SMOOTHNESS OF PAVEMENTS in CONNECTICUT
Phase 1- Report
INITIAL DATA PRESENTATIONS

June, 2000

Prepared by
Dr. Charles E. Dougan

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16. Abstract

The Connecticut Department of Transportation annually collects roughness data for the entire state highway system. The data are obtained via an ARAN system and are provided in the form of IRI units processed through a quarter-car alogorithm. Research was undertaken to determine the smoothness of various functional classes of highways and to determine factors affecting IRI values.

This report presents various IRI data developed for two consecutive years, 1997 and 1998. The IRI data are linked to ConnDOT's nodal representation of the state highway system. Analyses of factors affecting IRI are outlined and will be addressed in Phase 2 of the Project.

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Smoothness of Pavements in Connecticut
Phase 1- Report
Initial Data Presentations

Background and Introduction:

As far back as the mid to late 1950's, the staff of the then Connecticut State Highway Department was interested in the smoothness of pavements. At that time, the pavement's roughness, inverse of smoothness, was the pavement quality measured using a response-type BPR Roughometer. The device was a single-tire, frame-mounted on a trailer which was towed behind a survey van. Strain gauges on the system measured vertical displacements. These data were converted to cumulative inches per mile of roughness for the surface being evaluated. Due to various personnel and financial constraints the use of the BPR-type roughometer was discontinued in the early 1960's.

In the late 1970's DOT Research personnel employed a California profilograph to measure the smoothness of pavements. The device was a 10-foot straight edge manually pushed over the surface being evaluated. The system measured the amount or length of pavement outside of preset blanking values (high and low displacements). The percent of pavement out of tolerance was calculated and used as input to a statistically based specification for acceptance purposes. The use of this device was abandoned because of safety considerations and the fact that the system's operation was labor-intensive.

In the late 1980's the Federal Highway Administration (FHWA) planners required states to provide roadway smoothness assessments. These data were to be reported as International Roughness Index (IRI) values obtained from a quarter-car algorithm. For this purpose, Connecticut Department of Transportation (ConnDOT) Research staff built an automated road profiler based on a design provided by the South Dakota DOT. This system provided data for the Highway Performance Monitoring System (HPMS) sites in the State of Connecticut. Due to numerous operational problems encountered, the South Dakota system was phased out in the early 1990's when ConnDOT acquired its second-generation Automatic Road Analyzer (ARAN) systems.

International Roughness Index

A vehicle's response to road surface is a function of the combination of a vehicle's weight, the condition and configuration of its chassis and suspension, the size and inflation pressure of its tires, and a number of other factors (not to mention the influence of the road surface, itself). As vehicles (as well as their operators) come in all shapes and sizes, rarely do two users experience the identical ride over the same section of road. The accepted solution is to measure and analyze the road surface profile, rather than measuring the response of any single instrumented vehicle. A repeatable, objective assessment of ride quality is necessary in order to make an accurate measurement of the surface profile.

The IRI is a widely accepted roughness index in the United States and elsewhere in the world. FHWA requires states to use the IRI as the standard roughness index for reporting the roughness at the Highway Performance Monitoring Sections. The IRI was developed from the data obtained from the International Road Roughness experiment, which was sponsored by the World Bank and conducted in 1982 in Brazil /8/. The research results from a NCHRP project that was performed in the late 1970's was utilized during the development of the IRI /9/. The computer programs required to compute the IRI are presented in the World Bank Technical Paper Number 46 /10/. A primary requirement of the development of IRI was that it should correlate well with response-type roughness measuring equipment being used at the time. IRI has also been found to correlate well with subjective opinions of road users.

Technically, the IRI is a mathematical representation of the accumulated suspension stroke of a vehicle, divided by the distance traveled by the vehicle. The IRI is calculated mathematically from the measured longitudinal profile with use of a quarter car simulation along a single wheel path. The quarter car includes: one tire represented with a vertical spring, the mass axle supported by a tire, a suspension spring and a damper, and the mass of the body supported by the suspension for that tire. A simulation speed of 80 km/h (50mi/h) is used for the quarter car, and the simulated suspension motion is linearly accumulated and divided by the length of the profile to yield the IRI. The coefficients used in the mathematical equations were those that provided the maximum correlation to the output of the response-type roughness measuring systems. As inertial profilers typically measure longitudinal profiles along the two wheel paths, the average IRI for the section can be obtained by computing the IRI for each wheel path, and then averaging the two values.

ASTM Standard E1170, "Practices for Simulating Vehicular Response to Longitudinal Profiles of a Vehicular Traveled Surface," describes the method for conducting a quarter-car simulation that produces an IRI. Using a fairly sophisticated algorithm, a model of a quarter vehicle traveling at a specified speed is applied to a profile, and its reaction is measured and reported. This reference vehicle is complete with all the basic parameters necessary to describe an actual automobile (or at least a crucial point of it). These parameters include: 1) the mass of the vehicle body, suspension, wheels and tires; 2) spring stiffness coefficients for the vehicle springs, shocks and/or struts; and 3) damping coefficients indicative of a conventional shock absorbing system. The simulated suspension motion is accumulated and divided by the distance traveled to yield the IRI. Lower values represent a smoother ride; higher values indicate a rougher one.

Since 1996, ConnDOT staff have employed the ARANs to obtain IRI data on the highway network. Appendix 1 shows sample data presentations of the smoothness data obtained.

As stated above the IRI data were employed mainly to satisfy a federal-aid requirement. However, during the early to mid-1990's several national surveys of user satisfaction were conducted. These surveys vividly demonstrated that the highway users perceived the success or failure of a highway in terms of a smooth, unencumbered ride. In turn, the issue of pavement smoothness as an acceptance criterion for newly placed pavements and overlays was revisited as part of the National Quality Initiative (NQI). For this purpose, a trial specification was developed which employs smoothness, as measured in terms of IRI, as a major criteria for incentive/disincentive payments for hot-mix asphalt (HMA) pavements placed on ConnDOT projects.

While it is generally agreed that initially smooth pavements provide better service to the public and have longer service lives than initially rough pavements, little is known about the loss of smoothness over time. Issues such as the influence of pre-existing conditions on the IRI of a new surface, and the effect of cumulative loads and resultant damage and the ubiquitous environment on ride quality over time, are but a few of the pavement problems that will be addressed by a long-term analysis of IRI data. To address these and other issues, the ConnDOT in cooperation with the University of Connecticut have undertaken a study of all IRI data collected by ConnDOT staff during their annual videologging of the Connecticut Highway System. The study objectives are: (1) to determine the IRI values for the various functional classes of highways; and (2) to determine the factors having the greatest effect on IRI as a function of time. The project is designed to provide IRI data for several existing uses within ConnDOT; i.e. HPMS; evaluation of HMA acceptance specifications; and to address NQI issues. Looking toward the future, the IRI data could be used to address anticipated federal regulations regarding the smoothness of roads on the National Highway System (NHS).

Data Acquisition:

ConnDOT owns and operates two ARAN vehicles which are designated as Class 1 systems according to ASTM E950-98 or a Class 2 system if the World Bank classification is used. ConnDOT staff videolog and obtain IRI data on the entire State Highway System annually.

The IRI data are obtained from two laser sensors and two accelerometers located in the front bumper of the van aligned with each tire (wheelpath), which measure vertical displacements from a fixed reference point. The ARAN vehicle must travel at a speed of 35 kph or greater. For the year 2000 both vehicles are being retrofitted with IRI modules which will collect data at 20 kph and greater. These data are fed directly into an on-board computer. The PC processes the displacements through the World Bank's Quarter Car Algorithm to obtain IRI values at ten-meter intervals. All IRI data are indexed by route and cumulative distance and then stored on disk for subsequent analysis and use.

ConnDOT's multistep process for real-time determination of IRI is summarized in the following steps:

> (1) the relative vertical difference between two consecutive points is measured at 4-inch intervals and then averaged out to provide points 8-inch apart for the longitudinal profile;

2) the longitudinal profile of the road (for each wheelpath) using data from 1) above, is plotted;
3) these profiles are processed to filter out short (no effect on ride comfort) and long (hills) wavelengths; and,
4) a simulated drive-over of resultant profiles by a quarter car (single wheel with pneumatic tire on a suspension system supporting a known mass) with calculation of the vertical displacement of the mass per unit distance traveled is prepared using an on-board computer, to provide the final IRI value.

Measurement: The longitudinal profiles of the wheel paths in the lane being traversed by ConnDOT's automated road analyzer are measured by two independent sets of instrumentation. Each set consists of an accelerometer and laser emitter-receiver positioned directly ahead of and over the front tires. The laser measures the distance from the platform (in this case, bumper) to the road surface. Integrated twice with respect to time, the output of the accelerometer, which is located on the same platform as the laser, yields the vertical displacement (up or down) of the platform with respect to its zero position. The difference between the two outputs (laser and accelerometer) at preset intervals along the road results in the true longitudinal profile. This profile is then subject to a filtering process to eliminate long and short wavelengths, representing vertical curves and minor undulations, respectively, that do not affect passenger comfort. During network-level surveying, a profile point will normally be established every 8 inches.

Calculation: Using the filtered profile as input, software simulates the drive-over of the resultant profile by a so-called quarter car, consisting of a known mass, standard tire, and suspension with a given spring constant. The speed of this simulated drive over is 80 kph. The accumulated vertical displacement of the mass is then calculated for a certain preset distance interval along the profile (in our case, every 10 meters). This value is then multiplied by 100 to obtain a normalized IRI reckoned in meters/kilometer.

To assure that all systems are functioning daily quality checks are performed. They consist of traversing a known test section prior to going to the field test area. In this manner, systems adjustments can be made which assure high quality field data.

All ARAN videos and data are matched to the current year Highway Log. Currently it is a manual process to create the ARAN-Highway log linkage; however, beginning in the year 2000 ConnDOT staff will employ a global positioning system (GPS) for this purpose.

Data Analysis:

ConnDOT personnel have developed software to analyze IRI data. It was used throughout this effort to develop basic statistics for the IRI data under study.

For ConnDOT, it was determined that the IRI data would be linked to a nodal representation of the state highway system. This system is comprised of approximately 20,000 nodal points which designate changes in the route shown i.e. change in traffic volume, geometry (Ex. 2 vs 4 lanes), major intersections, pavement type change, construction projects, etc. By relating the IRI information to the nodal points, the data can be presented in many different ways by merely averaging respective values. Some examples of possible data presentations are: IRI for specific segments of a route; or, IRI by town or planning region, etc. The nodal system is maintained by personnel in ConnDOT's Bureau of Policy and Planning, and serves as the basis for various departmental publications and actions and to reiterate, IRI information for large sections of individual routes or regions of the State can be obtained by aggregating the data for individual nodes. Planning staff update all nodal data on an annual basis. These data are tied directly to the Highway Log for the year in which it was collected. This practice is necessary because of the changes that occur in the highway system annually.

Simultaneously, the research team have placed the IRI data in a large database developed by the team. The research database is tied to route and cumulative distance based on ConnDOT's Highway Log and will form the basis of subsequent analyses of factors affecting IRI measurements.

The data presented in this report are all in SI units; IRI-m/km, distance-km. Where IRI are shown it is the average IRI of the left and right wheel paths. Average IRI presented for various routes, systems etc. are the weighted averages of the IRI measurements. Where data supplied by ConnDOT, i.e., the Highway Bridge Log, were presented in English units, all pertinent data were converted to metric.

As stated above, all data are indexed to known points on a route as defined by the Highway Log. This operation is performed manually each year; i.e., all data for a route are adjusted to correspond to fixed locations, a bridge, an intersection, etc. For some time ConnDOT staff have been developing an automated system to replace this labor-intensive process and, beginning in the year 2000 the linking activity will be automated. It will be based on global positioning technology existing in the ARAN vehicles.

Initial Data Presentations:

Initially the average value for each roadway in the highway was calculated. This was accomplished using the ConnDOT software cited previously. Appendix 1 shows typical data output for a limited number of roadways. The Appendix also presents a summary of the average IRI for several highways on the state system for 1997 and 1998. The data shown are those collected as the ARAN vehicle is traveling in the log direction. The reverse direction is traveled as well with the ARAN recording data and images but is not presented.

For Pavement Management (PM) purposes, usually the data are averaged for both directions of individual highways. For divided highways the roadway lengths may differ slightly (log vs reverse direction) due to curvature and alignment of opposing roadways. In the case of a divided highway PM staff treat each roadway separately. All distances are corrected to those shown in the Highway Log for consistency.

IRI – Functional Class of Roadway- The data were then analyzed by functional classification in accordance with FHWA requirements, which defines highways by the type of population served, rural or urban. ConnDOT's Systems Inventory Section further classifies the network by population. Table 1 presents these breakdowns. The Connecticut DOT applies these classes to all roadways on the state highway system. It is interesting to note that the total mileage on the state network is almost equally divided between rural and urban.

Table 2 is a tabulation of the 1997 IRI data by Functional Class. Figure 1 presents the average data graphically in ascending order of classification left to right. Figure 2 shows the IRI for the left, right and both wheelpaths for each functional class as well as the weighted average IRI for the entire network. It is generally thought that the IRI measured in the right wheel path is greater than that measured in the left wheelpath. This is not true in several classes (i.e. 1 and 15). The reader should note that, due to the classification system criteria (Table 1); all functional classes of roadways are not on the Connecticut State Highway System. This is primarily due to the traffic volumes encountered in Connecticut.

In general, these data show that the Interstate Roadways, both urban and rural, are smoother than other less heavily traveled roadways in the state. It is the author's opinion that this reflects the emphasis placed by ConnDOT management on upgrading the ride characteristics of these systems. Viewing this in another light, this could also reflect the thicker pavement sections designed and placed on these facilities.

The average IRI of rural routes are shown in Table 3, and presented graphically in Figure 3. Note that IRI values for the interstate and arterials, fall below the weighted average of all rural routes.

Table 4 presents the IRI data for urban routes by population. Again, Figure 4 shows the data in bar chart form. The reader should note that the weighted average IRI value for urban vs rural routes are comparable (urban 2.338, rural 2.388). This strongly suggests that all roadways are being improved equally in turns of ride characteristics. Appendix 2 shows the IRI data for urban routes based on classes of population.

IRI data for each functional system are tabulated in Table 5 and graphically shown in Figure 5. These data support the philosophy of ConnDOT which was previously stated.

The National Highway System (NHS) is defined in Title 23 of the Code of Federal Regulation (CFR-23), Section 103 "Federal aid Systems". The detailed definition of the NHS is shown as Appendix 3. The NHS is the basis for allocation of federal-aid funding in Connecticut; thus, it is extremely important to all state agencies and local governments in the state. The author has been advised that FHWA staff in Washington, D.C., are considering a minimum IRI value as a criteria for receipt of federal funds. Individual states would be required to maintain the minimum smoothness value to qualify for federal-aid funds. To determine the IRI value of Connecticut's NHS the research team

Table 1

Definition of Functional Classes

Code	Rural	
01	Interstate	
02	Other Principal Arterial	
03	Minor Arterial	
04	Major Collector	
05	Minor Collector	
06	Unclassified(local usage)	
	Urban(population in thousands)	
11	Interstate	5-10
21	Interstate	10-25
31	Interstate	25-50
41	Interstate	>50
12	Other Freeway	5-10
22	Other Freeway	10-25
32	Other Freeway	25-50
42	Other Freeway	>50
13	Other Principal Arterial	5-10
23	Other Principal Arterial	10-25
33	Other Principal Arterial	25-50
43	Other Principal Arterial	>50
14	Minor Arterial	5-10
24	Minor Arterial	10-25
34	Minor Arterial	25-50
44	Minor Arterial	>50
15	Major Collector	5-10
25	Major Collector	10-25
35	Major Collector	25-50
45	Major Collector	>50
	No Major or Minor Collectors	
16	Unclassified	5-10
26	Unclassified	10-25
36	Unclassified	25-50
46	Unclassified	>50

Table 2 - Tabulation of 1997 IRI Data by Functional Class

Functional Class	Average IRI Left Wheel Path	Average IRI Right Wheel Path	Average IRI Both Wheel Path	Number of Profiling Points
11	1.426	1.408	1.417	304
01	1.649	1.576	1.612	16089
41	1.815	1.822	1.819	39145
42	1.965	1.955	1.960	33091
02	2.047	2.066	2.057	20411
03	2.018	2.172	2.095	80196
13	2.058	2.165	2.111	775
35	2.224	2.311	2.268	1409
43	2.376	2.580	2.478	74177
44	2.401	2.577	2.489	106679
45	2.431	2.587	2.509	10922
25	2.319	2.723	2.521	863
33	2.572	2.571	2.572	1657
24	2.340	2.817	2.579	246
46	2.447	2.503	2.594	4369
04	2.516	2.788	2.652	155027
23	2.666	2.789	2.728	1271
15	3.075	2.718	2.897	25
34	3.024	3.099	3.062	1771
14	3.229	3.547	3.388	1246
05	3.249	3.699	3.474	7113
06	3.581	4.127	3.823	1791
36	3.732	4.453	4.093	83

*log direction, bridges included

Figure 1

Average IRI on Functional Classification
(1997 data, bridges included, log direction)

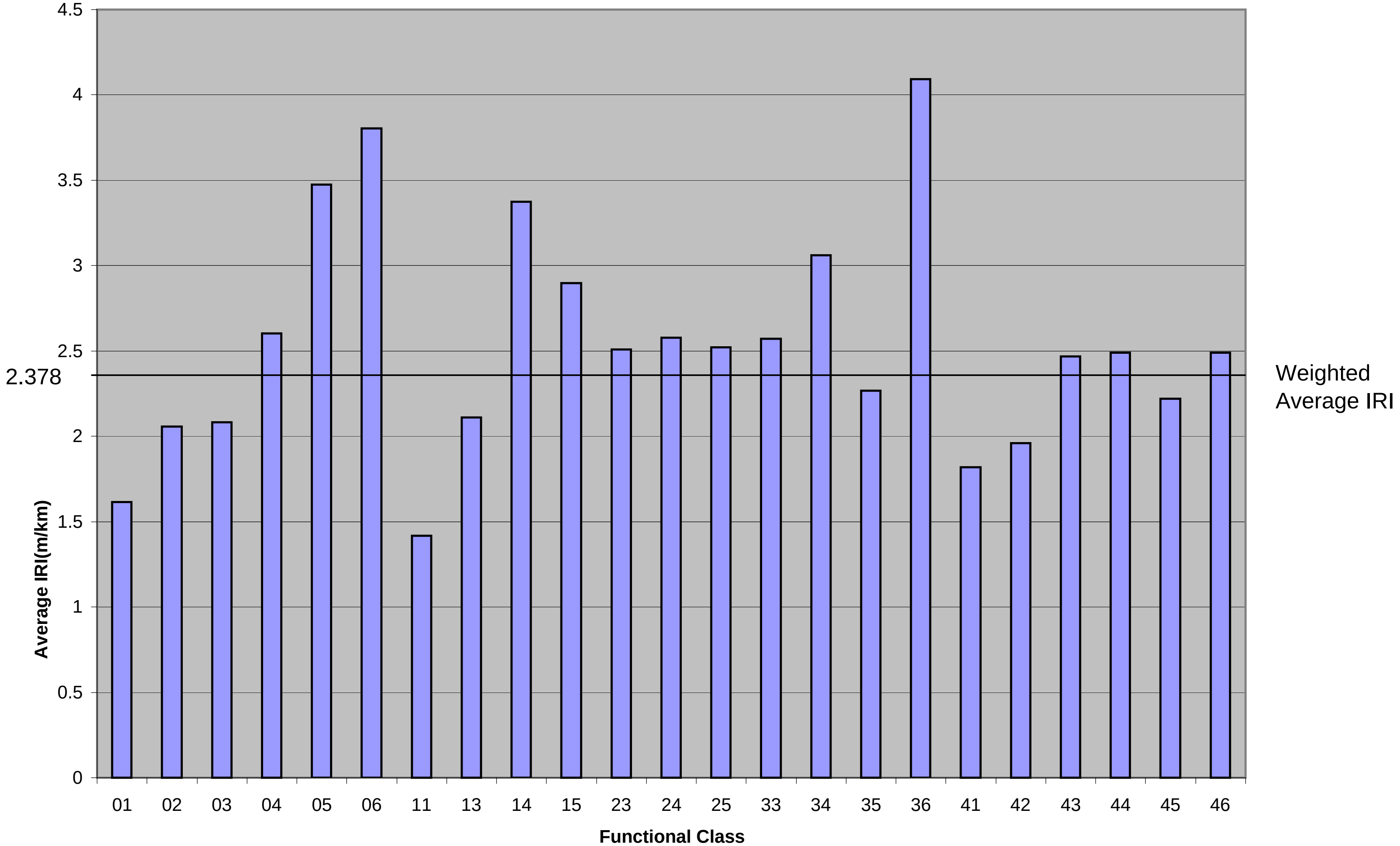


Figure 2

Average IRI of Functional Classes -Both Wheel Path

(1997 data, bridges included, log direction)

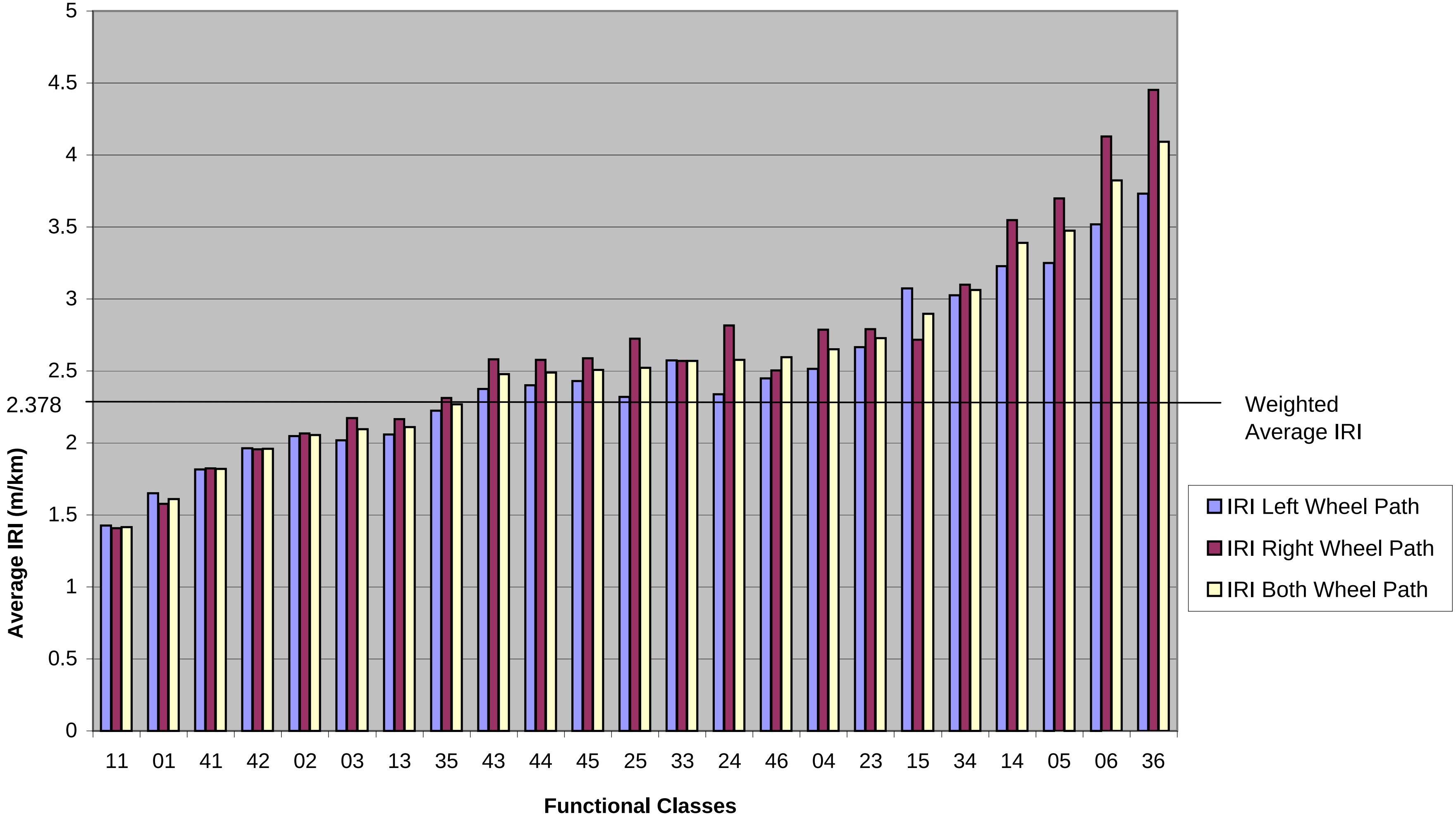


Table 3

Average IRI of Rural Routes

(1997 data, log direction, bridges included, both wheel path)

Functional Class	Average IRI	Number of Profiling Points
01	1.615	16089
02	2.057	20411
03	2.081	80196
04	2.604	155027
05	3.474	7113
06	3.805	1791

Table 4

Average IRI of Urban Routes

(1997 data, log direction, bridge included, both wheel path)

Population	Average IRI
5--10	2.698
10--25	2.520
25-50	2.686
50+	2.310

Figure 3

Average IRI of Rural Routes

(1997 data, bridges included, both wheel path, log direction)

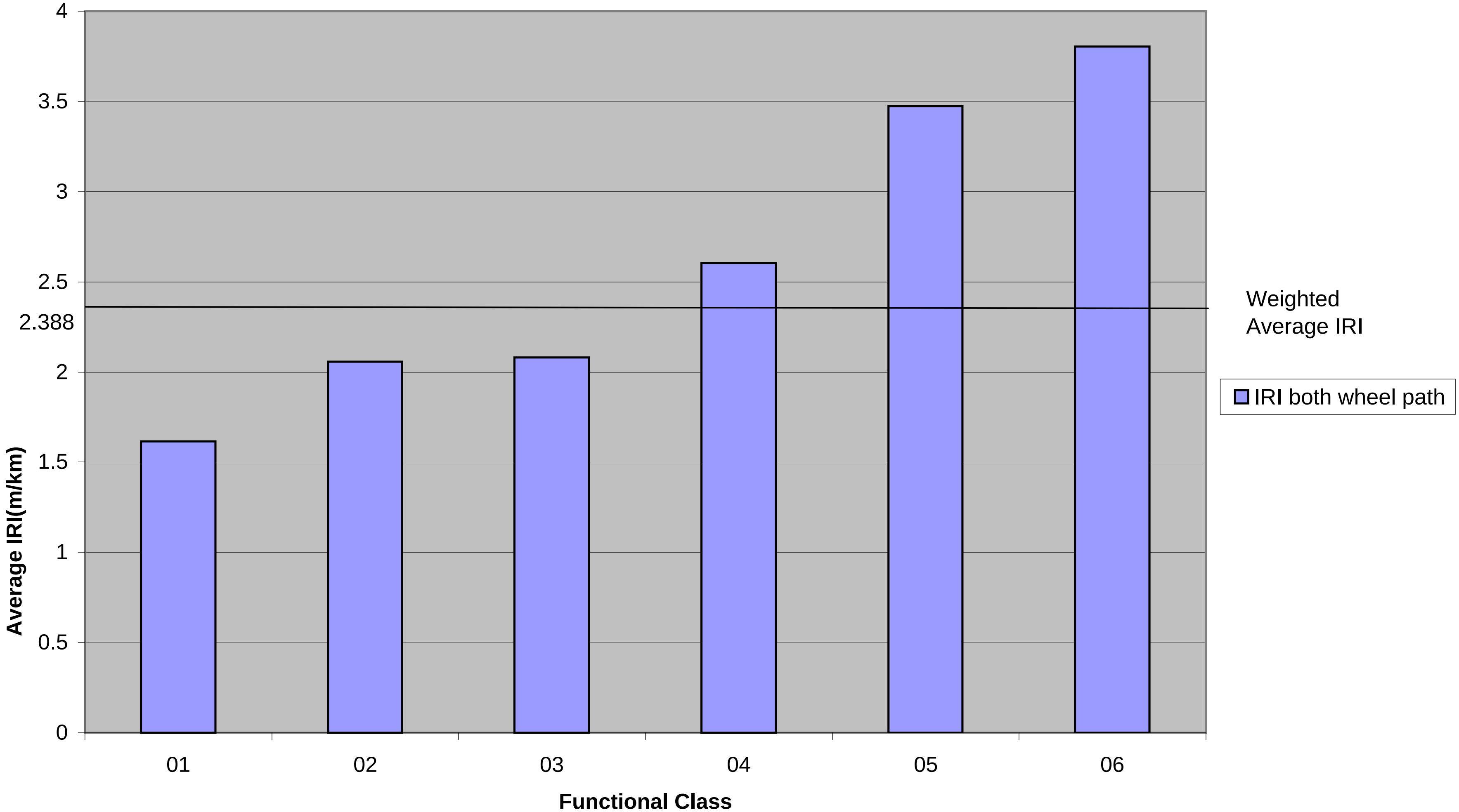


Figure 4

Average IRI of Urban Routes

(1997 data, bridges included, both wheel path, log direction)

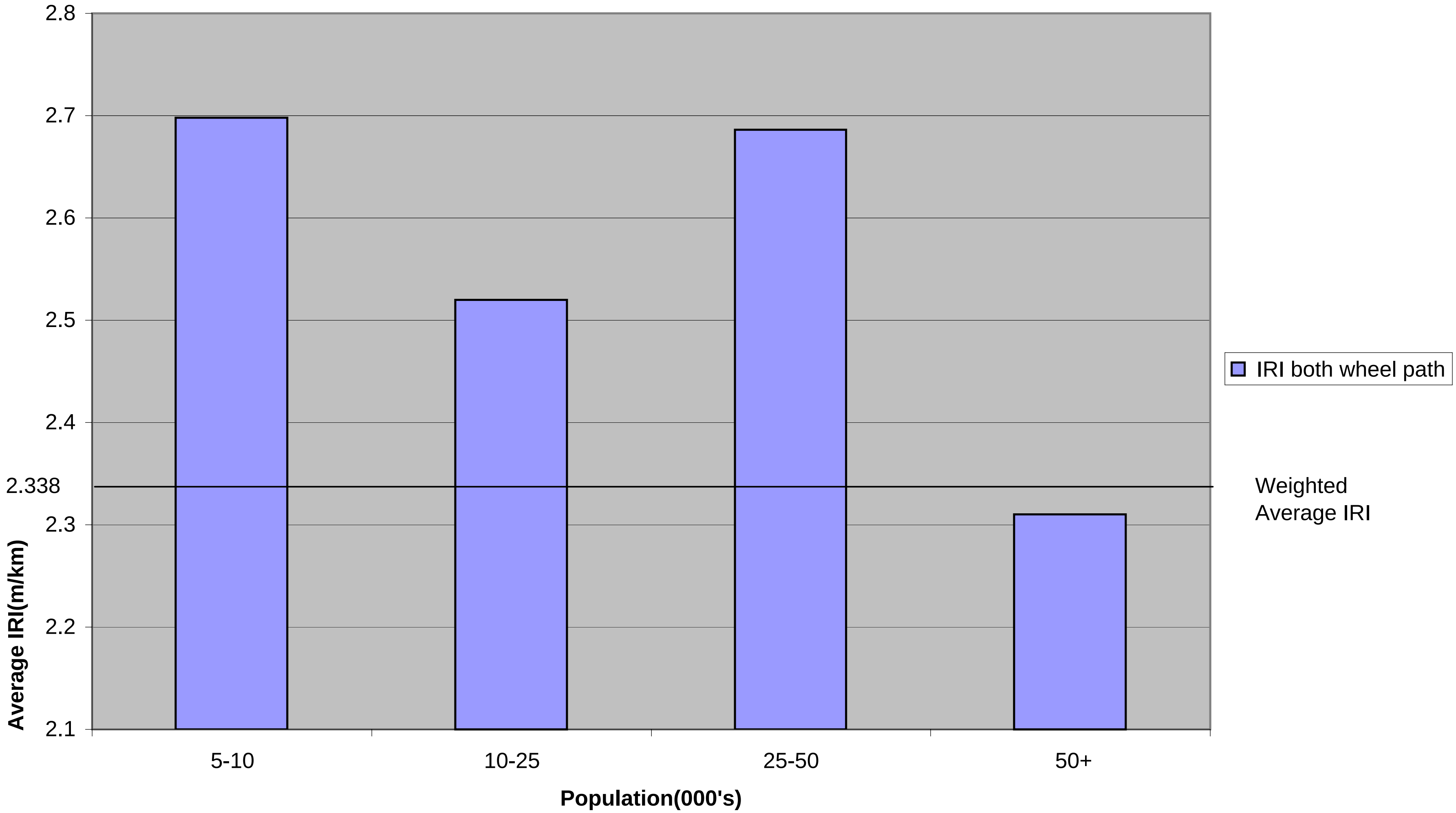


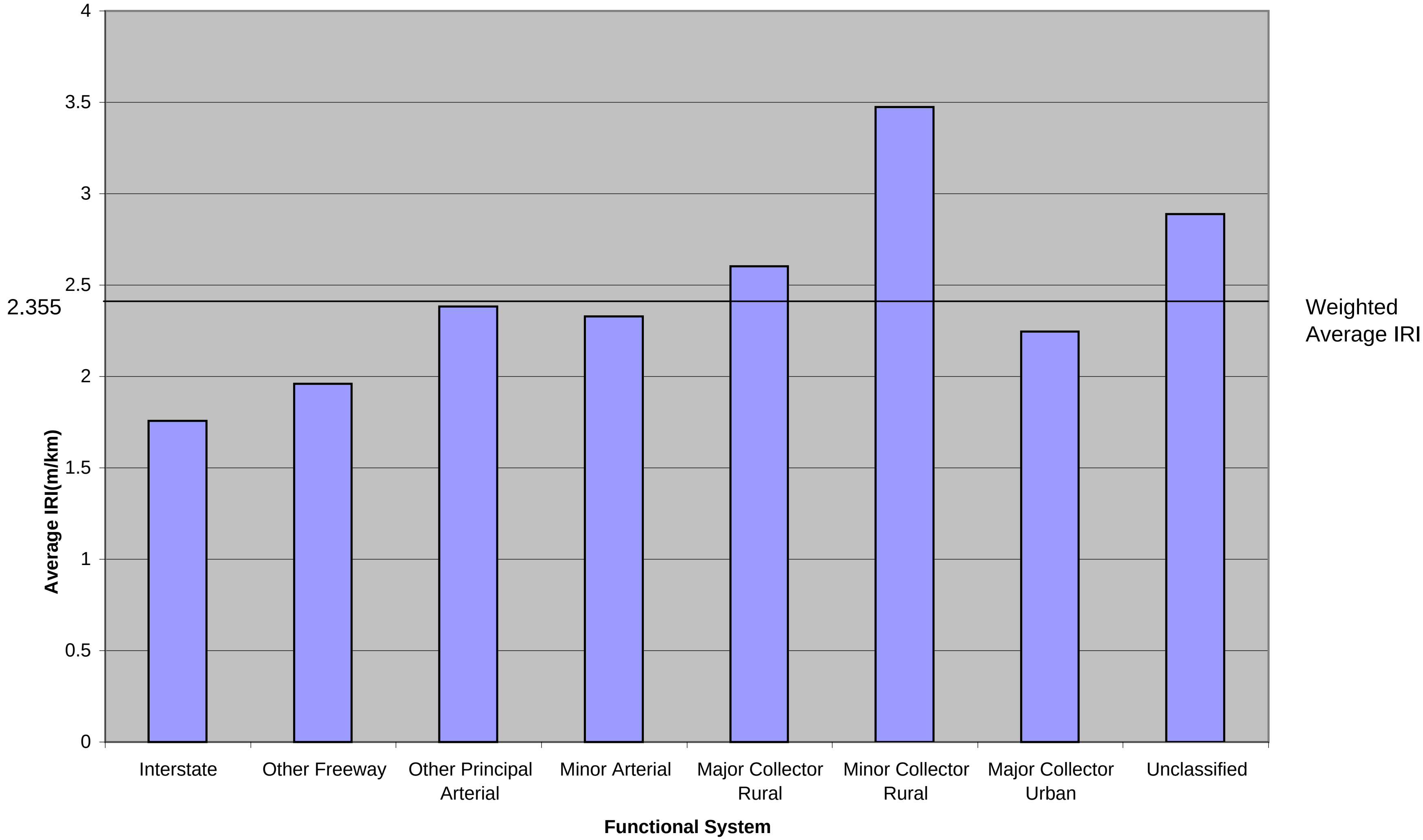
Table 5

Average IRI of Functional System
1997 data, bridges included

Number of Profiling Points	Functional System	Average IRI
55538	Interstate	1.758
33091	Other Freeway	1.960
98291	Other Principal Arterial	2.382
190138	Minor Arterial	2.329
155027	Major Collector Rural	2.604
7113	Minor Collector Rural	3.474
13219	Major Collector Urban	2.247
6243	Unclassified	2.889

Figure 5

Average IRI on Functional System(1997 data, bridges included,log direction)



obtained a listing of all routes on the NHS in the state and the IRI were calculated from our database. Table 6 presents these data for 1997 and 1998.

ConnDOT planners plotted sample 1998 IRI data on the highways comprising the NHS in Connecticut. The data were grouped by magnitude and assigned color designations. Figure 6 shows a small segment of the statewide plot obtained. It is the southwestern corner of Connecticut, which abuts Westchester County in New York. In Figure 6 the reader is directed to the IRI plot for I-95. The data shown for I-95 demonstrates the major influence of bridge roughness on IRI; roughness which is inherent in the construction technology used to build and rehabilitate bridges.

Based on the data in Figure 6, the researchers developed a computer program to remove bridge roughness from our IRI database. For this purpose, the bridge locations in the State Highway Bridge Log /6/ were used.

To the bridge lengths shown in the Log, 30m were added on each end of the bridge to account for roughness contributed by bridge approach slabs. Where bridges were closely spaced, within 60m of each other, they were considered one bridge. Appendix 4 shows the computer program and presents documentation on its use for the reader.

The IRI data were then reanalyzed without the bridge roughness component. Typical results are shown in Table 7. Table 8 presents the difference in IRI data for 1997 and 1998 while Figure 7 graphically depicts the IRI data with and without bridge roughness for 1997.

Initial Statistical Analyses Performed

Limited statistical analyses were conducted on the data. All computations were performed at a 95% confidence level using the SPSS statistical Computer Package Version 9.0. The analyses addressed: normality of the annual data population; the effect of bridge roughness on IRI of an entire length of roadway, and significant differences between annual data.

Concerning normality, the average value of IRI per data point (10-meter interval) was employed. The data were grouped by functional class because of the large number of data points. Initially it was assumed that the IRI data would be normally distributed, and the analyses conducted verified this hypothesis. Appendix 5 contains summaries of the statistical analyses performed on the entire data set. Three functional classes (06, 36 & 46) were judged to be outside the 95% confidence interval. The analysis was repeated after these outlier functional classes were removed. As expected, there was a slight improvement in the normality of the 1997 data set.

The influence of the bridge roughness on the average IRI per route was judged to be a concern. To address this issue the average IRI by functional class were statistically

Table 6

IRI[1] of the National Highway System

Route	Start(km)	End(km)	IRI97_w[2]	IRI97_o[3]	IRI98_w[4]	IRI98_o[5]
2*	0.15	93.37	1.780	1.797	1.861	1.801
2A	7.02	11.34	1.698	1.757	1.937	1.822
3	18.53	22.09	2.333	2.250	2.395	2.286
4	38.92	39.10	3.734	3.735	3.464	3.464
5	56.18	75.20	2.294	2.338	2.179	2.182
6	22.95	187.17	2.183	2.187	2.053	2.057
7	40.57	125.86	1.392	1.909	1.960	1.964
8	0.33	93.79	1.884	1.844	1.828	1.768
9*	0.65	65.52	1.779	1.760	1.715	1.698
10	16.18	87.34	2.247	2.228	2.304	2.301
11	17.36	28.64	1.329	1.321	1.373	1.358
12	0.15	20.00	2.126	2.140	2.125	2.104
15*	0.01	134.40	2.150	1.972	2.177	1.851
20	44.61	50.25	1.717	1.628	1.710	1.680
25	6.04	32.44	2.387	2.371	2.436	2.403
32	0.01	49.69	3.015	2.139	2.114	2.094
34	22.66	38.79	2.230	2.187	2.267	2.216
40	0.93	4.96	1.701	1.403	1.662	1.451
44	0.01	86.56	2.121	2.120	2.070	2.063
66	0.01	58.44	2.057	2.048	2.134	2.125
72	0.01	20.95	1.502	2.059	2.009	1.997
78*	0.32	0.69	2.553	2.313	2.692	2.564
82	26.56	28.24	2.460	2.328	2.418	2.379
84*	0.01	157.52	1.753	1.641	1.713	1.606
85	1.59	18.12	1.849	1.887	2.006	1.999
91*	0.01	93.32	1.951	1.852	1.736	1.631
95*	0.01	179.52	1.752	1.646	1.678	1.574
184	19.64	19.66	2.900	2.903	2.667	2.667
202	31.02	89.67	2.181	2.174	2.011	2.000

Route	Start(km)	End(km)	IRI97_w[2]	IRI97_o[3]	IRI98_w[4]	IRI98_o[5]	
291*	0.01	9.69	1.720	1.679	1.764	1.706	
384*	0.01	13.72	1.520	1.495	1.592	1.586	
395*	0.01	88.00	1.572	1.597	1.639	1.633	
401	0.01	1.79	1.586	1.699	1.750	1.750	
437*	0.01	0.71	3.472	3.338	3.620	3.635	
597*	0.01	0.97	2.561	2.173	2.168	1.757	
601*	0.01	0.24	8.369	9.087	999.000	999.000	[7]
684	0.01	2.27	999.000	999.000	999.000	999.000	[6]
691*	0.01	13.48	2.046	1.979	2.078	1.965	
693*	0.01	2.27	1.574	1.477	1.515	1.524	
695*	0.01	7.22	1.877	2.126	1.313	1.319	
706*	0.01	1.32	2.924	2.926	2.781	2.781	
753*	0.01	0.27	3.983	2.955	2.564	2.564	
796*	0.80	4.63	1.926	1.827	1.896	1.870	

[1] All IRI unit is m/km for the sections shown in the table
[2] IRI97_w- 1997 IRI including bridges
[3] IRI97_o- 1997 IRI excluding bridges
[4] IRI98_w - 1998 IRI including bridges
[5] IRI98_o - 1998 IRI excluding bridges
[6] Data for I-684 supplied by New York State Department of Transportation per agreement with ConnDot.
[7] 999 - No data. ARAN vehicle speed less than 35kph.

* Full length of highway in NHS - all other routes partial lengths only
** 4 sections of route in NHS
*** 3 sections of route in NHS

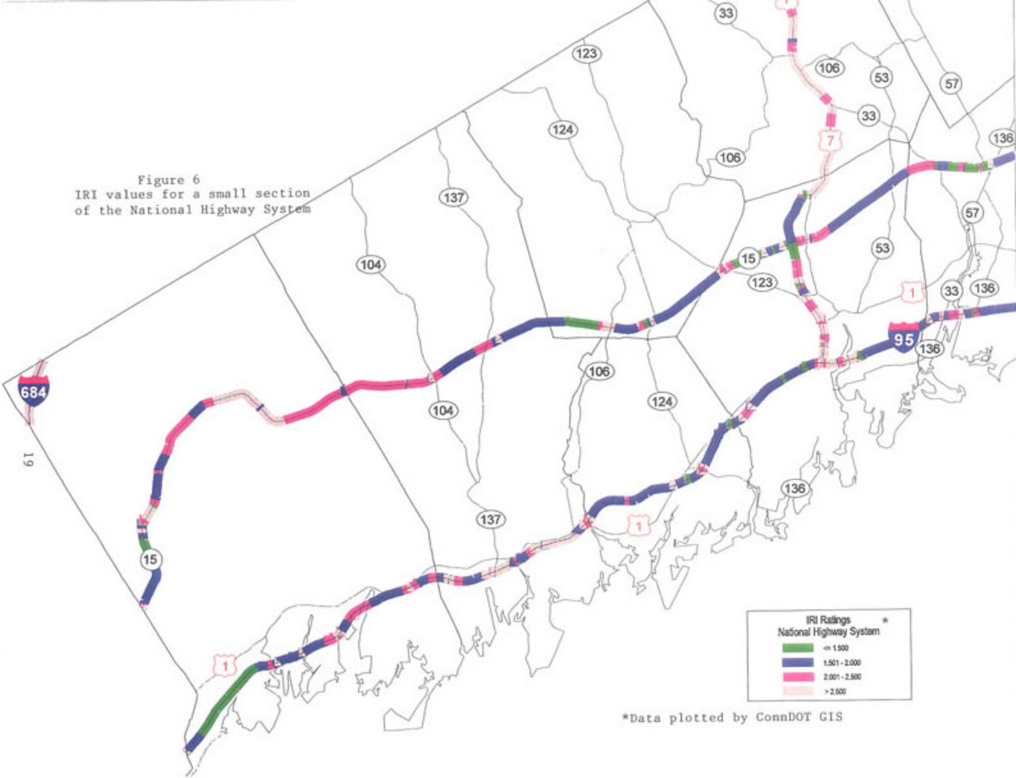


Figure 6
IRI values for a small section
of the National Highway System

*Data plotted by ConnDOT GIS

Table 7

Average IRI[1] By Functional Class Without Bridges

Functional Class	Average IRI Left Wheel Path	Average IRI Right Wheel Path	Average IRI Both Wheel Path	Number of Profiling Points
01	1.636	1.564	1.600	15126
02	1.945	1.939	1.942	21917
03	2.026	2.156	2.091	85838
04	2.467	2.730	2.599	144896
05	3.270	3.729	3.500	6991
06	3.631	4.292	3.962	1408
11	1.422	1.395	1.409	299
13	2.031	2.129	2.080	750
14	3.186	3.516	3.351	1215
15	2.961	2.841	2.901	17
23	2.470	2.531	2.501	1681
24	2.266	2.753	2.510	229
25	2.312	2.704	2.508	987
33	2.567	2.568	2.568	1610
34	2.796	3.006	2.901	949
35	2.209	2.298	2.254	1380
36	3.735	4.449	4.092	82
41	1.706	1.715	1.711	33474
42	1.911	1.903	1.907	21343
43	2.330	2.515	2.423	63602
44	2.392	2.574	2.483	101636
45	2.415	2.568	2.492	11057
46	2.717	2.867	2.792	2452

[1] All IRI data units m/km

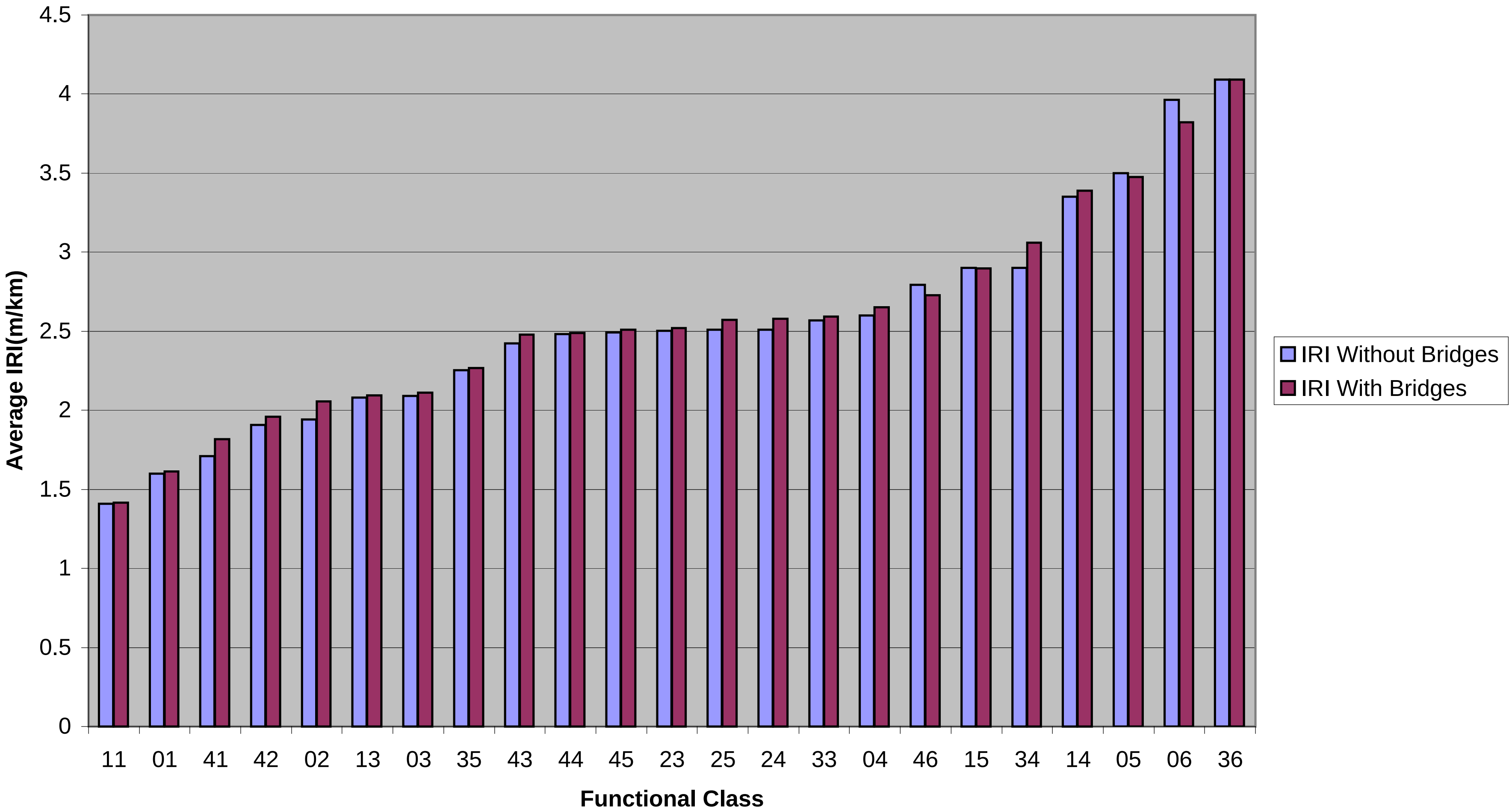
Table 8

Summary of 1997 and 1998 IRI[1] Data by Functional Class

Functional Class	IRI97_o[2]	IRI97_w[3]	Diff-97	IRI98_o[4]	IRI98_w[5]	Diff-98[6]
01	1.600	1.612	0.012	1.519	1.530	0.011
02	1.942	2.057	0.112	1.925	1.933	0.008
03	2.091	2.112	0.020	2.102	2.108	0.006
04	2.599	2.652	0.053	2.551	2.558	0.007
05	3.500	3.474	-0.026	3.592	3.588	-0.004
06	3.962	3.823	-0.140	3.923	3.925	0.002
11	1.409	1.417	0.008	1.438	1.442	0.004
13	2.080	2.095	0.015	2.140	2.149	0.009
14	3.351	3.388	0.037	3.493	3.532	0.039
15	2.901	2.897	-0.005	2.987	3.000	0.013
23	2.501	2.521	0.020	2.609	2.601	-0.008
24	2.510	2.579	0.068	2.248	2.252	0.004
25	2.508	2.572	0.063	2.605	2.622	0.017
33	2.568	2.594	0.026	2.397	2.405	0.008
34	2.901	3.062	0.016	2.872	2.875	0.003
35	2.254	2.268	0.013	2.231	2.242	0.011
36	4.092	4.093	0.001	3.875	3.875	0.000
41	1.711	1.819	0.107	1.661	1.775	0.114
42	1.907	1.960	0.053	1.825	1.904	0.079
43	2.423	2.478	0.055	2.429	2.446	0.017
44	2.483	2.489	0.006	2.515	2.531	0.016
45	2.492	2.509	0.017	2.535	2.557	0.022
46	2.792	2.728	-0.065	2.808	2.823	0.015

[1] All IRI data units m/km
[2] IRI97_o 1997 IRI excluding bridges
[3] IRI97_w 1997 IRI including bridges
[4] IRI98_o 1998 IRI excluding bridges
[5] IRI98_w 1998 IRI including bridges
[6] Diff = IRI_w - IRI_o

Figure 7
Average IRI by Functional Class
(1997 data, both wheel path, with and without bridges, log direction)



analyzed with and without bridges (process to remove bridge roughness described in the preceding section of this report). Based on the analysis performed, there is no significant difference with and without bridge roughness in the data set.

To analyze any significance between annual data sets, the NHS data for 1997 and 1998 (Table 6) were analyzed. The T-test for significance was employed at a 95% confidence level. All data analyzed included bridges. The results, presented in Appendix 5, show that there is no significant difference between the 1997 and 1998 NHS data.

Additional analyses will be undertaken as outlined in the next section of this report.

Future Parametric Analyses

The forgoing has set forth a framework from which a series of analyses will examine the influence of various factors on IRI.

Our initial efforts were focused on setting forth a series of data presentations for use in ConnDOT's HPMS submissions. It is hoped that these activities will evolve into a standard methodology to place IRI data on the department's nodal system annually. In turn, ConnDOT planners and engineers will have IRI data for: each route on the State system, with and without bridges; the various systems and route classifications; and, to define the NHS, with and without bridges. These annual data could also be used to define any changes in roadway smoothness, a user perception of the functionality of a roadway.

Individual studies will be performed to define and estimate the magnitude of various measured changes in IRI. These activities will address IRI changes by: route number; functional system i.e. NHS; class of route; as well as the total state highway network. The roughness contributed by bridges will be estimated. It is thought that bridge length is a major factor in bridge roughness, for example short span structures may be rougher than longer spans. This element, bridge length, will be examined to define this factor.

A major thrust of the parametric studies will be to estimate the magnitude of various factors on IRI. Variables such as: type of construction – PCC; full-depth HMA vs overlay; day vs night operations; roadway geometry-curvature and grade; traffic volume; and individual construction operations i.e. milling, patching, leveling, etc., will be addressed. At this time, a detailed listing of these studies, in priority order, is being developed by the researchers and the project advisory team.

Initial Findings and Interim Conclusions

(1) This report presents several options to present IRI data. The entire state system

has been analyzed and these data have been further divided by functional system, functional class, and urban and rural classes. The NHS has been presented separately to address its importance in resource allocation to Connecticut.

After exhaustive review and use by ConnDOT staff these presentations will be revised, if needed, to more fully address ConnDOT information needs.

(2) A computer program has been developed to remove bridge associated roughness from the IRI of the roadway. Initial studies show no sign of significant differences in IRI, with and without bridges, when the entire roadway length is considered. Further analyses will address the localized bridge roughness.

(3) There is no significant difference between years, based on an analysis of the 1997 and 1998 IRI data for the NHS. This finding is supported by selected studies now underway /11/.

(4) For rural roads the lowest IRI value is exhibited by the highest type of roadway design (Class 01=Interstate). The IRI value increases as the design of the roadway is lower.

(5) For urban roads, no obvious relationship can be seen between IRI and population.

(6) Unclassified routes, ie, classes 06 and 36, have larger IRI values than those of lower class number. Unclassified rural routes exhibit the highest IRI, due to unusual traffic and geometric conditions on these roadways.

REFERENCES

1- ASTM E867-97, “Terminology Relating to Vehicle-Pavement Systems”.

2- ASTM E950-98, “Standard Method of Test for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference”.

3- AASHTO PP37-99, “Standard Practice for Quantifying Roughness of Pavements”.

4- 1997 Connecticut State Highway Log, 12/31/97.

5- 1998 Connecticut State Highway Log, 12/31/98.

6- Connecticut State Highway Bridge Log, 8/22/94.

7- Gillespie, T.D. et al, “Operational Guidelines for Longitudinal Pavement Profile Measurement-FINAL REPORT” NCHRP Report 434.

8- Sayers M.W., et al, “the Internaional Road Roughness Experiment,” World Bank Technical Paper Number 45, World Bank, 1986.

9- Gillespie, T.D., et al, “Calibration of Response Type Road Roughness Measuring Systems,” NCHRP Report 228.

10- Sayers, M.W., et al, “Guidelines for Conducting and Calibrating Road Roughness Measurements,” World Bank Technical Paper Number 46, World Bank, 1996.

11- Perera, R.W. et al, “Investigation of Development of Pavement Roughness,” FHWA Report No. FHWA-RD-97-147, May 1998.

APPENDIX 1

SAMPLE ROUGHNESS
ANALYSIS REPORT

and

A SAMPLE SUMMARY of IRI VALUES
for 1997 and 1998

ROUGHNESS ANALYSIS REPORT
1999 CT-Route 4

Direction	:	-----Log km----		--Reverse km---	
Chainage Type	:	ARAN	SHL	ARAN	SHL
Start Range	:	75.190	75.164	75.210	75.164
End Range	:	0.000	0.000	0.000	0.000
Range Length	:	75.190	75.164	75.210	75.164
Interval Count	:	1			

==

SUMMARY

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	Logging Direction			Reverse Direction		
	Left	Right	Average	Left	Right	Average
Average IRI	2.170	2.162	2.166	2.110	2.209	2.159
Actual/Total	7252/7520	7252/7520		7316/7523	7316/7523	
Standard Dev.	1.033	1.089		1.004	1.152	
Range High	15.090	12.760		14.900	19.260	
Range Low	0.550	0.430		0.440	0.550	

ROUGHNESS ANALYSIS REPORT
1999 CT-Route 5

Direction :	-----Log km----		--Reverse km---	
Chainage Type :	ARAN	SHL	ARAN	SHL
Start Range :	0.010	0.010	0.260	0.010
End Range :	88.060	87.835	87.990	87.835
Range Length :	88.050	87.825	87.730	87.825
Interval Count : 1				

==

SUMMARY

==

	Logging Direction			Reverse Direction		
	Left	Right	Average	Left	Right	Average
Average IRI	2.101	2.308	2.205	2.074	2.271	2.173
Actual/Total	8334/8806	8334/8806		8307/8775	8307/8775	
Standard Dev.	1.147	1.395		1.084	1.344	
Range High	16.430	15.680		16.320	19.770	
Range Low	0.480	0.340		0.410	0.480	

Summary of IRI Values Including Bridges*

See notes at end of tabulation

Route	Length(km)	1997 Data, Log Direction: IRI Left Wheel Path	1997 Data, Log Direction: IRI Right Wheel Path	1997 Data, Log Direction: Average of IRI Left Wheel Path And IRI Right Wheel Path	1998 Data, Log Direction: IRI Left Wheel Path	1998 Data, Log Direction: IRI Right Wheel Path	1998 Data, Log Direction: Average of IRI Left Wheel Path And IRI Right Wheel Path
1	189.24	2.380	2.599	2.490	2.367	2.537	2.452
1A	3.11	2.506	2.775	2.640	2.601	2.972	2.786
2	93.37	1.834	1.821	1.828	1.859	1.896	1.878
2A	15.93	1.684	1.713	1.698	1.757	1.761	1.759
3	23.36	2.329	2.638	2.484	2.367	2.707	2.537
4	75.36	2.266	2.393	2.330	2.293	2.344	2.319
5	88.12	2.148	2.299	2.224	2.117	2.347	2.232
6	187.42	2.129	2.241	2.185	2.015	2.112	2.064
7	125.76	1.991	2.070	2.031	2.025	2.115	2.070
8	108.45	1.914	1.907	1.911	1.814	1.872	1.843
9	65.78	1.778	1.767	1.773	1.720	1.716	1.718
10	87.60	2.241	2.371	2.306	2.247	2.470	2.359
11	28.68	1.402	1.254	1.328	1.454	1.296	1.375
12	87.78	2.213	2.364	2.289	2.153	2.304	2.229
14	39.30	2.486	2.794	2.640	2.341	2.631	2.486
14A	16.64	3.884	4.662	4.273	3.760	4.599	4.180
15	134.40	1.986	1.974	1.980	1.869	1.908	1.888
16	27.46	1.991	2.197	2.094	1.749	1.913	1.831
19	11.24	2.312	2.559	2.436	2.516	2.637	2.577
20	50.78	2.904	3.138	3.021	2.872	3.061	2.967
21	9.15	2.351	2.526	2.439	2.505	2.611	2.558
22	22.67	2.303	2.467	2.385	2.292	2.486	2.389
25	45.96	2.216	2.311	2.264	2.203	2.318	2.261
27	5.17	2.764	2.976	2.870	2.839	3.048	2.944
30	34.17	2.358	2.464	2.411	2.455	2.576	2.516
31	23.04	2.425	2.674	2.550	2.124	2.197	2.161
32	88.33	2.172	2.307	2.240	2.181	2.265	2.223

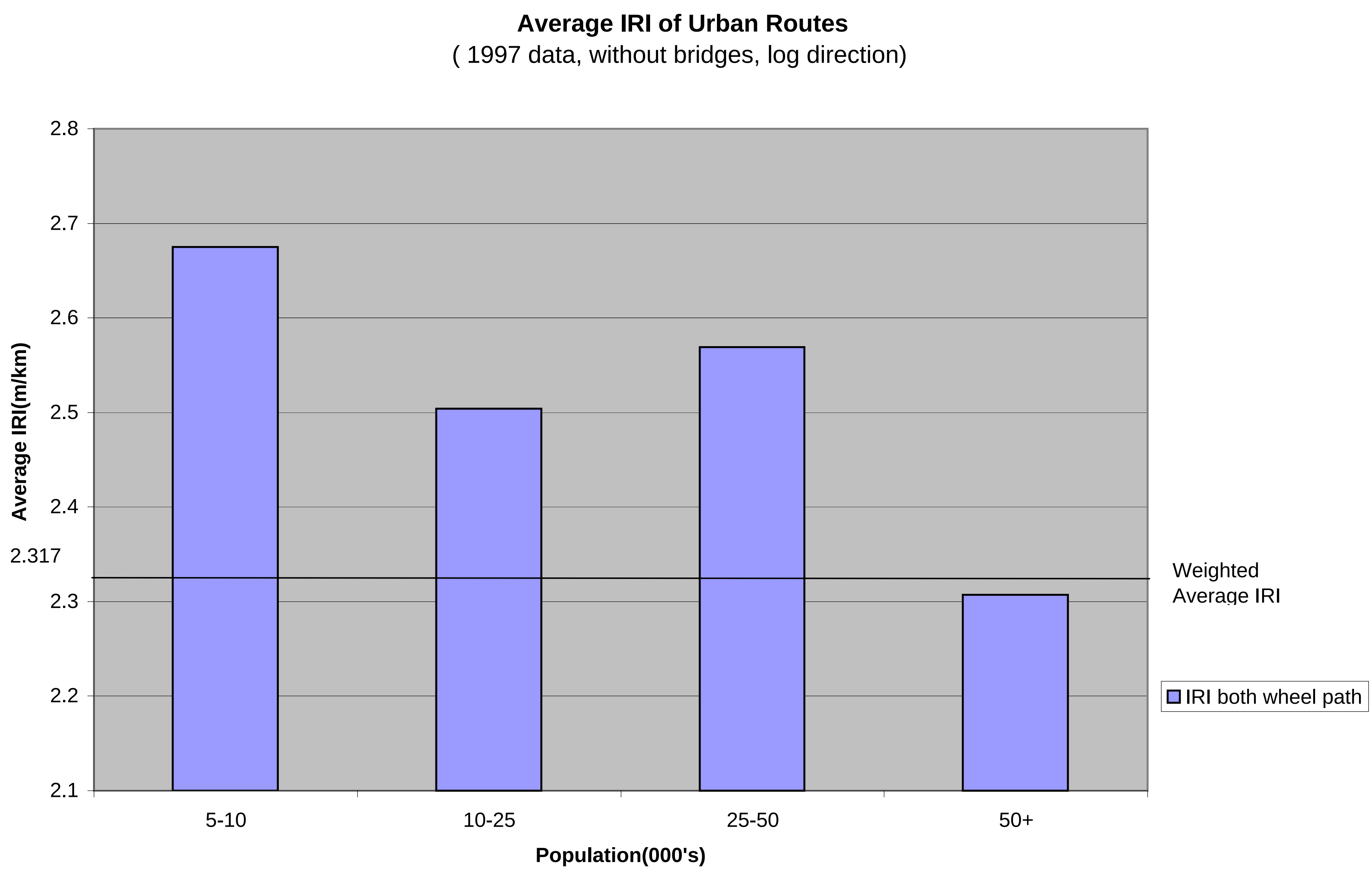
Route	Length(km)	1997 Data, Log Direction: IRI Left Wheel Path	1997: IRI Right Wheel Path	1997: Average of IRI Left Wheel Path And IRI Right Wheel Path	1998 Data, Log Direction: IRI Left Wheel Path	1998: IRI Right Wheel Path	1998: Average of IRI Left Wheel Path And IRI Right Wheel Path
33	23.16	2.515	2.671	2.593	2.590	2.798	2.694
34	39.54	2.308	2.417	2.363	2.265	2.420	2.343
35	9.19	2.253	2.747	2.500	2.498	2.924	2.711
37	30.06	2.278	2.530	2.404	2.243	2.439	2.341
39	36.58	2.156	2.359	2.258	2.115	2.432	2.274
40	5.01	1.645	1.650	1.648	1.700	1.722	1.711
41	28.81	1.735	1.788	1.762	1.745	1.779	1.762
42	21.96	2.984	3.196	3.090	2.910	3.084	2.997
43	8.15	4.153	4.834	4.494	4.098	4.648	4.373
44	171.09	2.038	2.134	2.086	2.040	2.173	2.107
45	16.57	3.245	3.553	3.399	2.766	3.185	2.976
47	19.78	2.047	2.243	2.145	2.055	2.231	2.143
49	35.29	2.676	3.161	2.919	1.883	2.191	2.037
53	37.98	2.256	2.485	2.371	2.225	2.430	2.328
55	4.25	2.030	2.416	2.223	2.032	2.387	2.210
57	15.31	2.271	2.406	2.339	2.271	2.471	2.371
58	29.92	2.262	2.345	2.304	2.255	2.365	2.310
59	19.37	2.218	2.376	2.297	2.193	2.342	2.268
61	14.78	1.899	2.133	2.016	1.829	2.074	1.952
63	84.79	2.246	2.286	2.266	2.222	2.331	2.277
64	13.03	2.093	2.353	2.223	2.043	2.226	2.135
66	61.82	2.177	2.211	2.194	2.140	2.199	2.170
67	49.99	2.096	2.108	2.102	2.062	2.140	2.101
68	35.58	2.249	2.377	2.313	2.240	2.406	2.323
69	56.69	2.082	2.282	2.182	2.044	2.274	2.159
70	17.48	2.454	2.636	2.545	2.475	2.789	2.632
71	30.86	2.593	2.825	2.709	2.375	2.634	2.505
71A	4.70	5.526	2.721	4.123	2.573	3.005	2.789
72	32.38	1.953	1.981	1.967	1.889	1.953	1.921
73	5.74	2.075	2.252	2.164	2.235	2.518	2.377
74	35.78	2.553	2.732	2.643	2.600	2.839	2.720
75	21.79	2.388	2.523	2.456	2.378	2.552	2.465

Notes:

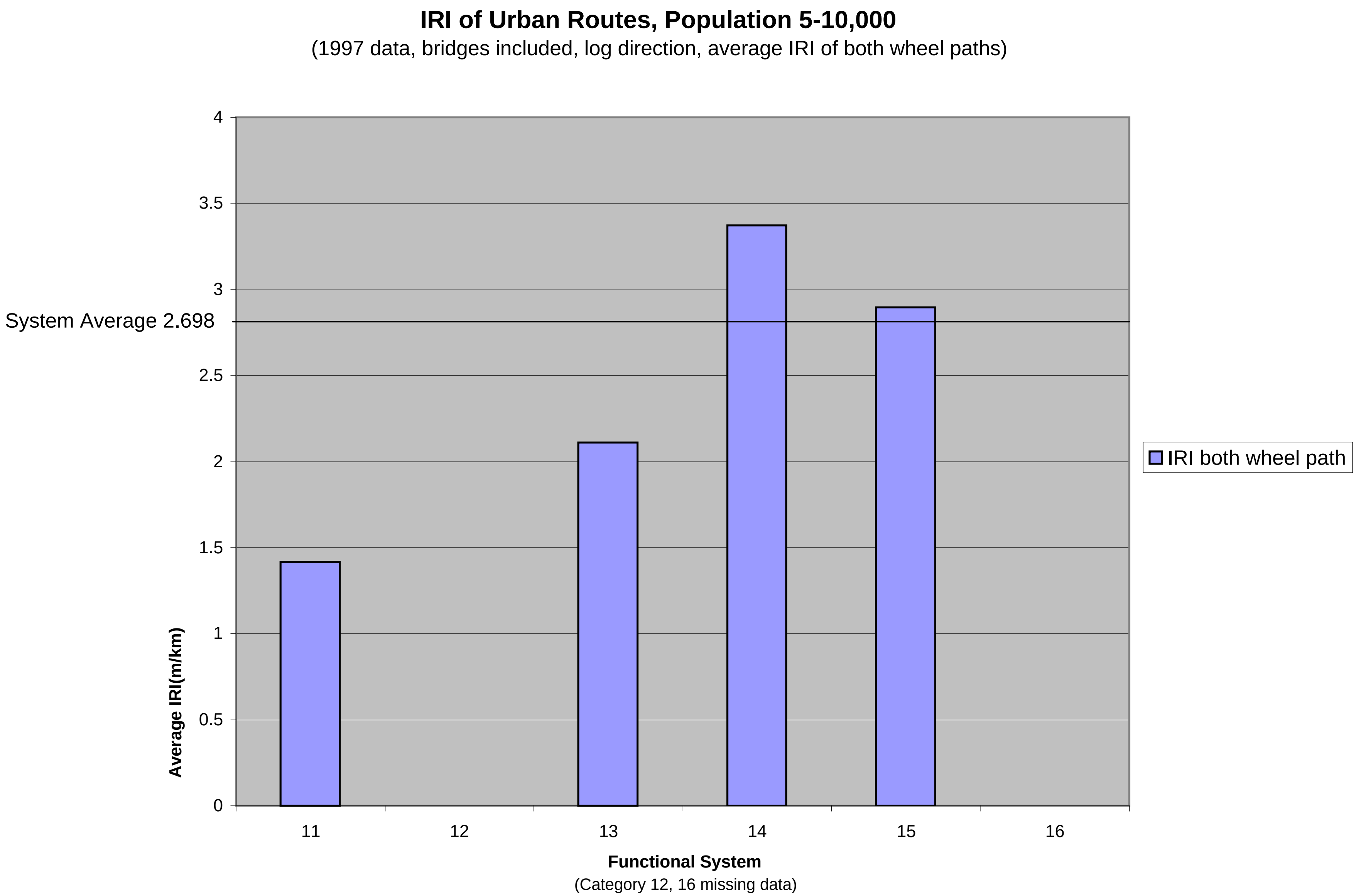
1- 999 in the Table denotes that no data are available. The main reason for the absence of data are low travel speed for the ARAN vehicle (<35 kph). Beginning in the year 2000 the ARAN vehicles will be able to collect data at travel speeds $\geq$ 20 kph.

APPENDIX 2

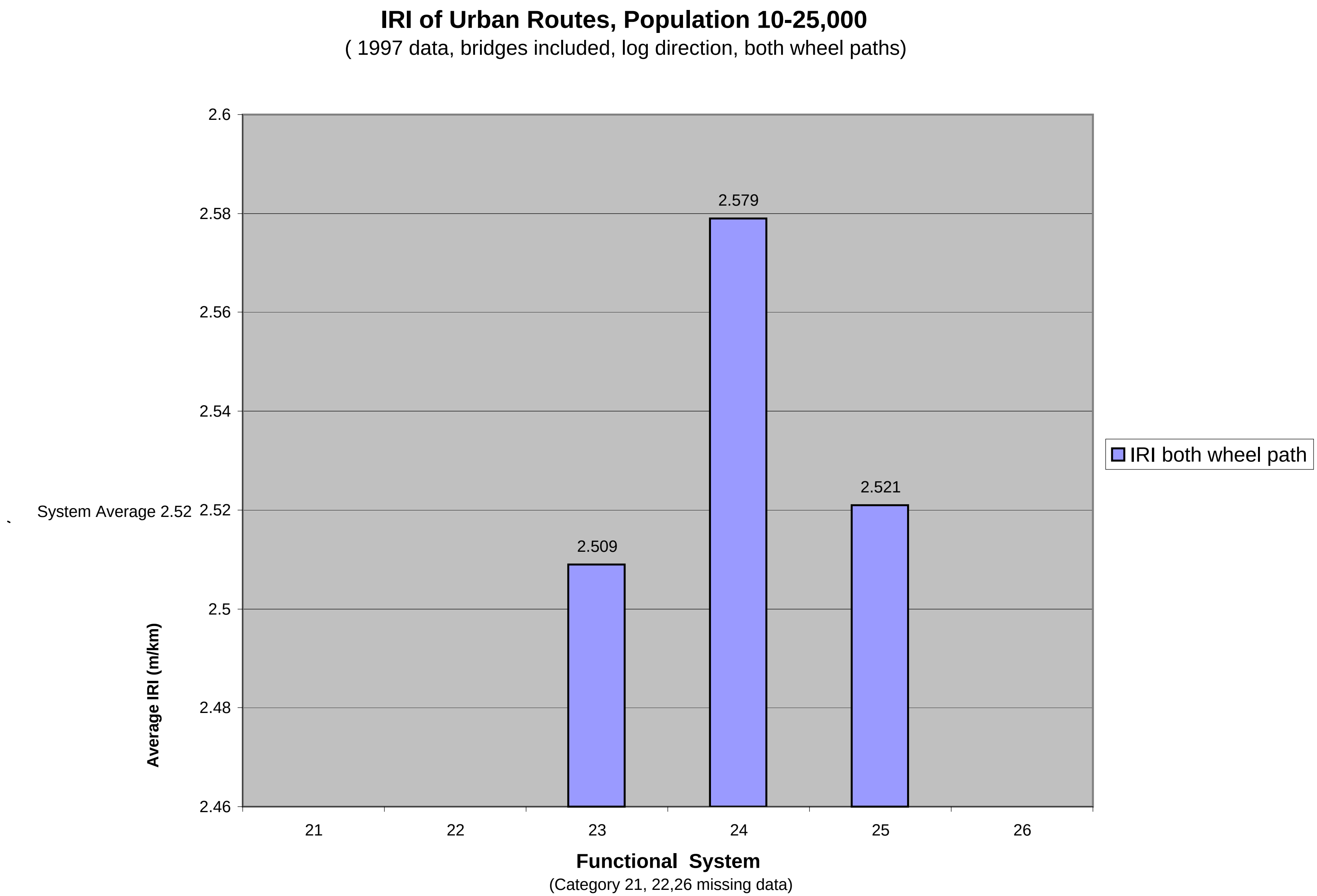
IRI Data for Urban Routes
Based on Population

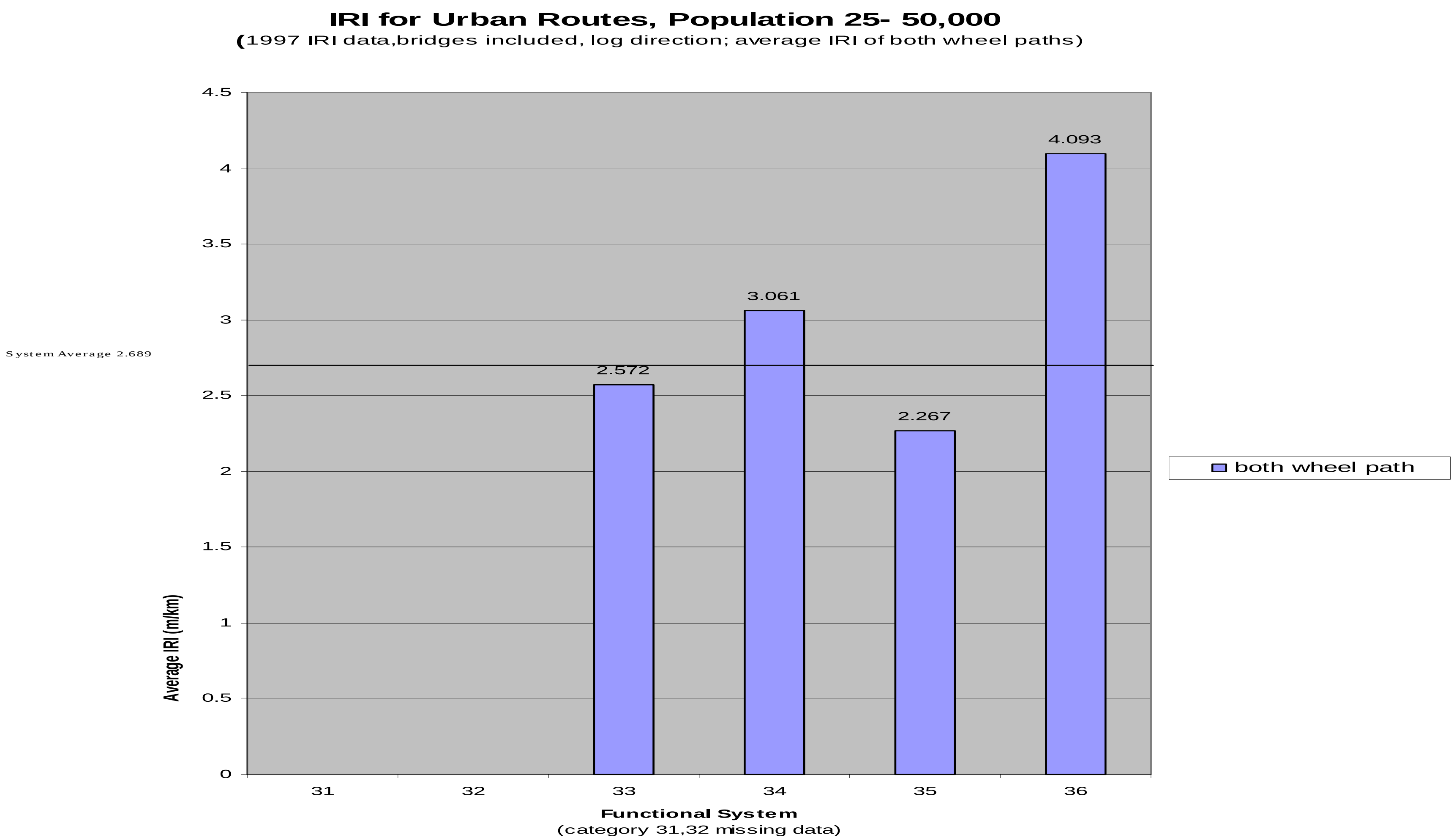


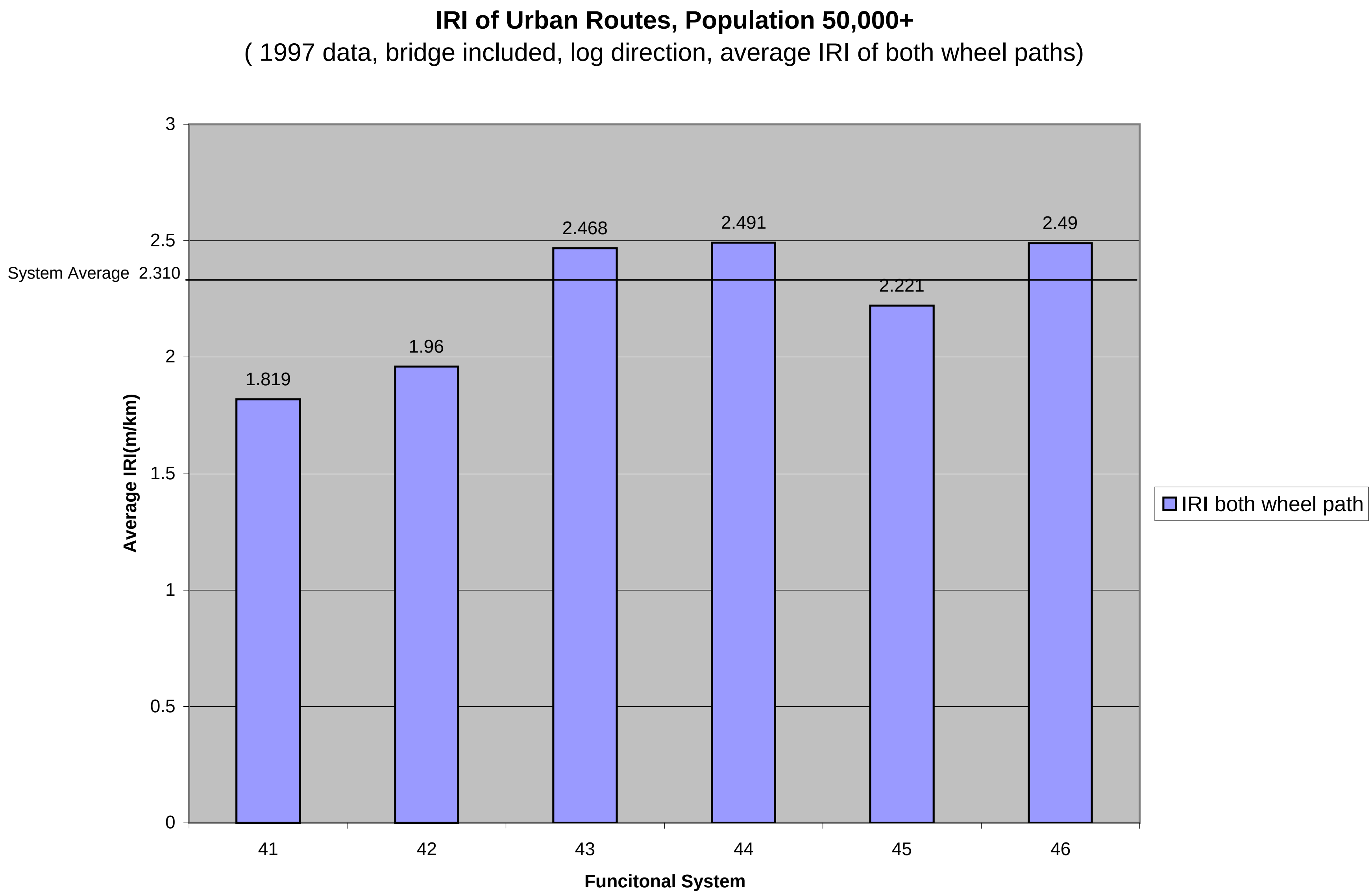
Average IRI of Urban Routes
(1997 data, without bridges, log direction)
Average IRI(m/km)
2.8
2.7
2.6
2.5
2.4
2.317
2.3
2.2
2.1
Weighted
Average IRI
IRI both wheel path
5-10
10-25
25-50
50+
Population(000's)



IRI of Urban Routes, Population 5-10,000
(1997 data, bridges included, log direction, average IRI of both wheel paths)
System Average 2.698
Average IRI(m/km)
4
3.5
3
2.5
2
1.5
1
0.5
0
11
12
13
14
15
16
Functional System
(Category 12, 16 missing data)
IRI both wheel path


IRI of Urban Routes, Population 10-25,000
(1997 data, bridges included, log direction, both wheel paths)
2.6
2.58
2.56
2.54
2.52
2.5
2.48
2.46
System Average 2.52
Average IRI (m/km)
2.509
2.579
2.521
21
22
23
24
25
26
Functional System
(Category 21, 22,26 missing data)
IRI both wheel path


IRI for Urban Routes, Population 25- 50,000
(1997 IRI data,bridges included, log direction; average IRI of both wheel paths)
System Average 2.689
Average IRI (m/km)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
4.093
3.061
2.572
2.267
31
32
33
34
35
36
Functional System
(category 31,32 missing data)
both wheel path


IRI of Urban Routes, Population 50,000+
(1997 data, bridge included, log direction, average IRI of both wheel paths)
System Average 2.310
Average IRI(m/km)
3
2.5
2
1.5
1
0.5
0
1.819
1.96
2.468
2.491
2.221
2.49
41
42
43
44
45
46
Funcitonal System
IRI both wheel path

APPENDIX 3

Definition of the National
Highway System

Reproduced from:
"Title 23-United State Code
Section 103 "Federal-aid System"

Title 23 – United States Code
Section 103. Federal-aid systems
(b) NATIONAL HIGHWAY SYSTEM

(1) DESCRIPITION. – The National Highway System consists of the highway routes and connections to transportation facilities depicted on the map submitted by the Secretary to Congress with the report entitled "Pulling Together: The National Highway Systems and its Connections to Major Intermodel Terminals" and dated May 24, 1996. The system shall--

(A) serve major population centers, international border crossings, ports, airports, public transportation facilities, and other intermodal transportation facilities and other major travel destinations;

(B) meet national defense requirements; and

(C) serve interstate and interregional travel

(2) COMPONENTS.-- The National Highway System described in paragraph (1) consists of the following:

(A) The Interstate System described in subsection (c).

(B) Other urban and rural principal arterial routes.

(C) Other connector highways (including toll facilities) that provide motor vehicle access between arterial routes on the National Highway System and a major intermodel transportation facility.

(D) A strategic highway network consisting of a network of highways that are important to the United States strategic defense policy and that provide defense access, continuity, and emergence capabilities for the movement of personnel, material, and equipment in both peacetime and wartime. The highways may be highway on or off the Interstate System and shall be designated by the Secretary in consultation with appropriate Federal agencies and the States.

(E) Major strategic highway network connectors consisting of highways that provide motor vehicle access between major military installation and highways that are part of the strategic highway network. The highways shall be designated by the Secretary in consultation with appropriate Federal agencies and the States.

(3) MAXIMUM MILEAGE.-- The mileage of highways on the National Highway System shall not exceed 178,250 miles.

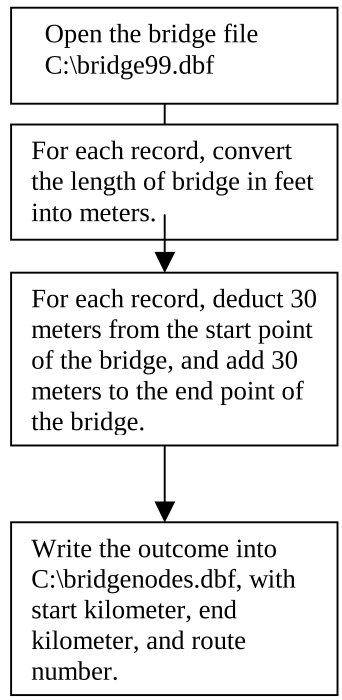
APPENDIX 4

COMPUTER PROGRAM to
REMOVE BRIDGE ROUGHNESS

Programs to Extract Bridges from the IRI Profiling File

Step 1:

Find out the start point and end point of each bridge and convert them into kilometers

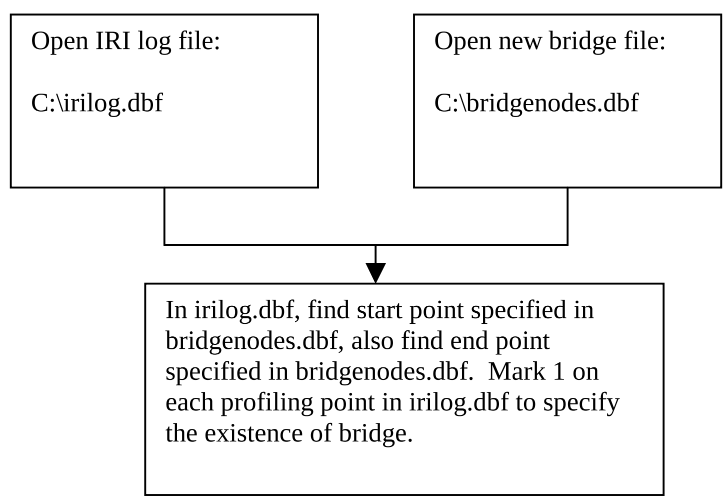


Outcome of Step 1:

A modified bridge file.

Step 2.

Extract Bridges in the Original IRI Profiling File



Outcome of Step 2:

In IRI original profiling files, 1s are marked on the sections with bridges.

Original IRI Profiling Files With Designated Bridges

route_id	route	dir	pid_km	r_iri	l_iri	avg_iri	max_iri	isvalid	iri_year	brg
1997001 L	1	L	9.29	1.91	3	2.46	3	TRUE	1997	0
1997001 L	1	L	9.3	2.2	3.92	3.06	3.92	TRUE	1997	0
1997001 L	1	L	9.31	1.92	2.63	2.28	2.63	TRUE	1997	0
1997001 L	1	L	9.32	1.37	2.51	1.94	2.51	TRUE	1997	0
1997001 L	1	L	9.33	2.08	1.88	1.98	2.08	TRUE	1997	0
1997001 L	1	L	9.34	2.7	2.35	2.53	2.7	TRUE	1997	1
1997001 L	1	L	9.35	5.42	3.06	4.24	5.42	TRUE	1997	1
1997001 L	1	L	9.36	5	4.44	4.72	5	TRUE	1997	1
1997001 L	1	L	9.37	3.27	2.96	3.12	3.27	TRUE	1997	1
1997001 L	1	L	9.38	1.17	1.57	1.37	1.57	TRUE	1997	1
1997001 L	1	L	9.39	1.36	2.51	1.94	2.51	TRUE	1997	1
1997001 L	1	L	9.4	1.43	2.71	2.07	2.71	TRUE	1997	1
1997001 L	1	L	9.41	2.59	1.38	1.99	2.59	TRUE	1997	0
1997001 L	1	L	9.42	1.56	2.13	1.85	2.13	TRUE	1997	0
1997001 L	1	L	9.43	1.39	2.08	1.74	2.08	TRUE	1997	0
1997001 L	1	L	9.44	1.83	2.25	2.04	2.25	TRUE	1997	0
1997001 L	1	L	9.45	4.14	3.51	3.83	4.14	TRUE	1997	0
1997001 L	1	L	9.46	2.81	4.02	3.42	4.02	TRUE	1997	0
1997001 L	1	L	9.47	2.87	2.25	2.56	2.87	TRUE	1997	0
1997001 L	1	L	9.48	3.12	3.62	3.37	3.62	TRUE	1997	0
1997001 L	1	L	9.49	2.8	2.71	2.76	2.8	TRUE	1997	0
1997001 L	1	L	9.5	1.67	2.45	2.06	2.45	TRUE	1997	0
1997001 L	1	L	9.51	2.01	3.02	2.52	3.02	TRUE	1997	0

0* No bridges
1 Includes bridges

Existing Bridge File Data, Calculated Length Removed

Bridge Number	ConnDot Identifier	Route	Bridge Starting Milepost	Bridge Length(ft)	Calculated Start(km)	Calculated End(km)	Bridge Length(km)	Total Length Removed(km)
01872		1	3.05	18	4.89	4.95	0.01	0.07
00314	A001	1	4.21	194	6.75	6.86	0.06	0.12
03481		1	5.82	17	9.34	9.40	0.01	0.07
03824	A001	1	6.75	147	10.84	10.93	0.04	0.10
00037	A001	1	8.64	252	13.88	14.01	0.08	0.14
00315	A001	1	8.97	48	14.41	14.47	0.01	0.07

Total Length Removed = 30m+Bridge Length +30m

```
*   Program to Extract Bridges from the IRI Profiling File


public nSt, nEnd, nRt
close tables
sele 4
*use c:\tempiri97.dbf order sm
*use c:\temp3.dbf order sm
*use c:\before11.dbf
*use c:\rawdatairi\dataprog\sourcefiles\117-136.dbf
*use c:\rt1.dbf
USE c:\rawdatairi\dataprog\sourcefiles\irilog98.dbf order sm
sele 2
use c:\bridge9-2.dbf
*use c:\bgtemp.dbf
*use c:\newbg.dbf
 *use c:\1-1.dbf
go top

do while .T.
if eof()
exit
endif
nRt=Route
nSt=Start_km
nEnd=End_km
sele 4
locate for Route=nRt AND Pid_km=nSt
if !found()
sele 2
skip
loop
endif

do while Pid_km<=nEnd AND Route=nRt
replace Brg with 1
if eof()
exit
endif
skip
loop
enddo
sele 2
skip
loop
enddo
```

APPENDIX 5

SUMMARY of STATISTICAL
ANALYSES PERFORMED

Normality Test

Frequencies

Statistics

IRIB

N	Valid	23
	Missing	0
Mean		2.5468
Std. Deviation		0.6896
Variance		0.4756
Skewness		0.668
Std.Error of Skewness		0.481
Kurtosis		0.335
Std. Error of Kurtosis		0.935
Range		2.68
Percentiles	25	2.08
	50	2.501
	75	2.901

IRIB

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.41	1	4.3	4.3	4.3
	1.60	1	4.3	4.3	8.7
	1.71	1	4.3	4.3	13.0
	1.91	1	4.3	4.3	17.4
	1.94	1	4.3	4.3	21.7
	2.08	1	4.3	4.3	26.1
	2.09	1	4.3	4.3	30.4
	2.25	1	4.3	4.3	34.8
	2.42	1	4.3	4.3	39.1
	2.48	1	4.3	4.3	43.5
	2.49	1	4.3	4.3	47.8
	2.50	1	4.3	4.3	52.2
	2.51	1	4.3	4.3	56.5
	2.51	1	4.3	4.3	60.9
	2.57	1	4.3	4.3	65.2
	2.60	1	4.3	4.3	69.6
	2.79	1	4.3	4.3	73.9
	2.90	2	8.7	8.7	82.6
	3.35	1	4.3	4.3	87.0
	3.50	1	4.3	4.3	91.3
	3.96	1	4.3	4.3	95.7
	4.09	1	4.3	4.3	100.0
	Total	23	100	100	

Modified Normality Test - Outliers Removed

V1	FUNC.CLS	IRIL	IRIR	IRIB	POINTS	V7	V8
#NULL!	04	2.47	2.73	2.60	########	#NULL!	#NULL!
#NULL!	01	1.64	1.56	1.60	15126.00	#NULL!	#NULL!
#NULL!	13	2.03	2.13	2.08	750.00	#NULL!	#NULL!
#NULL!	14	3.19	3.52	3.35	1215.00	#NULL!	#NULL!
#NULL!	11	1.42	1.40	1.41	299.00	#NULL!	#NULL!
#NULL!	15	2.96	2.84	2.90	17.00	#NULL!	#NULL!
#NULL!	24	2.27	2.75	2.51	229.00	#NULL!	#NULL!
#NULL!	23	2.47	2.53	2.50	1681.00	#NULL!	#NULL!
#NULL!	25	2.31	2.70	2.51	987.00	#NULL!	#NULL!
#NULL!	34	2.80	3.01	2.90	949.00	#NULL!	#NULL!
#NULL!	35	2.21	2.30	2.25	1380.00	#NULL!	#NULL!
#NULL!	33	2.57	2.57	2.57	1610.00	#NULL!	#NULL!
#NULL!	41	1.71	1.72	1.71	33474.00	#NULL!	#NULL!
#NULL!	44	2.39	2.57	2.48	########	#NULL!	#NULL!
#NULL!	43	2.33	2.52	2.42	63602.00	#NULL!	#NULL!
#NULL!	45	2.42	2.57	2.49	11057.00	#NULL!	#NULL!
#NULL!	42	1.91	1.90	1.91	21343.00	#NULL!	#NULL!
#NULL!	02	1.95	1.94	1.94	21917.00	#NULL!	#NULL!
#NULL!	03	2.03	2.16	2.09	85838.00	#NULL!	#NULL!
#NULL!	05	3.27	3.73	3.50	6991.00	#NULL!	#NULL!

Normality Test - Outliers Removed

Frequencies

Statistics

IRIB

N	Valid	20
	Missing	0
Mean		2.3866
Std. Deviation		0.538
Variance		0.2894
Skewness		0.221
Std.Error of Skewness		0.512
Kurtosis		0.047
Std. Error of Kurtosis		0.992
Range		2.09
Percentiles	25	1.9765
	50	2.4875
	75	2.5913

IRIB

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.41	1	5	5	5.0
	1.6	1	5	5	10.0
	1.71	1	5	5	15.0
	1.91	1	5	5	20.0
	1.94	1	5	5	25.0
	2.08	1	5	5	30.0
	2.09	1	5	5	35.0
	2.25	1	5	5	40.0
	2.42	1	5	5	45.0
	2.48	1	5	5	50.0
	2.49	1	5	5	55.0
	2.5	1	5	5	60.0
	2.51	2	10	10	70.0
	2.57	1	5	5	75.0
	2.6	1	5	5	80.0
	2.9	2	10	10	90.0
	3.35	1	5	5	95.0
	3.5	1	5	5	100.0
	Total	20	100	100	

Test the Influence of Existence of the Bridges on Average IRI Value, Broken Down by Functional Classes

Data Set

Each functional class has its Average IRI value calculated with bridges and Average IRI value calculated without bridges. The two different IRI values of each of the 23 functional classes are assigned to two groups: Group 1 is for the IRI value with bridge, which is coded as 1; Group 0 is for the IRI value without bridges, which is coded as 0.

Procedure

1. Check for the normality of the samples.
2. Calculate the mean of Group 1 and Group 0, using two sample T test to test if these two means are significantly different at 95% confidence interval.

Conclusion

These two means are not significantly different. That is to say, when broken down by functional classes, the existence of bridges does not make differences.

Functional Class	Average IRI Both Wheel Path (without bridges)	Average IRI Both Wheel Path (with bridges)
11	1.409	1.417
01	1.6	1.612
41	1.711	1.8185
42	1.907	1.96
02	1.942	2.0565
13	2.08	2.095
03	2.091	2.1115
35	2.254	2.2675
43	2.423	2.478
33	2.483	2.489
35	2.492	2.509
23	2.501	2.521
25	2.508	2.5715
24	2.51	2.5785
33	2.568	2.594
04	2.599	2.652
46	2.792	2.7275
15	2.901	2.8965
34	2.901	3.0615
14	3.351	3.388
05	3.5	3.474
06	3.962	3.8225
36	4.092	4.0925

T-Test

Group Statistics

	A	N	Mean	Std. Deviation	Std. Error Mean
B	1	23	2.57363	0.6657	0.13881
	0	23	2.54683	0.68965	0.1438

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	d.f	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
B	Equal variances assumed	0.016	0.901	0.134	44	0.894	2.6804E-02	0.19987	-0.37600	0.42961
	Equal Variances not assumed			0.134	44	0.894	2.6804E-02	0.19987	-0.37601	0.42962

T Test for the Difference Between 1997 and 1998 Data of NHS IRI Values

Data Set

The average IRI values of NHS sections for 1997 are included in group 1, which will be compared with that of 1998, included in group 2. Data of route 601 and 684 are excluded because of data missing. Route 184 is also excluded because it is only 20 meters long, which has only 2 data points, and the IRI value of so short a distance is not valid. Therefore, altogether we have 40 routes out of 43.

Procedure

1. Check for the normality of the data set.
2. Compare the mean of Group 1 and Group 2, using two sample T test to test if these two means are significantly different at 95% confidence interval.

Conclusion

These two means are not significantly different. That is to say, the IRI values of NHS sections for 1997 data are not significantly different with that of 1998 data.

T-Test

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
IRI97_98	1	40	2.123	0.6045	9.559E-02
	2	40	2.0678	0.4789	7.57E-02

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	d.f	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
IRI97_98	Equal variances assumed	1.386	0.243	0.453	78	0.652	5.527E-02	0.1219	-0.18750	0.298
	Equal Variances not assumed			0.453	74.12	0.652	5.527E-02	0.1219	-0.18770	0.2982