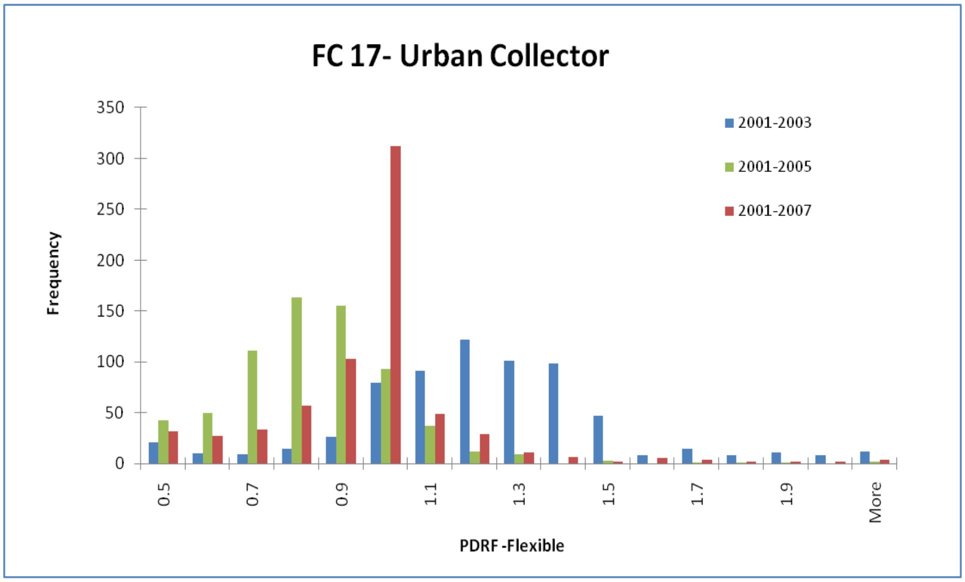

Figure 19. PDRAFs for Urban Collectors (Flexible Pavements).

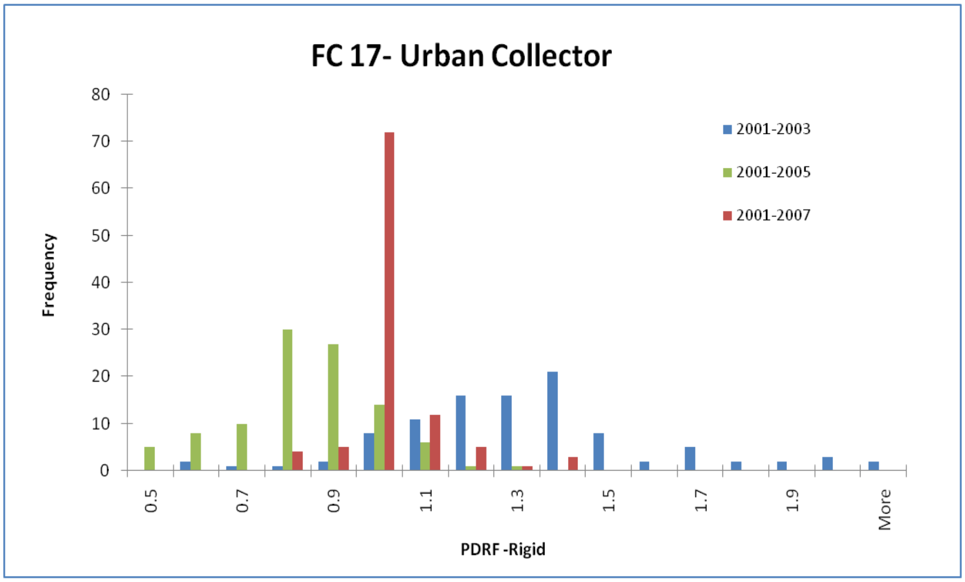

Figure 20. PDRAFs for Urban Collectors (Rigid Pavements).

Table 28. Statistics from calibration effort for urban freeways.

	Flexible Pavement Network			Rigid Pavement Network		
PDRAF	2001-2003	2001-2005	2001-2007	2001-2003	2001-2005	2001-2007
Mean	1.209	0.793	0.936	1.302	0.796	0.989
Max	7.455	2.742	10.236	3.991	1.263	1.330
Min	0.071	0.065	0.147	0.526	0.162	0.709

From Figures 19 and 20 and the statistics presented in Table 28, it can be seen that for urban collector roads the range of PDRAFs varies from about 0.1 to 10.2 with a significant concentration of PDRAFs in the range of 0.8 to 1.0. This large range of PDRAFs and the significant number of outlying values once again implies that the data used for the calibration effort has a large degree of variability and should be further evaluated to determine the underlying causes.

3.3 DISCUSSION OF RESULTS

From the results of the calibration effort presented in the previous section, it can be seen that the PDRAF is a data sensitive parameter. It is understood that the state of Texas spans over several climatic regions and the environmental effects on pavement deterioration can differ from region to region. Therefore, a range of PDRAFs was expected and observed for each functional class. Frequency plots and statistics were developed for each range to assist the analyst in determining some common PDRAF value for each functional class. However, it was observed that the variability between PDRAFs increased significantly for lower functional classes. In some instances, such as the urban principal arterials, urban minor arterials, and urban collector roads, the variability was so high that a common PDRAF could not be readily determined.

This led to wonder about the applicability of HPMS data for accurate calibration of the HERS-ST model. Therefore, the HPMS dataset for years 2001-2007 was accessed and the average change in IRI from year to year was observed for each functional roadway class. It was reasoned that, since all of the sections in the analysis were original sections, meaning that they were sections (apparently) that did not undergo a surface improvement between the years of 2001-2007, then the average IRI for each functional class should consistently increase from year to year. However, on the contrary, quite different results were found. Figures 21 and 22 present the average change in IRI for each functional class of the rural and urban pavement networks.

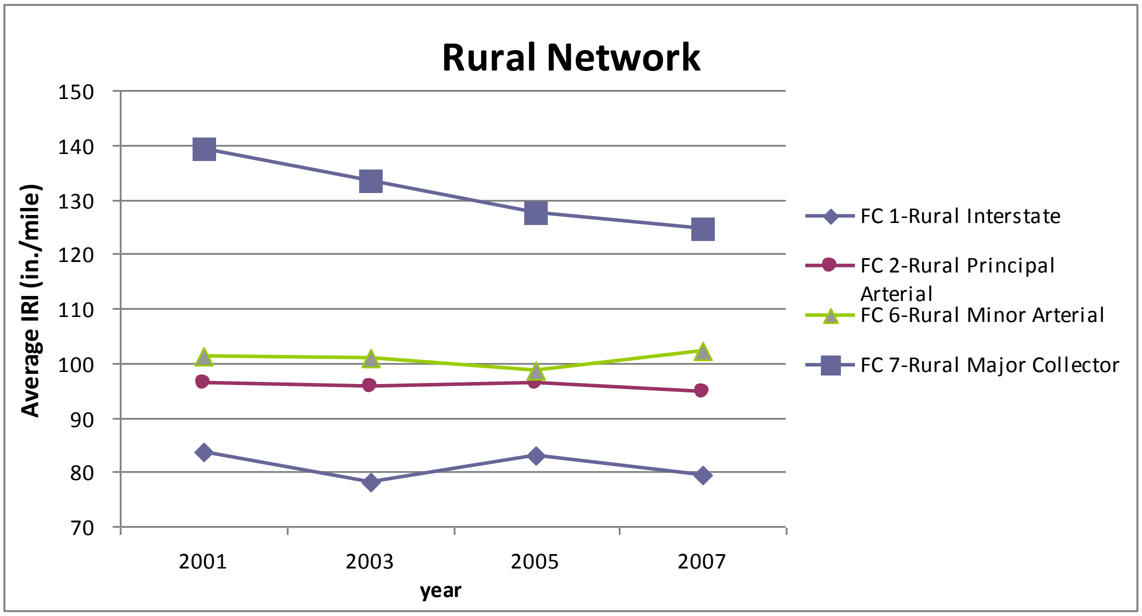

Figure 21. Average IRI for the Rural Pavement Network.

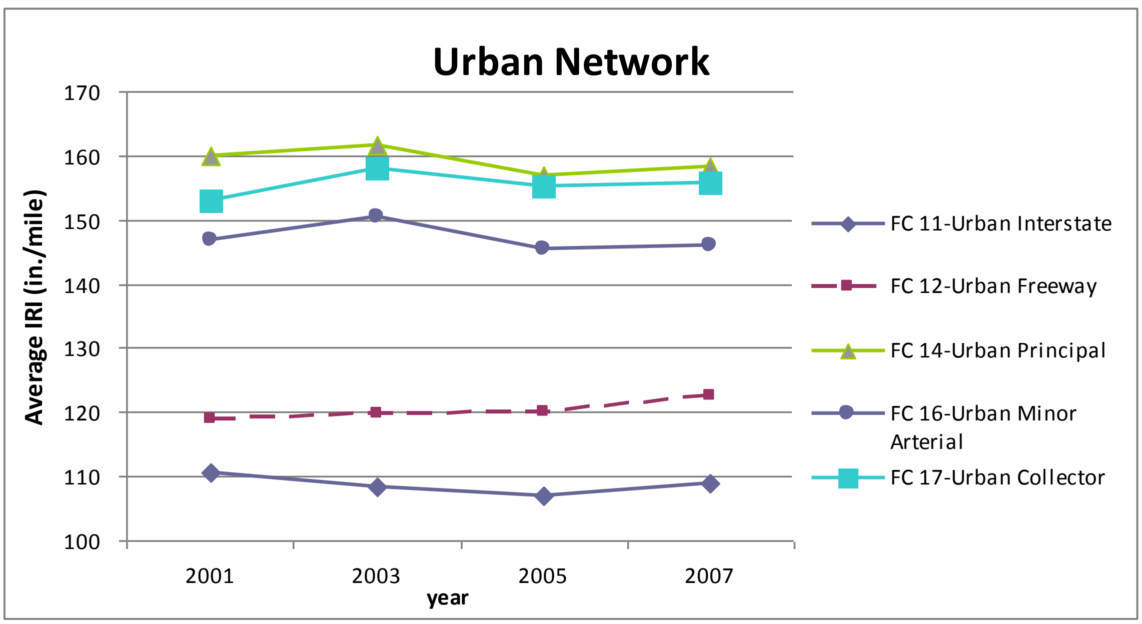

Figure 22. Average IRI for the Urban Pavement Network.

As it can be seen, the average IRI for several functional classes actually decreases with time. If the average IRI decreases with time, this means that the roadway network is actually improving. This led to another question: How can the roadway network be improving or maintaining at its current conditions over a period of 6 years if it experiences traffic, and no recorded surface improvements of any kind?

A detailed review of the HPMS Field Manual led to an important observation. As identified by the HPMS field manual, *"… twenty-five millimeters (one inch) or more of compacted pavement material must be put in place for it to be considered a surface improvement for HPMS purposes."* This excludes the practice of seal coat and surface treatment applications which are very common in the state of Texas.

TxDOT specification Item 316, Surface Treatments, defines surface treatments as one or more applications of asphalt material covered with a single layer of aggregate. Surface treatments are applied directly to a prepared based. A seal coat differs from a surface treatment in that the asphalt material and the aggregates are applied directly to a paved surface. Surface treatments and seal coats are typically less than one inch in depth. The function of a surface treatment or a seal coat is to *"provide a waterproof seal with the underlying structure, arrest pavement deterioration of surfaces showing distress, and to provide a skid-resistant surface"* (TxDOT, 2004). Surface treatments and seal coats are a least expensive solution of maintaining the roadway infrastructure, however, they are only a temporary solution as their average life is only between 6-8 years.

TxDOT spends approximately $180 million per year on its preventive maintenance program. Surface treatments and seal coats are an important part of that program. Table 29 presents the number of lane-miles maintained by TxDOT from 1999-2002 through the application of seal coats.

Table 29. Lane-miles maintained by seal coats (TxDOT, 2004).

Year	Contracted Seal Coat, lane-miles	State Force Seal Coat, lane-miles
1999	10,950	3,410
2000	17,740	3,035
2001	17,350	2,850
2002	16,665	2,990

As it can be seen these are significant numbers and they account for about 10% of the entire Texas roadway network. If every year approximately 10% of the roadway network is rehabilitated with surface treatments and seal coats and these maintenance procedures are not accounted for by the HPMS dataset, then this might serve as an explanation for the dilemma presented by Figures 21 and 22.

3.4 INCONSISTENCIES IN THE DATA

In the review of the Texas HPMS dataset from years 2001-2007, there were some inconsistencies found among the data. For example:

1) The structural number on certain sections varied from year to year without any recorded rehabilitation work.
2) The surface pavement type indication on certain sections also varied from year to year without apparent reason.

These were relatively small inconsistencies which were accounted for with proper filtering. It was also noticed that numerous sections in the lower functional classes (minor arterials and collectors) were not assigned an IRI or were assigned an IRI of 0.0, while other sections were assigned a PSR of 5.0.

3.5 FINAL CONCLUSION AND RECOMMENDATIONS

In order for HERS-ST to become an effective tool in assessing transportation system needs, it was seen that the pavement deterioration model embedded in the model needed to be calibrated to better represent actual state-wide pavement performance. However, in the calibration effort it was noticed that the preventive maintenance program applied by the state of Texas and its effects on state-wide pavement performance was not readily accounted for by the HPMS dataset. This led to a calibration effort which excluded this important factor and, because of this, the calibrated pavement deterioration rate adjustment factors cannot be merited as representative of the state's pavement deterioration conditions.

This can become a significant issue for other states that will attempt in the future to calibrate the HERS-ST pavement deterioration model to state-representative conditions. In order to mitigate this issue the following measures are proposed:

3) Include surface treatments and seal coats as an entry field into the HPMS dataset. The field should specify the type of surface treatment and the year the surface treatment was performed.
4) Include a Preventive Maintenance option in the HERS-ST model that will allow the analyst to specify the amount of funding spent on preventive maintenance per funding period, and the percentage of the network in lane-miles this preventive maintenance program will cover for every funding period. This will lead to identifying the costs and benefits associated with a preventive maintenance program and its appropriate effects on pavement performance.

The final recommendation of this report aims at highlighting the importance of collecting quality data. In 2007, standard sample data was collected for 9,048 roadway sections throughout the state of Texas. Collecting road data for this many sections can become an overwhelming procedure for any state DOT, and as a result it was noticed that there were many inconsistencies in the data collected, particularly for the lower functional classes. Therefore, it is the recommendation of this report to decrease the number of sections for which data are collected and, instead, rely on higher expansion factors to represent the Texas transportation network. This in turn, would allow the DOT to collect data which are of higher quality. Having accurate data is important because our ability to plan for our future transportation needs heavily relies upon the state of our current transportation system.

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