Network Summary Analysis Report
[FINAL]

Prepared for:

Amarillo, TX

Prepared by:

Stantec Consulting Inc.
8211 South 48th Street
Phoenix AZ 85044-5355

January 30,2009

Executive Summary

The City of Amarillo (City) is responsible for the administration of a paved roadway network consisting of Arterial, Collector, and Local-Residential roads, totaling approximately 2,061 lane-miles as indicated in Table E.1.

Table E.1: City of Amarillo Entire Paved Network

Functional Class	Sections	Ln-miles
Arterial	1,152	492.8
Collector	474	104.7
Local – Residential	7,875	1,463.3
Entire Paved Network	**9,501**	**2,060.8**

For many years, municipalities have extensively used pavement management systems to develop budget projections based upon the current condition of the road network. In 2008, the City commissioned Stantec Consulting Inc. (Stantec) to implement a pavement management system, RoadMatrix, for the City of Amarillo road network. To facilitate the development of the pavement management system, Stantec completed the following tasks:

- Collection of pavement roughness and surface distress data on Arterial, Collector, and Local-Residential roads using Stantec's RT3000
- Collection of pavement deflection data on Arterial and Collector roads using Stantec's Falling Weight Deflectometer
- Capture of digital video data for all surveyed road sections in a single direction coinciding with the direction of the pavement condition survey
- Implementation of Stantec's RoadMatrix pavement management system

While this is the first network-level condition survey for the City of Amarillo, it is recommended that the City continue to invest in network level data collection. Typically, municipalities follow a three-year survey program cycle, whereby the network is evaluated once every three years or a third of the network is evaluated every year in a recurring cycle.

The analysis of the collected condition data indicates that the majority of the paved road sections are providing at least a minimum acceptable performance to the road users as noted by the network average Pavement Quality Index (PQI) of 78.5. The results of the present status and backlog (present needs) are provided in Table E.2.

Table E.2: City of Amarillo Network Present Status

Functional Class	Present Status				Backlog	
	PQI	RCI	SDI	SAI	Ln-miles	% F/C
Arterial	72.6	64.7	69.7	77.9	173.6	35.2
Collector	65.8	58.5	72.2	73.5	50.2	48.0
Local – Residential	81.4	58.0	81.4	n/a	120.9	8.3
Entire Paved Network	78.5	59.6	78.1	77.1	344.7	16.7

While the Entire Paved Network has a backlog of 16.7%, the Arterial and Collector networks have backlogs of 35.2% and 48.0%, respectively. While the majority of lower volume roads, i.e., the Local-Residential roads, which represent nearly three-quarters of the Entire Paved Network (71%), are performing at an acceptable level; a significant portion of the higher volume roads, i.e., Arterial and Collector roads, are failing to provide an acceptable level of service.

Based on results from the needs analysis, priority programming analysis was conducted for the ten-year period beginning in 2008. The following funding scenarios were analyzed:

- Performance-based scenario to 'Maintain PQI=78.5', which would be required to maintain the current level of service of the City's Entire Paved Network, i.e., PQI=78.5
- Performance-based scenario to 'Maintain PQI=80', which would be required to slightly improve the current level of service of the City's Entire Paved Network, i.e. PQI = 80
- 'Need Driven' scenario, which identifies the actual budget requirements required to bring the network to the levels of service identified within the pavement management system
- 'Do Nothing' scenario, which identifies the level of service provided by the City's Entire Paved Network should no investment be made in maintenance or rehabilitation

Analysis results show that to maintain the City's Entire Paved Network current level of service, as defined by the Pavement Quality Index (PQI), would require an investment of approximately $87 million over the next ten years. Subsequently, if the City wishes to increase the current level of service to a network average of PQI=80 by the end of the 10-year program, an additional $18 million ($105 million total) would be needed over the next ten years.

Since maintaining a network average of PQI=80 provides very similar results to the 'Need Driven' scenario ($105 million vs. $104 million), the network performance will not be able to improve beyond this level of service without increasing the minimum acceptable PQI values for each of the functional classes and/or revisiting the decision trees, which may be something to consider in the future as more condition data becomes available.

PERFORMANCE INDICATORS

Riding Comfort Index (RCI)

- Index representing the roughness or riding comfort of a pavement section
- Index represented by a value on a scale of zero (0) to 100, where zero is considered an extremely rough surface and 100 is an extremely smooth surface
- Value calculated based on the results of the pavement roughness survey, during which longitudinal profiles of the left and right wheel paths in the survey travel lane are measured and used to simulate the dynamic response of a reference vehicle traveling over the measured profile
- Roughness surveys are typically completed for the entire paved road network

Surface Distress Index (SDI)

- Index representing the presence, severity and extent of various surface distresses (e.g., cracking, potholes, etc.) occurring throughout a given pavement section
- Index represented by a value on a scale of zero (0) to 100, where zero is considered a significantly distressed pavement surface and 100 indicates that no surface distresses exist
- Value calculated based on the results of the surface distress survey
- Surface distress surveys are typically completed for the entire paved road network

Structural Adequacy Index (SAI)

- Index representing the ability of a pavement section to support expected loading (traffic) conditions, and is indicative of pavement strength
- Index represented by a value on a scale of zero (0) to 100, where 50 is a pivot point that indicates the pavement's structural strength is just enough to adequately support the current traffic loads. An index less than 50 represents inadequate structural support and greater than 50 represents structural support that is better than required to accept the current traffic loads
- Value measured (indirectly) using a Falling Weight Deflectometer (FWD) unit, which is a device that quantifies the deflection of a pavement produced by a series of load applications

- Deflection tests are typically performed on roads of higher functional classes (e.g. Arterials and Collectors) and/or on roads that are subject to heavy traffic loads (bus routes, truck routes, etc.)

Pavement Quality Index (PQI)

- Index representing the overall condition of a pavement section
- Index represented by a value on a scale of zero (0) to 100, where zero is considered unacceptable and 100 is considered excellent
- Value calculated using one of three PQI models, each of which is based on a weighted combination of RCI, SDI and SAI, where available
- PQI model for higher functional classes (Arterials and Collectors) is primarily roughness-driven (i.e., riding comfort is of primary concern but considers ride comfort then surface distresses and then the structural adequacy)
- PQI model for lower functional classes (Local-Residentials, etc.) is based on surface distress ratings
- PQI model incorporates the structural adequacy of a pavement where data are available (typically on heavy-traffic routes)

Table of Contents

EXECUTIVE SUMMARY ..... *i*

PERFORMANCE INDICATORS III
Riding Comfort Index (RCI) iii
Surface Distress Index (SDI) iii
Structural Adequacy Index (SAI) iii
Pavement Quality Index (PQI) iv

1.0 PROJECT OVERVIEW 1.1

2.0 DATA COLLECTION 2.1
2.1 ROUGHNESS AND SURFACE DISTRESS SURVEY 2.1
2.2 DIGITAL VIDEO SURVEY 2.2

3.0 ANALYSIS 3.1
3.1 STRUCTURAL COMPOSITION 3.1
3.2 ROUGHNESS – RIDING COMFORT INDEX (RCI) ANALYSIS 3.2
3.3 SURFACE DISTRESS INDEX (SDI) ANALYSIS 3.2
3.4 STRUCTURAL ADEQUACY INDEX (SAI) ANALYSIS 3.3
3.5 PAVEMENT QUALITY INDEX (PQI) ANALYSIS 3.3
3.6 PERFORMANCE PREDICTION MODELING AND NEEDS ANALYSIS 3.4
3.7 PRIORITY PROGRAMMING ANALYSIS 3.10
3.7.1 Input Parameters 3.10
3.7.2 Analysis 3.11

4.0 ANALYSIS RESULTS 4.1
4.1 PRESENT STATUS ANALYSIS 4.1
4.1.1 Riding Comfort Index (RCI) Analysis 4.1
4.1.2 Surface Distress Index (SDI) Analysis 4.1
4.1.3 Structural Adequacy Index (SAI) Analysis 4.4
4.1.4 Pavement Quality Index (PQI) Analysis 4.7
4.2 IMPROVEMENT NEEDS ANALYSIS 4.10
4.3 PRIORITY PROGRAMMING ANALYSIS 4.13

5.0 CONCLUSIONS AND RECOMMENDATIONS 5.1

APPENDIX A: DETERMINATION OF RIDING COMFORT INDEX (RCI) 1

APPENDIX B: DETERMINATION OF SURFACE DISTRESS INDEX (SDI) 1

APPENDIX C: DETERMINATION OF STRUCTURAL ADEQUACY INDEX (SAI) 1

APPENDIX D: DETERMINATION OF PAVEMENT QUALITY INDEX (PQI) 1

APPENDIX E: DECISION TREES 1

APPENDIX F: FUNCTIONAL CLASS PERFORMANCE DISTRIBUTION 1

APPENDIX G: 10 YEAR PROGRAM BASED ON 'MAINTAIN PQI=80' FUNDING SCENARIO 1

1.0 Project Overview

The City of Amarillo is responsible for the maintenance and rehabilitation of approximately 2,061 lane-miles of paved roads. This network, along with the City's investment in curbs, and gutters, form a valuable asset to be managed in a cost-effective manner in order to provide a desirable level of service to the stakeholders of the network.

The City commissioned Stantec Consulting Inc. to implement Stantec's pavement management system, RoadMatrix. A key component of an effective pavement management program is to regularly assess the condition of the road network, which can then be used to assess the performance of the network over time.

A pavement management program, which includes a regular commitment to collect condition data, will enable City staff to achieve the following:

- Estimate the future condition of the pavement network and determine the rehabilitation requirements over the next ten years
- Identify feasible rehabilitation alternatives for each section and, based on this information, assemble ten-year rehabilitation programs for various funding scenarios
- Estimate the impact that these programs will have on the condition of the road network over the ten-year analysis period

In 2008, pavement roughness and surface distress data were collected on approximately 2,061 lane-miles of the City's paved road network, including flexible, rigid, and brick roads. Deflection data was also collected on approximately 591 lane-miles.

The data collected during the field surveys were used to identify the Present Status of the pavements in terms of four performance indicators:

- SDI - Surface Distress Index
- RCI - Riding Comfort Index
- SAI - Structural Adequacy Index
- PQI - Pavement Quality Index.

The significance of these indicators is discussed further in Section 3 of this report.

A long-term pavement performance model was used to estimate the rehabilitation requirements of the City's Entire Paved Network for a ten-year period, beginning in 2008. The Entire Paved Network is comprised of all paved roads for which the City is responsible. Pavement rehabilitation programs were then developed using life-cycle-economic analyses based upon a

series of budget and level-of-service scenarios. The impact of these programs on the future condition of the Entire Paved Network was estimated.

The progression of tasks associated with the RoadMatrix implementation is depicted in Figure 1.1.

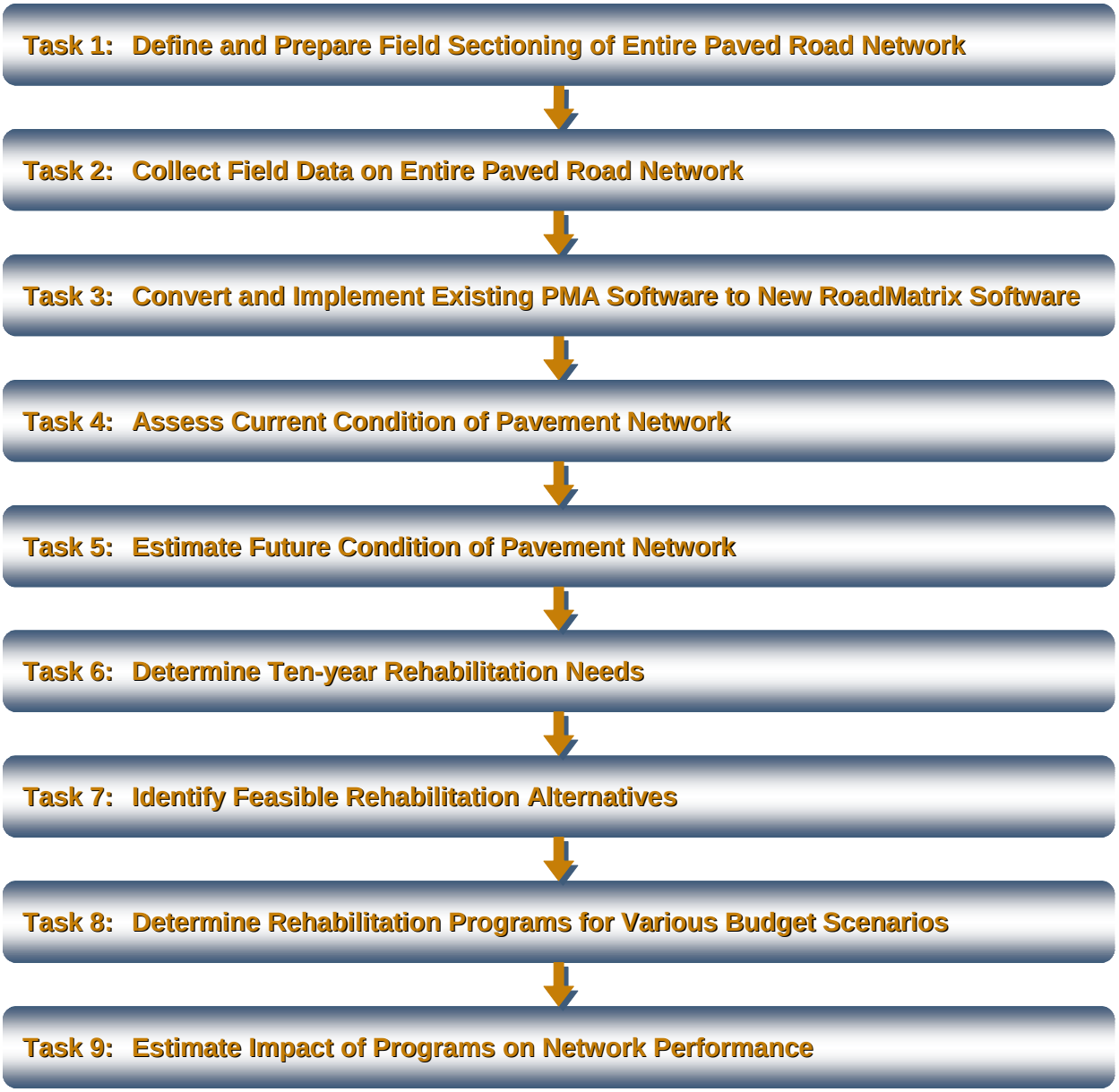

Figure 1.1: Implementation of RoadMatrix Pavement Management Application

2.0 Data Collection

2.1 ROUGHNESS AND SURFACE DISTRESS SURVEY

The roughness and surface distress survey was conducted on the majority of the City of Amarillo's paved road network in the spring of 2008.

The roughness of each section was measured using the RT3000 unit, a specially equipped van with accelerometers and laser sensors mounted to the front bumper. This technology was used to measure the longitudinal profile of the pavement surface in each wheel path of the survey travel lane. The profile data were then used to calculate an International Roughness Index (IRI)[1], reported at 100-feet intervals.

The survey was generally conducted in the outside lane of the northbound or eastbound lanes of each road segment. Road sections with four or more traffic lanes and divided road sections were tested in both directions of travel. The RT3000 unit was operated at speeds of 15 mph or more, to ensure reliable profile data were being collected.

The surface distress survey recorded the extent and severities of various distress classifications, such as load associated cracking, non-load associated cracking, surface deformation, and surface defects.

The following thirteen distress types were inventoried:

Flexible Pavements
• Patching
• Rippling & Shoving
• Raveling/Streaking
• Flushing & Bleeding
• Distortion
• Excessive Crown
• Progressive Edge Cracking
• Alligator Cracking
• Potholes
• Block/Map Cracking
• Longitudinal Cracking
• Transverse Cracking
• Wheel track Rutting

[1] The IRI is an internationally accepted measure of pavement roughness and is widely used by many State transportation agencies and organizations such as the World Bank.

2.2 DIGITAL VIDEO SURVEY

High-resolution digital video data was collected simultaneously with the pavement condition survey, using a double 1,280 x 960 dpi camera system mounted in the RT3000 vehicle. The image data was collected in raw AVI file format at approximate 13-feet image intervals. For each survey pass on each individual road section, a separate AVI file was created. The AVI format was also reduced into sectional JPG groupings and all image data were linked to its corresponding road segment through the RoadMatrix application. A sample image showing the camera orientation used for the digital video data collection is shown in Figure 2.1.

Figure 2.1: High-Resolution Digital Video Survey

3.0 Analysis

3.1 STRUCTURAL COMPOSITION

Pavement layer materials and thicknesses are used to convert the pavement structure to an equivalent thickness of granular base material. The equivalent granular thickness (EGT) is determined by assigning equivalence factors to the type of material forming each layer. EGT values play a vital role in calculating and predicting the future performance (i.e. deterioration) of a pavement section. The EGT factors for each of the layer types identified in RoadMatrix are shown in Table 3.1.

Table 3.1: Layer Types EGT Factors

Code	Layer Type	EGT Factor
2	HMAC (Hot Mix Asphaltic Concrete)	2
5	CPCD (Concrete Pavement Contraction Design)	2.5
6	CRC (Continuously Reinforced Concrete)	3
7	Prime	1
8	Brick	2
9	CST (One Course Surface Treatment)	1
10	AC (Asphalt Concrete) Stabilized Base	1
11	PCC (Portland Cement Concrete) Stabilized Base	1
12	Composite Flexible Base	0.8
13	Composite Caliche Base	0.8
14	Soil Cement Base	0.8
15	Lime Stabilized Subgrade	0.67
16	Fly-Ash Stabilized Subgrade	0.67
17	Subgrade	0.67
18	Composite Subgrade	0.67

Where the actual structural composition of a pavement section is not known, EGT override values can be used. The City of Amarillo was able to provide actual layer information data (through coring/boring surveys or noted during utility cuts or rehabilitation projects) for most of the pavements within the RoadMatrix. In fact, less than 2% of the network has EGT overrides. City staff should continue to update the layer attribute information in the RoadMatrix system to calculate actual EGT values, since pavement thickness is one factor that directly impacts the predicted deterioration rate of a road section.

3.2 ROUGHNESS – RIDING COMFORT INDEX (RCI) ANALYSIS

The RT3000 unit is used to determine the longitudinal profile of the pavement surface, reported as an IRI value. Roughness measurements are correlated to an assessment of ride quality as determined by the ratings of a group of representative users of the pavements. This subjective assessment is termed the Riding Comfort Index (RCI).

The following equation was used to convert IRI measurements to RCI values:

$$RCI = 25.6 - 3.62 * Log(IRI)$$

where: IRI = International Roughness Index from the longitudinal profile of the right wheel path at 100-feet intervals to a standard of 30 mph and 100-feet intervals.

The RCI value for each road section ranges from zero (0) to 100, where an index of 100 is indicative of an extremely smooth pavement and an index of zero is indicative of an extremely rough pavement.

The method used to determine the relationship between IRI and RCI is described in detail in Appendix A.

3.3 SURFACE DISTRESS INDEX (SDI) ANALYSIS

The RT3000 surface distress survey provided a rating of the severity and extent of each of the thirteen surface distresses present in each station (i.e. 100-feet intervals) of every section in the network. These distress ratings were transformed to a zero (0) to 100 scale for each of the thirteen individual distress types, which were further combined using distress-specific weighting factors to generate an overall Surface Distress Index (SDI) for each station. A sectional SDI score was then computed based on these stational SDI scores. An index of 100 indicates a perfect (no distress) surface and an index of zero indicates a significant level of surface distress.

Appendix B provides a description of the procedure used to determine the SDI values.

3.4 STRUCTURAL ADEQUACY INDEX (SAI) ANALYSIS

The structural adequacy of a pavement indicates the pavement's ability to carry expected traffic loads while providing an acceptable level of service. The structural adequacy of a pavement is determined by analyzing the measured deflection of the pavement under a controlled loading condition and comparing this response to the maximum allowable deflection associated with anticipated loading conditions.

Seasonally adjusted deflection measurements are used along with traffic data to determine Structural Adequacy Index (SAI) values for each section. The SAI is represented by a value on a scale of zero (0) to 100; where a value of 50 represents a structural strength that just adequately supports the current traffic loads; a value less than 50 represents inadequate structural support; and a value greater than 50 represents more-than-adequate structural support.

A detailed description of the method used to calculate SAI values is presented in Appendix C.

3.5 PAVEMENT QUALITY INDEX (PQI) ANALYSIS

The Pavement Quality Index (PQI) provides an overall indication of the condition of a pavement with regard to present and future service to the user, and is derived through a combination of the sectional RCI, SDI, and SAI values.

The City's RoadMatrix system is employing different PQI models throughout the road network, depending on each section's defined functional classification.

- For higher classified roads (i.e. Arterials and Collectors), where higher traffic volumes and higher traffic speeds are common, an 'RCI-driven' PQI model is currently used in the City's pavement management application. In this model, the RCI value is the primary index used in the PQI calculation, which is then adjusted based on SDI values less than 100, and adjusted again for SAI values greater than 50 (adjusted up because the pavement is considered more than structurally adequate) or less than 50 (adjusted down for structurally inadequate pavement). These adjustments represent a section's potential to deteriorate.
- For lower road classifications in the network (i.e. Local – Residential), where traffic factors may not be as important from a PQI perspective, an 'SDI-only' PQI model is used. This model directly relates the PQI score to the SDI score for the road section.

As is the case with RCI, SAI, and SDI, the PQI varies between zero (0) and 100, where zero represents the worst condition of pavement and 100 represents the best condition of pavement.

The PQI models are documented in Appendix D.

3.6 PERFORMANCE PREDICTION MODELING AND NEEDS ANALYSIS

The PQI values of pavements typically decrease over time. In order to estimate future rehabilitation requirements of a pavement network, it is necessary to model the deterioration of PQI values. The rate of decrease of PQI depends on many factors, but it can be demonstrated that the principal factors are the traffic loading conditions, the properties and thickness of the pavement structure layers, and the strength of the underlying subgrade. The factors used to model pavement performance within the RoadMatrix are:

- Equivalent granular thickness (EGT) in three levels (Thin, Medium, Thick)
- Traffic volume (AADT) in three levels (Low, Medium, High)
- Subgrade strength in two levels (Strong, Weak)

The criteria used to classify traffic (AADT) and structural (EGT) threshold levels are shown in Table 3.2 and Table 3.3, respectively.

Table 3.2: Functional Classification and Traffic Levels

Code	Description	Traffic Limits (AADT) Low<Med<High	
1	Local – Residential	100	1,000
2	Collector	1,000	5,000
3	Arterial	2,000	10,000

Table 3.3: Pavement Types and Thickness Levels*

Code	Description	Thickness Level Thin<Med<Thick		Rating System	Performance Curve Set
1	Flexible	10	20	Asphalt	Set 1
2	Composite	10	20	Asphalt	Set 2
3	Rigid - PCC	10	20	Portland	Set 3
4	Brick	10	20	Asphalt	Set 4
5	Gravel	0	0	Unknown/Undefined	Set 6

*It should be noted that only Flexible and Rigid pavements were included in the analysis.

The distributions of the functional classifications, pavement types, and maintenance districts across the City of Amarillo network are provided in Figure 3.1, Figure 3.2, and Figure 3.3, respectively.

Insert

Figure 3.1: Functional Classification Distribution

Map

Insert

Figure 3.2: Pavement Type Distribution Map

Insert

Figure 3.3: Maintenance District Distribution Map

The critical values which define the boundaries of each level for functional classification (traffic level) and pavement type (thickness level) were determined in consultation with City staff. It is believed that the validity of the classification scheme is improved by drawing on the experience of those most familiar with the types of road structures found in a specific region. The validity of these threshold values and actual sectional data stored in the software should be reviewed annually and updated to reflect actual conditions, since these parameters directly determine the predicted performance of the pavement sections.

The combination of the three factors; thickness, traffic and subgrade strength, results in 18 possible classes of pavements and each of these 18 pavement classes is assigned an individual performance curve. In other words, the performance model for a pavement type consists of a family or set of performance curves. A set of curves can be assigned to each pavement type and consists of 18 individual performance curves. The performance curves plot the deterioration of the PQI over time, typically 50 years, and the differences between the curves are based on variations in levels of the pavement thickness, subgrade strength and traffic volume. The majority of the paved road sections (9,241 out of 9,471 flexible sections) in the RoadMatrix are listed as having a medium pavement thickness with a weak subgrade and a medium traffic loading as shown in Table 3.4.

Table 3.4: Specifications for Amarillo's RoadMatrix Performance Curves

Curve Number (Count of Sections[2])	Number of Sections	Thickness	Traffic	Subgrade
5	6	Thin	Medium	Weak
6	2	Thin	High	Weak
8	5	Medium	Medium	Strong
10	1	Medium	Low	Weak
11	9,241	Medium	Medium	Weak
12	194	Medium	High	Weak
17	19	Thick	Medium	Weak
18	3	Thick	High	Weak

The applicable PQI performance curves for flexible pavements (Set 1) are shown in Figure 3.4. The performance curves were set up to reflect the conditions experienced by the City of Amarillo and are comparable to those used for other agencies in Texas, New Mexico and Arizona and surrounding areas.

[2] The section count shown in this table only includes flexible pavement sections

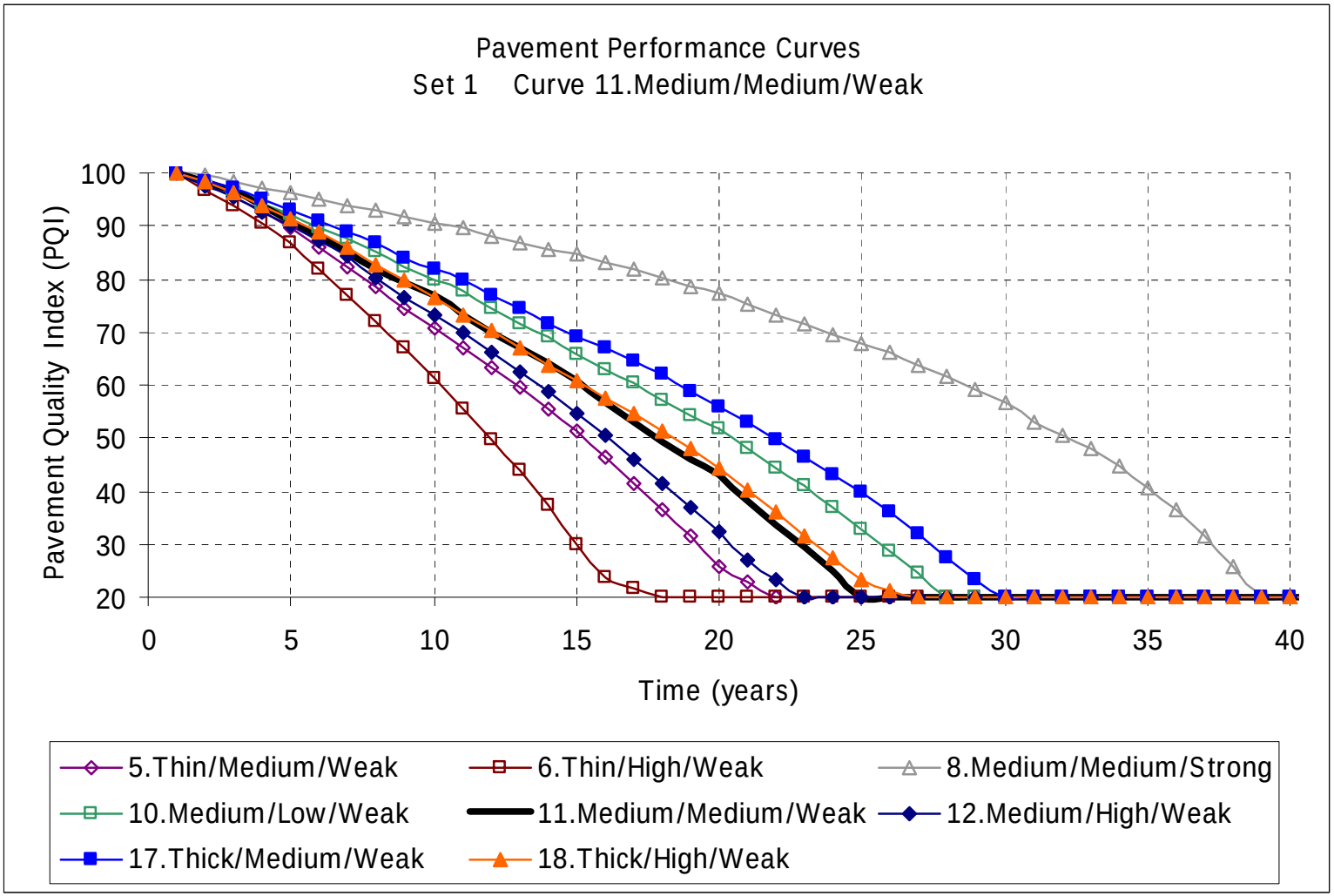

Figure 3.4: Performance Curves[3]

[3] The highlighted curve indicates the deterioration model applied to the majority of road sections with the City's RoadMatrix system.

Based on the performance modeling described above, the year in which the PQI of a section is predicted to fall to or below a minimum acceptable PQI level is defined as the Need Year for that section (i.e. the first year where some form of rehabilitation strategy may be required). The minimum acceptable PQI have been set for each functional classification of road within RoadMatrix as shown in Table 3.5.

Table 3.5: Minimum PQI Thresholds

Functional Class	Minimum PQI
Local-Residential	60
Arterial	65
Collector	65

3.7 PRIORITY PROGRAMMING ANALYSIS

Decision Trees, used to identify technically feasible strategies, and a life-cycle economic analysis, used to assess the relative effectiveness of each strategy, were employed to develop ten-year rehabilitation programs that maximize the benefit of each dollar expended while keeping within the budget constraints specified for each year in the programming period.

The final result of this analysis is a pavement improvement program stating which pavement sections are recommended for rehabilitation, the year in which an intervention should be implemented for each section and the type of rehabilitation strategy which should be implemented for each section, along with the projected costs.

3.7.1 Input Parameters

The priority programming analysis requires the identification of rehabilitation strategies for each section and their associated unit costs. Table 3.6 presents the rehabilitation strategies and associated unit costs and benefit levels to be considered in the analysis.

Appendix E presents the decision trees which identify the appropriate strategies to be considered given various pavement conditions and other criteria. Different decision trees were built using combinations of functional classification (Arterial, Collector, Local-Residential) and pavement type (flexible, rigid-PCC).

Table 3.6: Rehabilitation Alternatives

Code	Description	Benefit Level	Unit Cost (per ft^2)
1	Construction	4	$4.50
2	Reconstruction	4	$4.50
3	Edge Mill and 1" Overlay	3	$0.61
4	Seal Coat	1	$0.30
5	Crack Seal	2	$0.02
6	Edge Mill and 2" Overlay	3	$1.10
7	1" Overlay	3	$0.41
8	2" Overlay	3	$0.80

3.7.2 Analysis

The decision tree analysis determines the appropriate rehabilitation alternatives based on pre-defined criteria (i.e., pavement condition, geometry, traffic volumes, etc.). Using these strategies, their unit costs, and the performance prediction model, a life cycle economic analysis technique was used to determine rehabilitation strategies that could be applied throughout the network in specific years to maximize the benefit of capital expenditures while staying within the budget constraints specified for each year of the programming period.

The rehabilitation alternatives above were analyzed to develop the City's ten-year budget based upon maintaining the network's current level of service as well as a 'Need Driven' budget and a 'Do Nothing' budget.

When assembling the programs, a rehabilitation project for a section can be implemented in its Need Year or any time thereafter, depending on its cost-effectiveness relative to other potential projects and the available budget.

An inflation rate of 3.0% was used within the analysis. No discount rate was applied to the analysis; therefore, all values are in 2008 dollars.

4.0 Analysis Results

4.1 PRESENT STATUS ANALYSIS

The following subsections discuss and summarize the condition of the Entire Paved Network for the City of Amarillo based on the Arterial, Collector and Local-Residential paved roads. Sections with brick, gravel, and unknown/undefined pavement types were excluded from all analysis scenarios. This subset accounts for 2,061 lane-miles of the entire network and contains all paved road sections surveyed in 2008.

4.1.1 Riding Comfort Index (RCI) Analysis

A chart showing the distribution of RCI values, weighted by lane-miles, is shown in Figure 4.1. The plot indicates a mean RCI of 59.6 for the City's Entire Paved Network. A map illustrating the geographical distribution of the RCI across the Entire Paved Network is provided in Figure 4.2.

Table 4.1 below shows the distribution of the network between poor, marginal, and acceptable RCI values. The results indicate that approximately one-half of the Entire Paved Network is exhibiting marginal ride characteristics and slightly less than half of the Entire Paved Network is exhibiting acceptable ride quality characteristics.

Table 4.1: Ride Quality Distribution for Analysis Sections

RCI Range	Ride Quality	Sections	Ln-miles	% of Entire Paved Network
RCI < 40	Poor	272	37.6	1.8%
40 ≤ RCI < 60	Marginal	5,368	1,068.0	51.8%
RCI ≥ 60	Acceptable	3,861	955.3	46.4%

RCI distribution charts for each functional classification of road are also provided in Appendix F.

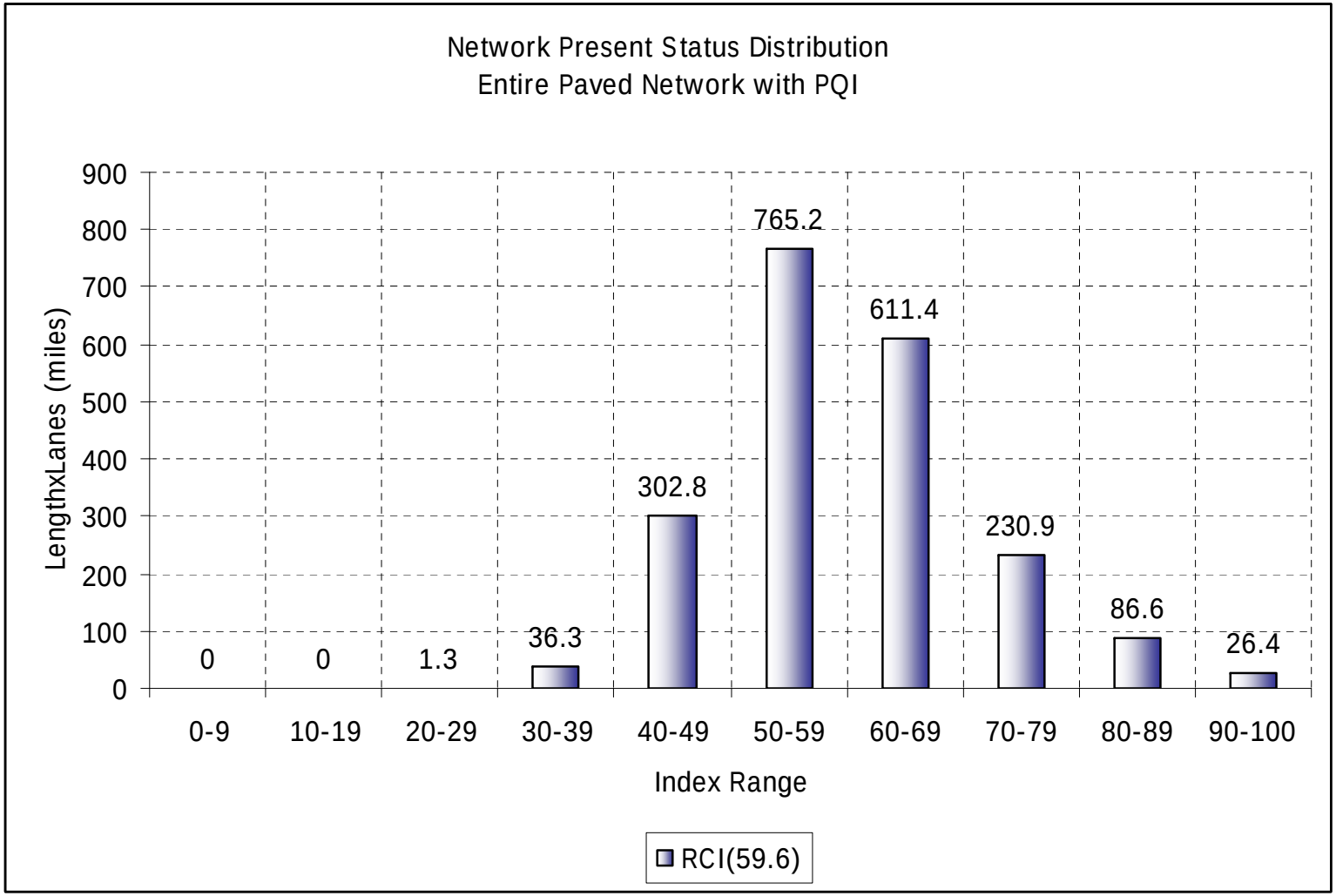

Figure 4.1: RCI Distribution for Entire Paved Network

Insert

Figure 4.2: Riding Comfort Index Distribution Map

4.1.2 Surface Distress Index (SDI) Analysis

A chart showing the distribution of SDI values, weighted by lane-miles, is shown in Figure 4.3. The mean SDI of 78.1 indicates that, overall, the analysis network is in good condition from a surface distress perspective. A map illustrating the geographical distribution of the SDI across the Entire Paved Network is provided in Figure 4.4.

Table 4.2 below shows the distribution of the network between acceptable, marginal distressed, and poor distressed pavements. The results indicate that more than three-quarters for the Entire Paved Network are exhibiting acceptable distress levels.

Table 4.2: Surface Distress Quality Distribution for Analysis Sections

SDI Range	Distress Quality	Sections	Ln-miles	% of Entire Paved Network
SDI < 40	Poor	194	51.6	2.5%
40 ≤ SDI < 70	Marginal	1,632	426.8	20.7%
SDI ≥ 70	Acceptable	7,675	1,582.6	76.8%

SDI distribution charts for each functional classification of road are also provided in Appendix F.

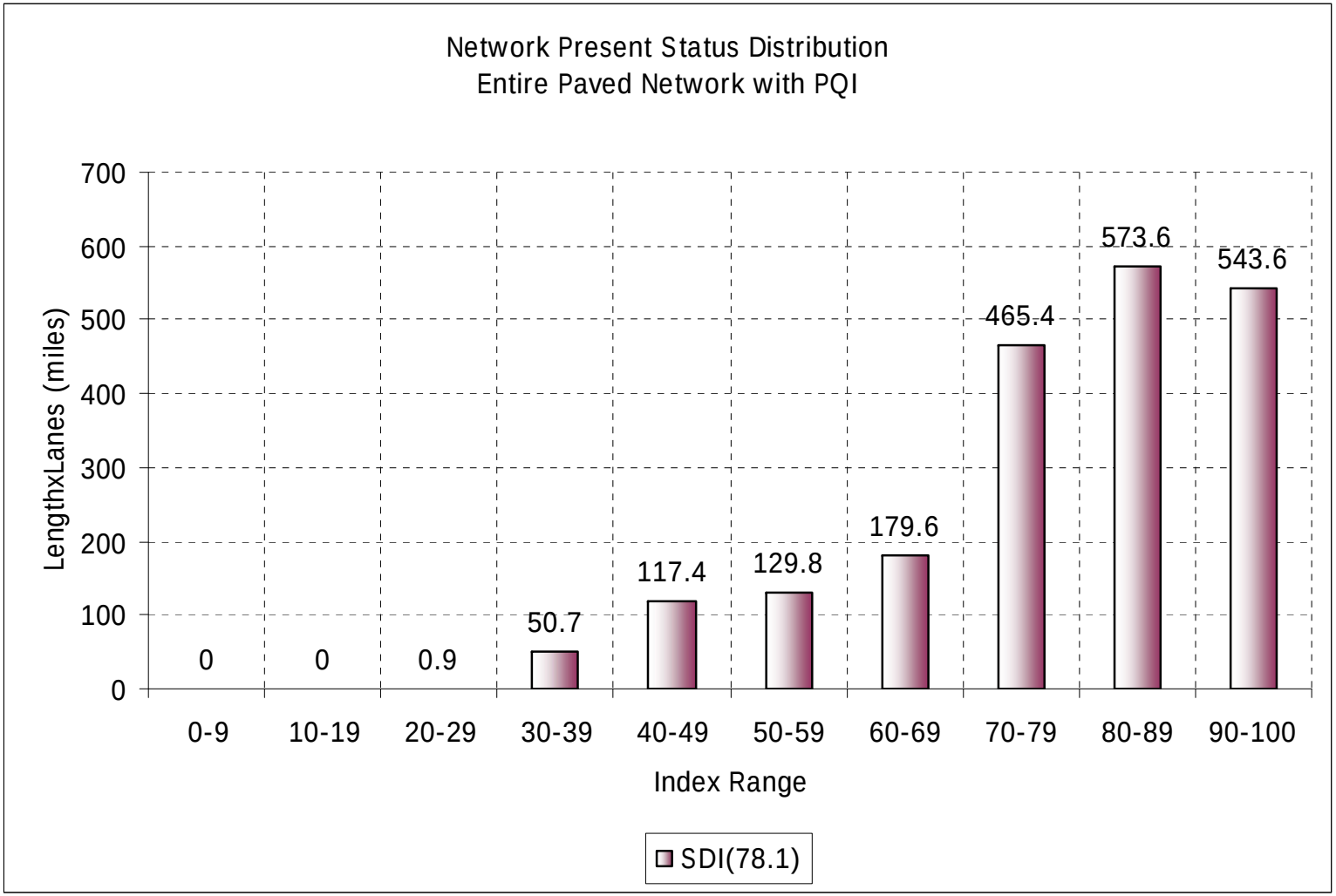

Figure 4.3: SDI Distribution for Entire Paved Network

Insert

Figure 4.4: Surface Distress Index Distribution Map

4.1.3 Structural Adequacy Index (SAI) Analysis

A chart showing the distribution of SAI values, weighted by lane-miles, is shown in Figure 4.5. The chart indicates a mean SAI of 77.1 for the Entire Paved Network surveyed for SAI. It should be noted that less than one-third (28.7% or 590.6 lane-miles) of the sections were surveyed for SAI these are included in this analysis. A map showing the geographical distribution of the SAI across the Entire Paved Network (with SAI data) is provided in Figure 4.6.

Table 4.3 shows the distribution of the network between structurally adequate and structurally inadequate SAI values. The results indicate that the vast majority of the Entire Paved Network that was surveyed for SAI has structurally adequate pavements.

Table 4.3: Structural Adequacy Distribution for Analysis Sections

SAI Range	Distress Quality	Sections	Ln-miles	% of Entire Paved Network Surveyed for SAI*
SAI < 50	Structurally Inadequate	50	31.0	5.2%*
SAI ≥ 50	Structurally Adequate	1,551	559.6	94.8%*

* 590.6 lane-miles were surveyed for SAI and are included in the analysis. The remaining 1,470 lane-miles were not surveyed for SAI and are therefore not included in the analysis.

SAI distribution charts for the Arterial and Collector functional classes of road are also provided in Appendix F. Local-Residential roads were not surveyed for SAI data.

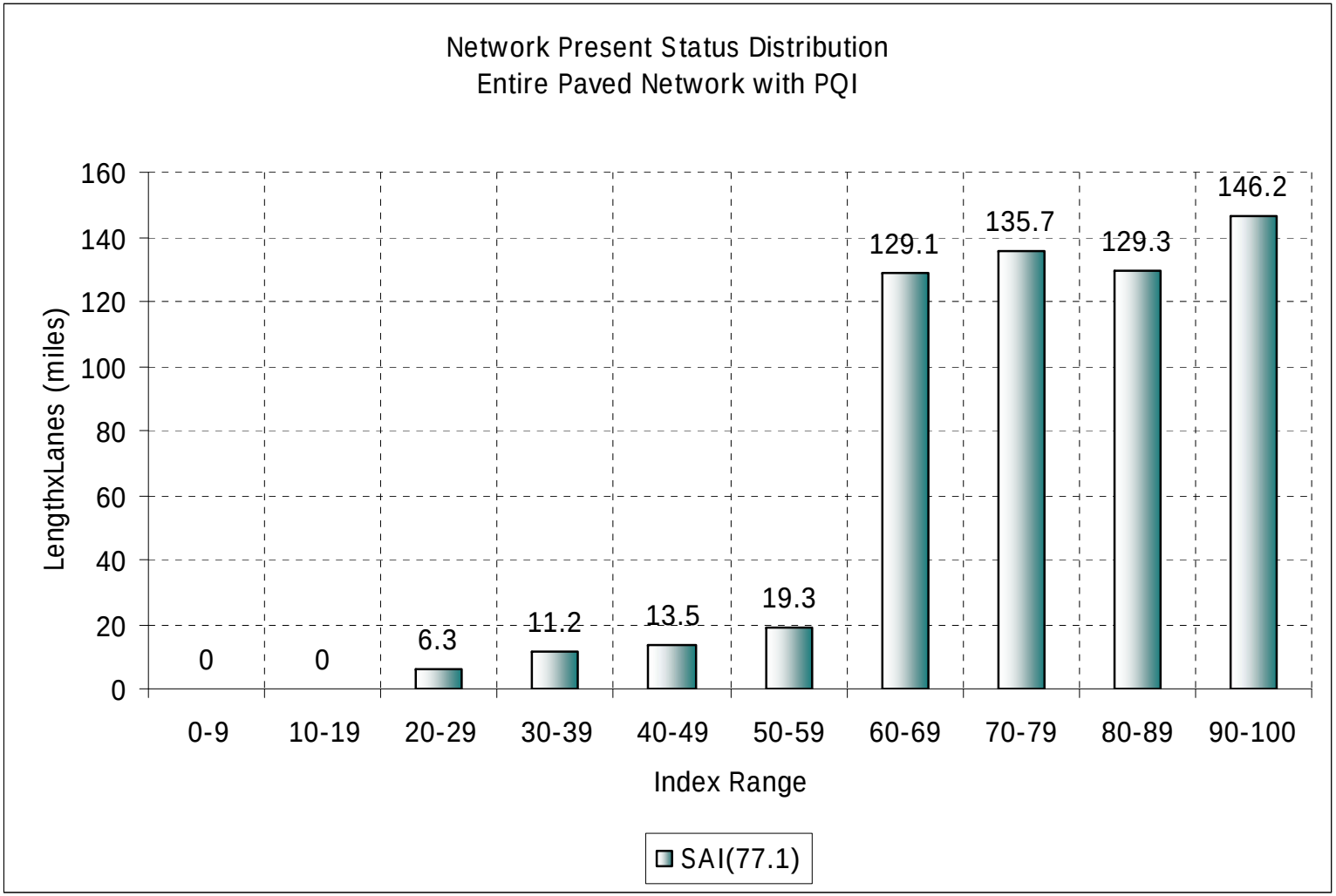

Figure 4.5: SAI Distribution for Entire Paved Network

Insert

Figure 4.6: Structurally Adequacy Index Distribution Map

4.1.4 Pavement Quality Index (PQI) Analysis

A chart showing the present status PQI distribution for the Entire Paved Network for the City of Amarillo is shown in Figure 4.7. Overall, there is a calculated mean PQI of 78.5 indicating the majority of the network is providing an acceptable level of service. The geographical distribution of the PQI performance across the Entire Paved Network is provided in Figure 4.8.

Each functional classification has been assigned a minimum acceptable PQI trigger value which is used to determine when a particular road section, in a given functional classification group, may require some form of rehabilitation. Table 4.4 shows the average PQI for each road functional classification and the total lane-miles that was at or below the minimum acceptable PQI.

Table 4.4: Summary of PQI Deficient Sections (by Functional Class)

Functional Class	Avg PQI	Min PQI	Sections		Length (Ln-miles)		% Deficient
			Total	Deficient	Total	Deficient	
Arterial Paved Network	72.6	65	1,152	429	492.7	155.8	**31.6%**
Collector Paved Network	65.8	65	474	244	104.6	46.2	**44.2%**
Local – Residential Paved Network	81.4	60	7,875	585	1,463.5	115.7	**7.9%**
Entire Paved Network	**78.5**		**9,501**	**1,258**	**2060.8**	**317.7**	**15.4%**

PQI charts for each functional classification of road are also provided in Appendix F.

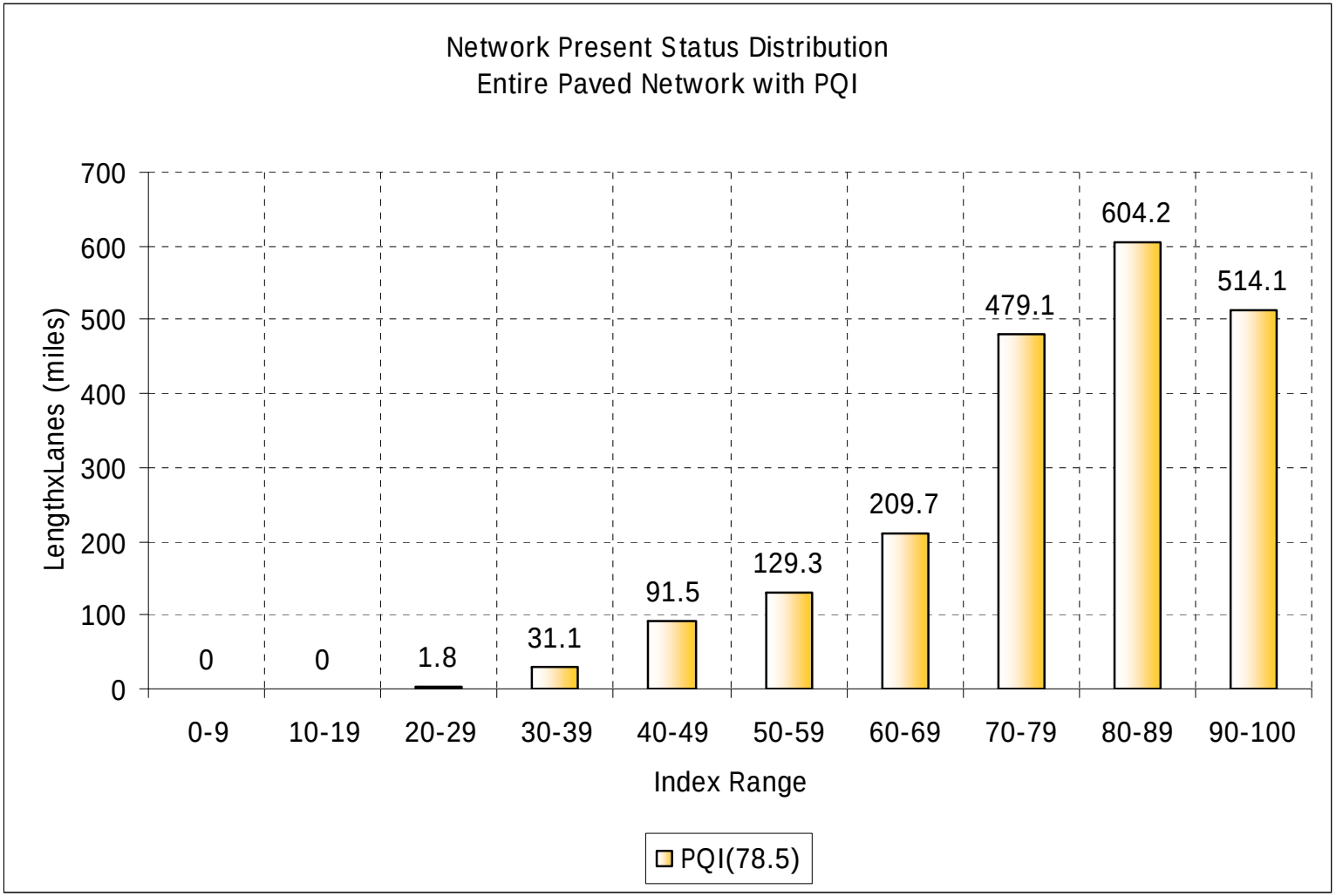

Figure 4.7: PQI Distribution for Entire Paved Network

Insert

Figure 4.8: Pavement Quality Index Distribution Map

4.2 IMPROVEMENT NEEDS ANALYSIS

The Need Year of a pavement is defined as the year in which the PQI of the pavement falls to or below a critical value known as the minimum acceptable PQI. The minimum acceptable PQI value was defined for flexible pavements for the City of Amarillo with PQI_{min} = 60 for Local-Residential roads and PQI_{min} = 65 for Arterials and Collectors. Several sectional variables were also considered in conjunction with the appropriate performance curve to determine the Need Year for all pavement sections in the network.

The Need Year distribution for the City of Amarillo Entire Paved Network is presented in Figure 4.9. The distribution shows that approximately 344.7 lane-miles, or 16.7 percent of the Entire Paved Network, will fall below the minimum acceptable PQI in 2008. Beyond 2008, between 2.5 percent and 10.4 percent (average 6.4%/annum) of the Entire Paved Network is expected to fall below the minimum acceptable PQI in each year throughout the remainder of the ten-year analysis period from 2009 to 2017. In total, approximately 1,536.1 lane-miles, or 74.9 percent of the Entire Paved Network, is identified as failing to meet the minimum acceptable PQI during the ten-year analysis period.

The geographical distribution of the Need Year across the Entire Paved Network is also provided in Figure 4.10.

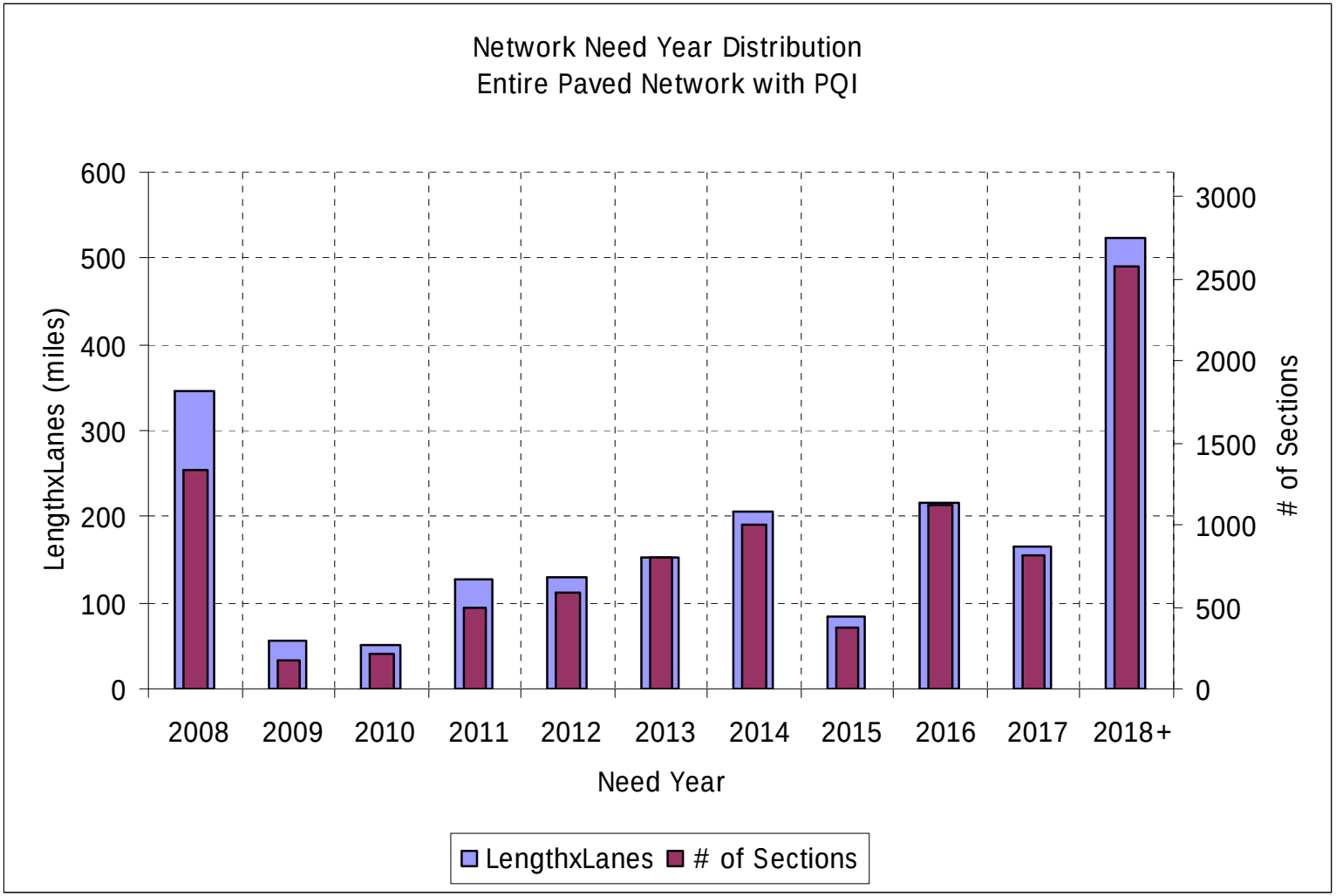

Figure 4.9: Need Year Distribution for Entire Paved Network

Insert

Figure 4.10: Need Year Distribution Map

4.3 PRIORITY PROGRAMMING ANALYSIS

Without the burden of limited funding, pavement sections would be rehabilitated whenever required. In the real world, budgetary constraints often determine the timing and implementation of rehabilitation strategies. To accommodate this real world requirement, an analysis was performed using the following funding scenarios;

- Maintain PQI=78.5 Budget
- Maintain PQI=80 Budget
- Do Nothing Budget
- Need Driven Budget

'Maintain PQI = 78.5'

To maintain the current level of service (PQI=78.5), approximately $87 million in rehabilitation funds would be required over the next ten years (see Table 4.1). The percentage of the Entire Paved Network below the minimum acceptable PQI would decrease from 15.1 percent in 2008 to 6.9 percent by the year 2017.

Table 4.1: City of Amarillo Maintain PQI=78.5 Budget Scenario

Year	Cost	Lane-Len-PQI	Lane-Len-Def	Lane-Len-Def %
2008	$20,489	78.5	310.1	15.1
2009	$11,604,394	78.5	249.7	12.1
2010	$5,957,219	78.5	165.6	8.0
2011	$6,590,881	78.5	113.2	5.5
2012	$12,007,498	78.5	95.9	4.7
2013	$11,660,683	78.5	87.0	4.2
2014	$7,783,062	78.5	90.3	4.4
2015	$15,841,695	78.5	70.9	3.4
2016	$7,708,958	78.5	130.7	6.3
2017	$7,545,187	78.5	141.3	6.9
Total	**$86,720,066**			

'Maintain PQI=80'

To increase the current level of service to PQI=80 would require approximately $105 million in rehabilitation funds over the next ten years (see Table 4.2).

Table 4.2: City of Amarillo Maintain PQI=80 Budget Scenario

Year	Cost	Lane-Len-PQI	Lane-Len-Def	Lane-Len-Def %
2008	$7,522,109	80.0	246.7	12.0
2009	$7,130,013	80.0	177.2	8.6
2010	$9,641,179	80.0	93.1	4.5
2011	$16,890,260	80.0	59.4	2.9
2012	$15,294,231	80.0	31.7	1.5
2013	$10,674,807	80.0	26.3	1.3
2014	$7,707,060	80.0	33.9	1.7
2015	$14,319,314	80.0	16.8	0.8
2016	$7,745,615	80.0	77.3	3.8
2017	$7,713,428	80.0	80.0	3.9
Total	**$104,638,016**			

The resulting 10-year priority program derived from this funding scenario is presented in Appendix G.

'Do Nothing'

Table 4.3 shows that if no rehabilitation is performed, the network average PQI would decrease from 78.5 in 2008 to 49.3 by the year 2017. As a result, the percentage of the Entire Paved Network below the minimum acceptable PQI would increase from 15.2 percent in 2008 to 74.2 in 2017.

Table 4.3: City of Amarillo Do Nothing Budget Scenario

Year	Cost	Lane-Len-PQI	Lane-Len-Def	Lane-Len-Def %
2008	$0	78.5	312.8	15.2
2009	$0	75.4	382.9	18.6
2010	$0	72.4	441.2	21.4
2011	$0	69.2	525.0	25.5
2012	$0	65.9	641.2	31.1
2013	$0	62.5	845.3	41.0
2014	$0	59.2	962.3	46.7
2015	$0	55.9	1141.6	55.4
2016	$0	52.6	1354.8	65.7
2017	$0	49.3	1529.1	74.2
Total	**$0**			

'Need Driven'

From a needs perspective, a total of approximately $104 million would be required over the ten-year programming period (2008 – 2017) to implement the software-recommended rehabilitation alternative for each section in its defined need year. Any over provision of this amount will not result in a better network performance unless a section is allowed to be rehabilitated more than once during the ten-year analysis period.

Table 4.4: City of Amarillo Need Driven Budget Scenario

Year	Cost	Lane-Len-PQI	Lane-Len-Def	Lane-Len-Def %
2008	$44,149,764	86.0	0.0	0.0
2009	$3,426,892	84.2	0.0	0.0
2010	$4,024,946	82.2	0.0	0.0
2011	$5,729,451	81.3	0.0	0.0
2012	$6,054,984	80.5	0.0	0.0
2013	$7,821,230	80.2	3.0	0.1
2014	$9,931,235	80.8	9.5	0.5
2015	$4,393,864	79.3	15.5	0.8
2016	$10,283,206	80.1	27.9	1.4
2017	$8,606,300	79.9	35.1	1.7
Total	**$104,421,872**			

A summary of the all budget scenarios is presented in Table 4.8.

Table 4.5: City of Amarillo Budget Scenario Summary

Budget Scenario	Total 10-Year Funding Requirement	Average Network PQI in 2017	Percent Network Deficient 2017
Maintain PQI = 78.5	$86,720,066	78.5	6.9
Maintain PQI = 80	$104,638,016	80.0	3.9
Do Nothing	$0	49.3	74.2
Need Driven	$104,421,872	79.9	1.7

All scenarios compared side-by-side illustrate that, with annual budget increases, the network performance will improve through an increase in the network average PQI and a decrease in total network percentage below the minimum acceptable PQI. However, the network performance would not be further improved if budget allocation went beyond the need driven budget, based on the current PQI trigger values. Results of the Maintain PQI=80, Do Nothing and Need Driven are presented graphically in Figure 4.11.

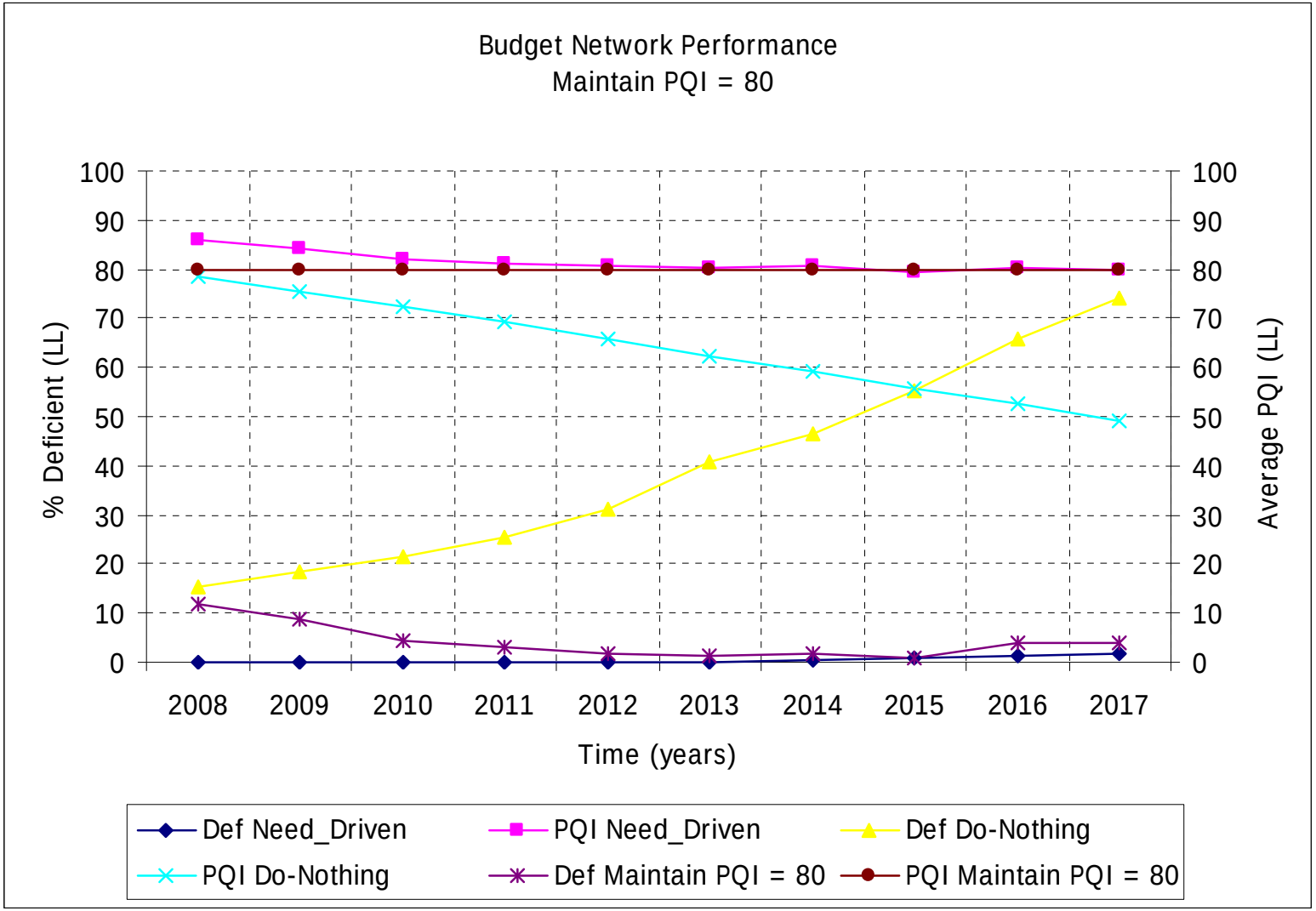

Figure 4.11: Funding Impact on Network

5.0 Conclusions and Recommendations

The results of the Present Status and Needs Analysis contained in this report indicate that the majority of the City of Amarillo Entire Paved Network is providing at least a minimum acceptable performance to the road users as noted by the network average PQI of 78.5. While the majority of the low-volume roads (Local-Residential roads) are providing an acceptable level of service, a significant portion of the high-volume roads (Arterial and Collector roads) are not providing an acceptable level of service.

The implementation of the RoadMatrix pavement management application will provide the City with a tool that will allow them to prioritize the locations where funds available can be best spent to provide the greatest value to the community at large.

Moving forward, it is recommended that the City evaluate the validity of some of this key parametric data used in the various Present Status, Performance Prediction and Needs/Priority Programming analyses in the RoadMatrix software. It should be stressed that the analysis within RoadMatrix will provide a good network level analysis that will provide an overall indication of the scale of the problem at hand and will provide recommendations of specific locations where the investment in rehabilitation would be beneficial.

Where possible, currently assumed override values for the following data attributes should be replaced with actual data, as the results output by the system analyses will only be as good as the data driving them:

- Rehabilitation strategies and their associated unit rates should be updated regularly and, at a minimum, prior to annual economic and priority programming re-analysis to ensure that present industry costs are accurately accounted for.
- Although the decision trees used for rehabilitation strategy selection were recently created, it is recommended that they be reviewed periodically, to ensure that the recommendations they are providing closely reflect the practices employed in the City's pavement management plan.
- Attributes used in Performance Prediction modeling (traffic volumes, structural layer types and thicknesses and sub-grade strength) should be updated regularly.
- It is recommended that surface distress and roughness data be collected at least every three years. Alternatively, one-third of the network could be surveyed every year.

Appendix A

Determination of Riding Comfort Index (RCI)

Appendix A: Determination of Riding Comfort Index (RCI)

Pavement roughness may be classified into three types:

- The most commonly used roughness measurement relates to the longitudinal profile of the pavement, generally along the wheel path, and involves a range of wave amplitudes and frequencies related to the smoothness of ride.
- The second type is transverse profile roughness and is generally perpendicular to the direction of travel with hydro-planning (rut depths) and vehicle maneuver considerations being important. Information with respect to transverse profile is very useful at the detailed, project level of rehabilitation analysis but not for the network level pavement management.
- A third type of roughness is micro-roughness, as determined by the surface texture of the pavement: this type is related to skid resistance.

At the network level of pavement management, the longitudinal roughness is of prime importance and thus, in this project, is the only type of roughness that is considered.

In order to represent a pavement's performance from a user perspective, a Riding Comfort Index (RCI) is determined. Acceptable performance can be gauged from a lack of persistent complaints by the traveling public and/or maintenance personnel. This complaint level is representative of a pavement's ability to carry traffic under normal operating conditions while meeting the expectations of the users.

Riding comfort can be determined by asking drivers of automobiles for their considered opinions. A systematic approach is to form a panel of raters made up of a group of local people who represent the average user of the road system and then have them rate the riding quality of a given pavement. This rating is based on the "feel" of the road that they experience and describes the riding comfort as "good", "fair", "poor", etc. It would not be very practical to have the entire network evaluated in this manner for obvious reasons, therefore, a simpler, more convenient method is employed.

The longitudinal roughness of a road section is collected using a specially equipped van (RT2500/3000) with a piezo-electric accelerometer and ultrasonic sensor mounted rigidly to the front bumper. An on-board micro-processor transforms the acceleration and sensor readings to an International Roughness Index (IRI). In this way, all roadway distortions affecting ride are measured by vertical actions imposed on the vehicle. It is generally accepted that the movement felt by a passenger would be a consequence of the movement of the vehicle, therefore, this provides for a reliable comparison between subjective ride ratings and objective mechanical measurements as collected by a test unit.

Once the network has been surveyed for roughness, sections may be rated by a panel of stakeholders such that the entire range of roughness numbers is covered. The panel's rating of "very good" to "very poor" are then converted onto a scale of zero (0) to 100, where zero

represents a totally unacceptable ride comfort and 100 represents the best possible ride comfort. The next step involves a correlation of these converted ratings to the RT3000's roughness numbers.

The resulting regression equation obtained from the correlation analysis represents the total spectrum of riding comfort versus unit measured roughness. Figure A.1 provides a graphical presentation typical of this relationship. Once this is done, all roughness numbers from the RT3000 unit can be converted to a Riding Comfort Index (RCI). This developed procedure allows for an economical, consistent representation of the acceptability of all sections within an agency's road network.

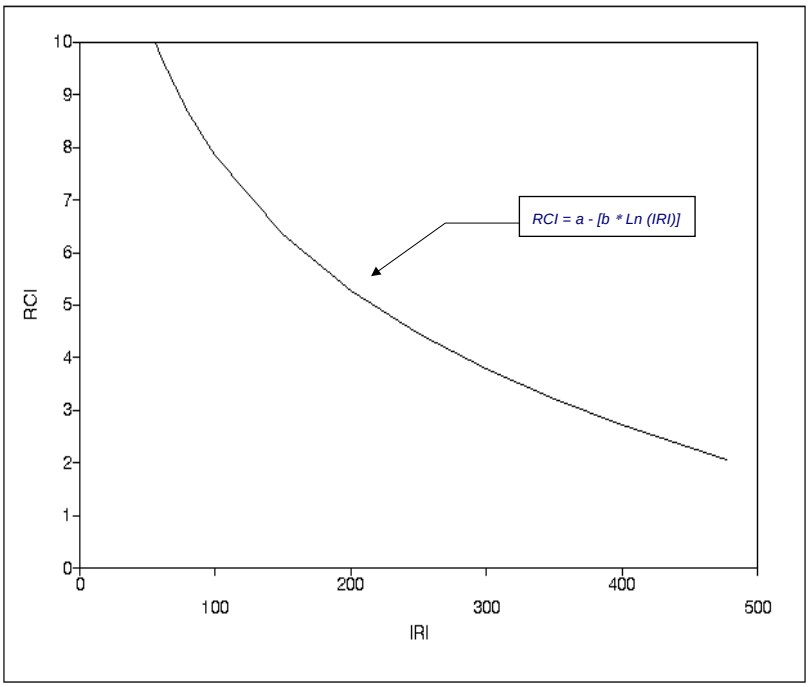

Figure A.1: Sample Relationship between IRI and RCI

When an agency has established a IRI-RCI correlation, it should remain reasonably stable for several years, although of course, much more frequent recalibration of the roughness device may be needed. It should be noted that panel ratings may change with time and / or region. This is primarily due to the range of serviceability levels experienced by the users, and to a lesser degree, to the changes in the overall serviceability spectrum of the specific network in a region and changes in vehicle characteristics.

Appendix B

Determination of Surface Distress Index (SDI)

Appendix B: Determination of Surface Distress Index (SDI)

The procedure described herein was developed as a means of converting the flexible pavement surface distress ratings produced by the operators of the survey unit into index values between zero (0) and 100. This includes the production of indicators for individual distress types at each station, the production of one index value for each station (i.e. combining all types of distress into one value) and the production of one index value for an entire pavement section.

DISTRESS CODES

The pavement distress manifestations evaluated by the raters are recorded in the survey unit in a coded form which ranges from 00 (no distress) to 25 (severe throughout). The first digit is the severity and the second digit is the extent as described in Table B.1.

Table B.1: Severity and Extent Codes

Severity and Extent Codes		
Numeric Code	**Severity Code Definition**	**Extent Code *Definition***
0	None/Slight	None
1	Moderate	Few
2	Severe	Intermittent
3	--	Frequent
4	--	Extensive
5	--	Throughout

For example, if alligator cracking on a flexible pavement is found to be moderate in severity and extensive in occurrence, a value of '14' would be recorded, the '1' indicating moderate severity and the '4' indicating extensive occurrence.

There are 13 types of distresses considered in the formulation of SDI as indicated in Table B.2. A code is assigned to each distress type for every station sampled along the length of a pavement section.

Table B.2: Distress Types

Item #	Distress Types	Abbrev.
1	Patching	Pat
2	Rippling & Shoving	Rip
3	Ravelling & Streaking	Rav
4	Flushing & Bleeding	Flu
5	Deformation & Distortions	Dis
6	Excessive Crown	Exc
7	Progressive Edge Cracking	Edg
8	Alligator Cracking	Alg
9	Potholes	Pot
10	Map Cracking	Map
11	Longitudinal Cracking	Lon
12	Transverse Cracking	Trn
13	Wheel Track Rutting	Rut

DISTRESS SCORES

The distress code for each distress type is converted to a score out of 10 with 10 being perfect and zero (0) being completely unacceptable. The distress codes are converted to scores as shown in Table B.3. These are later referred to as unadjusted scores for each distress type.

Table B.3: Distress Scores

Severity Code	Extent Code					
	0	1	2	3	4	5
0	10	9	8	7	6	5
1	10	7	6	5	4	3
2	10	4	3	2	1	0

A matrix is used to assign Distress Index (DI) values for each distress type on the basis of severity and nominal extent codes. Consider an example in which the nominal extent code for moderate severity alligator cracking was determined to be '3'. Repeating the process for the slight and high severity levels, it can be shown that the nominal extent code for slight severity alligator cracking is '1', and that the nominal extent code for high severity alligator cracking is '2'. Therefore, the DI values for low, moderate, and high severity alligator cracking are '9', '5', and '3' respectively. Given this information, a total DI value for alligator cracking can be calculated. The total DI is an average of the individual DI values for each severity level weighted by length. Note that a DI score for the 'no distress' situation is also included in the calculation.

ADJUSTED DISTRESS SCORES

The basic Distress Index (DI) values are adjusted to reflect the relative importance of each individual distress type, resulting in an Adjusted Distress Index (ADI) for each distress type. This is done through the use of the distress influence exponents. The greater the importance of the distress, the higher the value of the influence exponent in relation to the values of influence exponents for other distress types.

From the standard influence exponents for thirteen flexible pavement distress types it can be seen that alligator cracking has the greatest influence on SDI, followed by wheel track rutting, as shown in Table B.4.

Table B.4: Influence Exponents

Item	*Asphalt Rating System*	
#	*Distress Description*	*Exponent*
1	Patching	1.7
2	Rippling & Shoving	1.8
3	Ravelling & Streaking	1.8
4	Flushing & Bleeding	1.8
5	Deformation & Distortions	2.2
6	Excessive Crown	2.2
7	Progressive Edge Cracking	2.8
8	Alligator Cracking	3.3
9	Potholes	1.6
10	Map Cracking	2.4
11	Longitudinal Cracking	2.9
12	Transverse Cracks	2.7
13	Wheel Track Rutting	3.0

Table B.4 lists the appropriate influence exponent required to calculate the adjusted distress index (***Adjusted DI***) for each distress.

DISTRESS CLASSES

The distress data are grouped into classes based on whether the adjusted distress index creates a critical condition for each distress class using the appropriate trigger value. When all distress items have been evaluated for each station (100-feet interval) the class weighting factors are determined based on whether the individual classes are critical.

Table B.5: Distress Classes

Class #	Asphalt Rating System	
	Class Description	# in Class
1	Load Associated Distresses	2
2	Non-Load Associated Distresses	3
3	Surface Deformations	4
4	Surface Defects	4

The SDI for each pavement section is determined after all stations have been processed. This involves evaluating the contribution of each of the 13 individual distress items to the section SDI.

Appendix C

Determination of Structural Adequacy Index (SAI)

Appendix C: Determination of Structural Adequacy Index (SAI)

The structural adequacy of a pavement is determined by comparing the measured deflection of the pavement with a criterion of structural adequacy. This appendix summarizes the method used to determine the Structural Adequacy Index (SAI) of the pavements considered in this study.

MAXIMUM TOLERABLE DEFLECTION

The maximum tolerable deflection (MTD) is the criterion of structural adequacy. To calculate the MTD it is first necessary to calculate a truck factor and a design traffic number (DTN).

The truck factor (TF) is used to convert average daily traffic to equivalent passes of an 80 kN (18 kip) single axle load. It is calculated using the following equation.

The standard axle load is the standard used to express the load demand on pavement structures:

$$TF\ DTV_{Period} = 0.0353 + 0.003 \bullet DTV_{Period\ Period}$$

where

TF_{Period} is range limited (0.75 in. ≤ TF_{Period} ≤ 2.00 in.)

DTV_{Period}	=	Design traffic volume
Period	=	Period of calculation (1 year or the length of the programming period)

The design traffic number (DTN) represents the number of standard axle loads expected to travel in the 'design lane' on the average day for the programming period. This is calculated next (DTN_{Period}):

$$DTN_{Period} = DTV_{Period} \bullet \frac{Commercial}{100} \bullet TF_{Period}$$

where

DTV_{Period}	=	Design traffic volume for the programming period
Commercial	=	Commercial traffic content
TF_{Period}	=	Truck Factor for the programming period
Period	=	Length of the programming period

The Total Equivalent Single Axle Loads (***TESALS***) represents the number of standard axle loads expected to be applied over the first year and the subsequent programming period. The following describes how to calculate the Total Equivalent Single Axle Loads for the period, ($TESALS_{Period}$).

$$TESALS_{Period} = DTV_{Period} \bullet \frac{Commercial}{100} \bullet TF_{Period} \bullet Period \bullet Days$$

where

DTV_{Period}	=	Design traffic volume for the period of calculation
Commercial	=	% Commercial traffic content
TF_{Period}	=	Truck Factor for the period of calculation
Period	=	Period of calculation (1 year or the length of the programming period)
Days	=	Number of days per year represented in the AADT (normally 360 days)

Maximum Tolerable Deflection (MTD) can be determined either as a function of traffic or asphalt thickness. Both of these are illustrated below, starting with the calculation of the Maximum Tolerable Deflection as a function of traffic, *f*(Traffic).

Calculate Maximum Tolerable Deflection = *f*(Traffic).

A relationship between the MTD and Total Equivalent Single Axle Loads (***TESAL***) has been published by the Transportation Association of Canada (formerly the Roads and Transportation Association of Canada). This relationship is expressed by the following graph and equation:

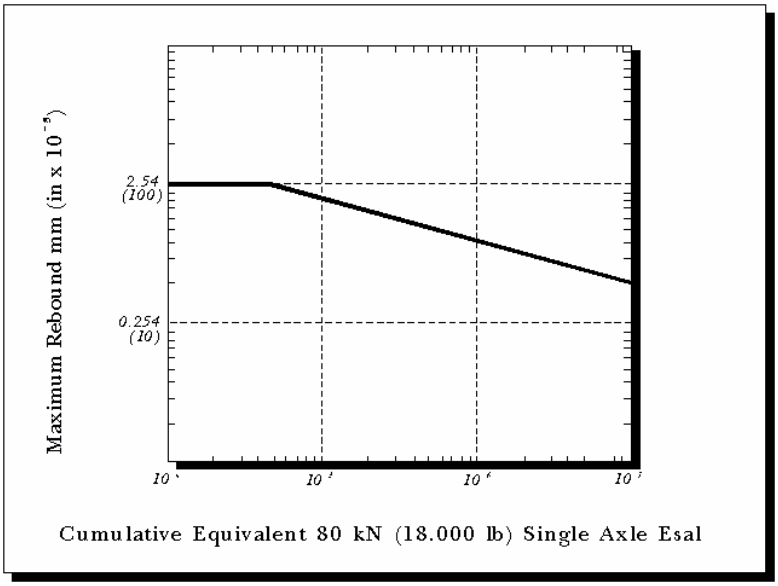

Figure C.1: Maximum Tolerable Deflection versus TESALs

$$MTD_{bb} = \frac{2.56}{TESAL_1^{LOG_{10}2}}$$

where

MTD_{bb} is range limited (0.02 in. ≤ MTD_{bb} ≤ 0.10 in.)

$TESAL_1$ = Total Equivalent Standard Axle Loads in the first year of the programming period

Before updating the section results, the MTD_{bb} is converted to a Dynaflect and correlated FWD value based on the **SAI Model** assigned to the section.

We can also determine MTD where Maximum Tolerable Deflection is a function of Asphalt Thickness.

Maximum Tolerable Deflection = *f*(Asphalt Thickness)

A lookup table is used to determine the ***MTD*** based on the total Asphalt Thickness of the section:

Table C.2: MTD versus Asphalt Thickness

***MTD* = *f*(Asphalt Thickness)**	
Asphalt Thickness (mm)	***MTD* (Dynaflect Units)**
0 – 70	1.10
71 – 90	1.08
91 – 110	1.05
111 – 135	1.01
136 – 165	0.94
166 – 190	0.88
191 – 215	0.85
216 – 245	0.80
246 – 270	0.77
271 – 290	0.74
=> 291	0.72

STRUCTURAL ADEQUACY INDEX

A flexible pavement is considered to be structurally inadequate if the design deflection is greater than the MTD. To evaluate the degree of structural deficiency or adequacy, a Structural Adequacy Index (SAI) is used. The values for SAI range from a “perfect” score of 100 to zero (0). A value of 50 indicates a barely adequate pavement structure (i.e., in most cases, a design deflection equal to the MTD).

SAI is derived from Table C.3 using the following procedure:

1. Calculate the difference between the design deflection and MTD
2. Determine the percentage of deflection measurements (adjusted to a spring value) which exceed the calculated MTD, for a positive difference calculated in 1
3. Determine the traffic range (low, medium, high) using the traffic ranges presented in the main body of the report
4. Read the value of density corresponding to the parameters evaluated in steps 1, 2 and 3 from Table A.1
5. Subtract the density determined in step 4 from adequate score of 5 to give the SAI

For cases where the difference calculated in step 1 is negative, a similar procedure is used. Instead of determining the percentage of deflection readings exceeding the MTD, the percentage of deflection readings below the MTD is determined.

The density value is then determined by reversing the order of the traffic columns so that the “High Traffic” column applies to the ranges of low traffic volumes, the “Low Traffic” column to the high range of traffic volumes, “Medium Traffic” column again to the medium range of traffic volumes. Then, instead of subtracting the corresponding density from 50, the density is added to 50 to give the SAI.

This method of evaluating structural adequacy gives a “bonus” to pavements whose design deflections are less than the MTD requirement for structural adequacy. Thus, the SAI determined in this manner reflects the degree of both structural inadequacy and structural adequacy. To illustrate this method of determining SAI, two examples (one for a negative difference and one for a positive difference) are presented.

Table C.3: Flexible SAI Calculation

Difference	$Adjusted_1 \leq MTD_{Adjusted}$			$Adjusted_1 > MTD_{Adjusted}$		
	Low Traffic	Medium Traffic	High Traffic	Low Traffic	Medium Traffic	High Traffic
≤ -2.70	10.00	10.00	9.50	10.00	10.00	8.80
-2.60	10.00	10.00	9.50	10.00	10.00	8.50
-2.50	10.00	10.00	9.50	10.00	10.00	8.50
-2.40	10.00	10.00	9.30	10.00	10.00	8.30
-2.30	10.00	10.00	9.30	10.00	9.80	8.30
-2.20	10.00	10.00	9.30	10.00	9.80	8.30
-2.10	10.00	10.00	9.00	10.00	9.50	8.00
-2.00	10.00	10.00	9.00	10.00	9.50	8.00
-1.90	10.00	10.00	9.00	10.00	9.00	8.00
-1.80	10.00	10.00	8.80	10.00	9.00	7.80
-1.70	10.00	9.80	8.80	10.00	8.80	7.80
-1.60	10.00	9.80	8.80	9.80	8.80	7.80
-1.50	10.00	9.80	8.50	9.80	8.50	7.50
-1.40	10.00	9.50	8.50	9.80	8.50	7.50
-1.30	10.00	9.50	8.30	9.50	8.30	7.50
-1.20	10.00	9.30	8.30	9.50	8.30	7.30
-1.10	9.80	9.30	8.30	9.50	8.30	7.30
-1.00	9.80	9.00	8.00	9.30	8.00	7.00
-0.90	9.50	8.80	8.00	8.80	8.00	7.00
-0.80	9.30	8.50	7.80	8.50	7.80	6.80
-0.70	9.00	8.30	7.80	8.30	7.80	6.50
-0.60	8.80	8.00	7.50	8.00	7.00	6.30
-0.50	8.30	7.50	7.00	7.50	6.50	6.00
-0.40	8.00	7.00	6.50	7.00	6.00	5.80
-0.30	7.50	6.50	6.30	6.50	5.80	5.50
-0.20	6.50	6.00	5.80	5.80	5.50	5.30
-0.10	5.80	5.50	5.30	5.30	5.30	5.00
0.00	5.00	5.00	5.00	5.00	5.00	5.00

Difference	$Adjusted_1 \leq MTD_{Adjusted}$			$Adjusted_1 > MTD_{Adjusted}$		
	Low Traffic	Medium Traffic	High Traffic	Low Traffic	Medium Traffic	High Traffic
0.00	5.00	5.00	5.00	5.00	5.00	5.00
0.10	5.00	4.70	4.70	4.70	4.50	4.20
0.20	4.70	4.50	4.20	4.20	4.00	3.50
0.30	4.50	4.20	3.50	3.70	3.50	2.50
0.40	4.20	4.00	3.00	3.50	3.00	2.00
0.50	4.00	3.50	2.50	3.00	2.50	1.70
0.60	3.70	3.00	2.00	2.50	2.00	1.20
0.70	3.50	2.20	1.70	2.20	1.70	1.00
0.80	3.20	2.20	1.50	2.20	1.50	0.70
0.90	3.00	2.00	1.20	2.00	1.20	0.50
1.00	3.00	2.00	0.70	2.00	1.00	0.20
1.10	2.70	1.70	0.50	1.70	0.70	0.20
1.20	2.70	1.70	0.50	1.70	0.70	0.00
1.30	2.50	1.70	0.50	1.70	0.70	0.00
1.40	2.50	1.50	0.20	1.50	0.50	0.00
1.50	2.50	1.50	0.20	1.50	0.20	0.00
1.60	2.20	1.20	0.20	1.20	0.20	0.00
1.70	2.20	1.20	0.00	1.20	0.20	0.00
1.80	2.20	1.00	0.00	1.20	0.00	0.00
1.90	2.00	1.00	0.00	1.00	0.00	0.00
2.00	2.00	0.50	0.00	1.00	0.00	0.00
2.10	2.00	0.50	0.00	1.00	0.00	0.00
2.20	1.70	0.20	0.00	0.70	0.00	0.00
2.30	1.70	0.20	0.00	0.70	0.00	0.00
2.40	1.70	0.00	0.00	0.70	0.00	0.00
2.50	1.50	0.00	0.00	0.50	0.00	0.00
2.60	1.50	0.00	0.00	0.50	0.00	0.00
≥ 2.70	1.20	0.00	0.00	0.50	0.00	0.00

Example 1

If a two lane pavement section has a design deflection of 2.57, the MTD has been calculated at 1.87, the AADT is 1000, and 45 percent of the adjusted measured deflections exceed the MTD, then:

Difference = Design Deflection – MTD = 0.70,

30% <= 45% <= 60%; medium frequency of exceeded MTD,

AADT = 1000, low traffic

from Table 1, density = 2.0

SAI = 5.0 – 2.0 = 3.0.

Example 2

For a two lane pavement section with a design deflection of 1.23, an MTD of 1.65, and AADT of 1000, and 65 percent of the adjusted measured deflections below the MTD then:

Difference = MTD – Design Deflection = 0.42 or approximately 0.40

60% <= 65%; high frequency of adjusted measured deflection below MTD

AADT = 1000, low traffic; therefore, use “High Traffic” column in Table 1

from Table 1, density = 3.0

SAI = 5.0 + 3.0 = 8.0

Appendix D

Determination of Pavement Quality Index (PQI)

Appendix D: Determination of Pavement Quality Index (PQI)

PHILOSOPHY

Since pavements exist to serve their users, the PQI should depend primarily on the aspects of the pavement directly affecting the user. Because RCI affects the user in terms of the comfort of ride afforded by the pavement, RCI is the main contributor to Pavement Quality.

The Structural Adequacy Index (SAI) reflects the pavement's ability to support specific amounts and types of traffic loads. An inability to support applied loading usually results in permanent deformation and damage to the pavement in terms of cracking, potholes, faulting, etc. Therefore, even if a pavement has good surface condition (visibly) and is fairly smooth, a low SAI indicates the potential for rapid deterioration under the prevailing or expected loading conditions.

The Surface Distress Index (SDI) is a composite rating of the surface condition of the pavement. It includes various forms of cracking and properties of the surface mix such as bleeding, binder loss, aggregate loss and weathering. The consequence of a low Surface Distress Index again depends on the expected loads and also environmental conditions. Although a badly cracked pavement may presently provide a good ride to its users, the potential for rapid deterioration of the smoothness of ride in the future is high.

MODELS

The developed PQI models can be grouped into two categories:

- Basic relationships, and
- Deterioration potential functions.

These two types of models are used together to estimate PQI depending on the value of SAI. Since an SAI value of 50 indicates that the design deflection of the pavement measured is just equal to the maximum tolerable deflection, pavements with an SAI greater than 50 have less deterioration potential than do pavements having as SAI less than 50.

Figure D.1 shows how PQI varies with RCI, SAI and SDI. Referring to the design for SDI=100, the curve for SAI=50 corresponds to the basic relationship:

$$PQI_{basic} = RCI$$

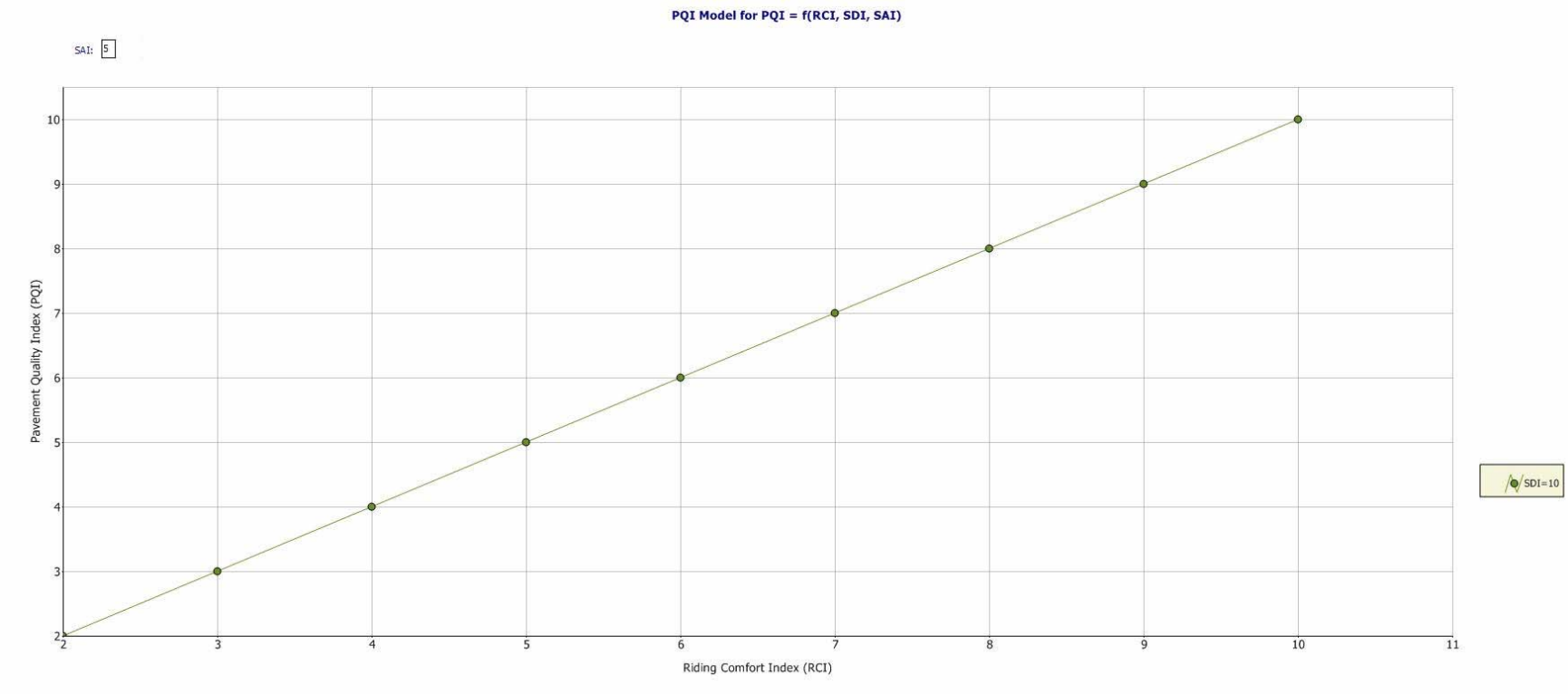

Figure D.1: PQI Model (RCI Driven)

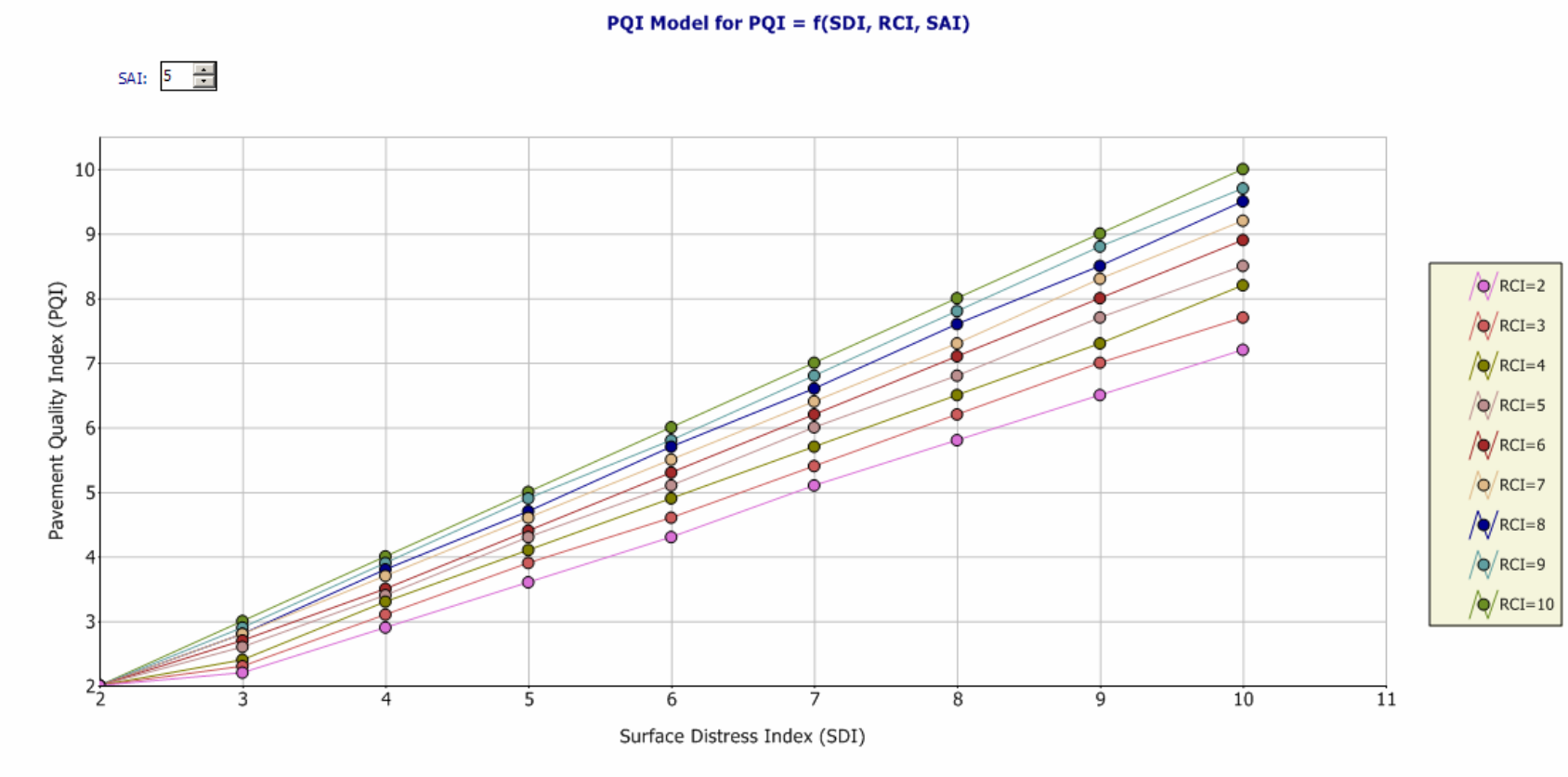

Figure D.2: PQI Model (SDI Driven)

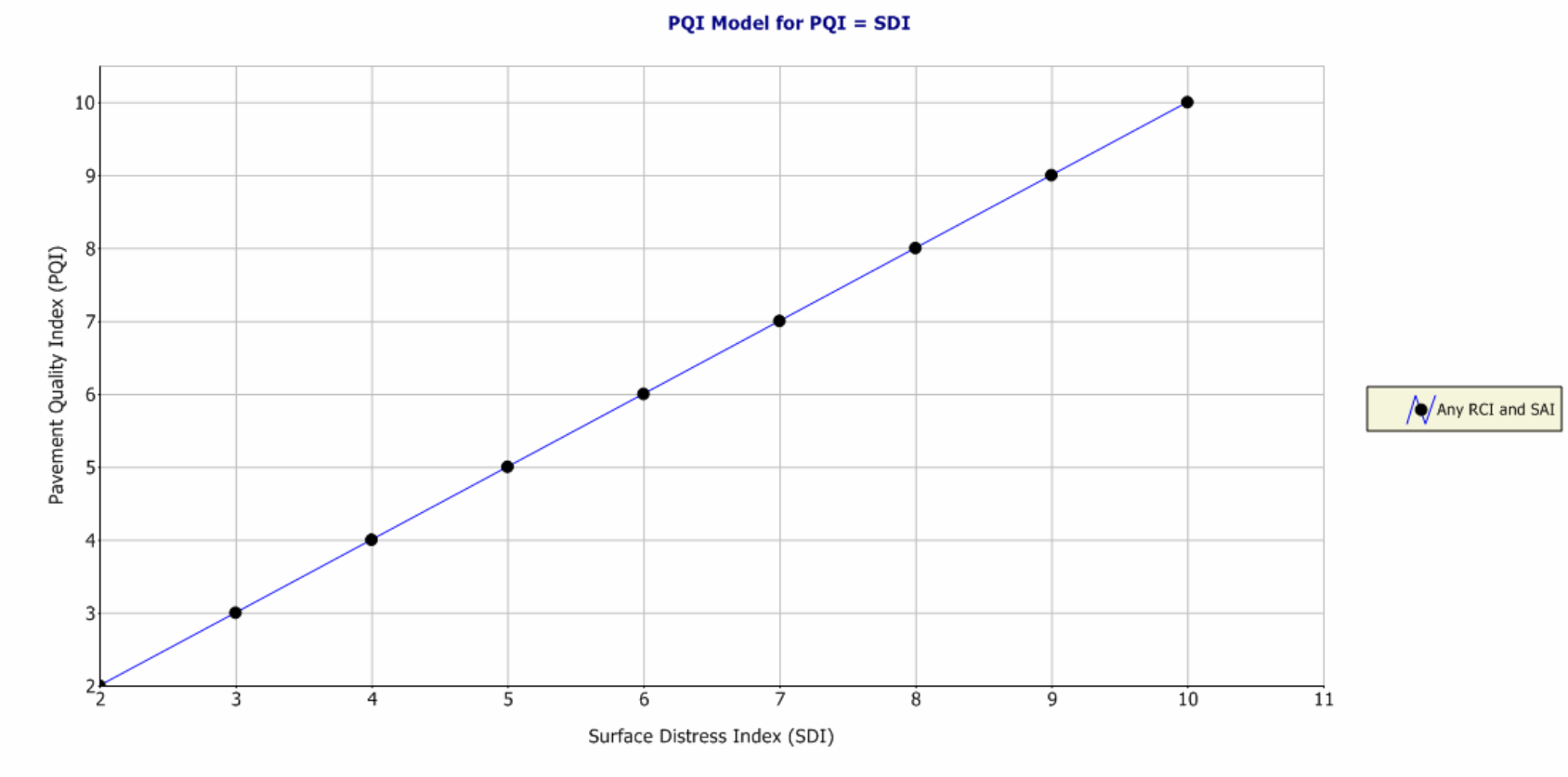

Figure D.3: PQI Model (SDI only)

PQI DATE

Once the PQI has been calculated, it is important to determine the PQI rating date in order to 'age' a pavement for rehabilitation performance prediction. The PQI date is assigned based on the relative contribution of the individual performance indicators contributing to the PQI for the corresponding model, in our case, the PQI Date is equal to the RCI Date.

The PQI is predicted for each pavement section for the first year in the programming period (usually the current year) using the appropriate performance curves.

Appendix E

Decision Trees

Appendix E: Decision Trees

In order to estimate the rehabilitation requirements of a pavement network over a period of time (i.e. the 'programming period'), it is necessary to estimate the performance of the pavements in the network over this period. The length of the programming period is typically defined as ten years. The pavement performance was estimated through engineering models which predict the deterioration of PQI scores over time.

A decision tree approach was used to determine technically feasible rehabilitation strategies for each section requiring rehabilitation during the programming period. The decision trees were designed in order to ensure that the decision process accurately models the decision process employed by the Agency. A decision tree exists for every combination of functional classification and pavement type to accommodate potential differences in decision logic between the various combinations. For example, a certain set of decisions might be specified for Arterial roads with a rigid pavement structure. However, in all likelihood, a different set of decisions would be necessary for local roads with a flexible pavement structure.

Decision tree sets were created for the following functional classifications:

- Arterial
- Collector
- Local – Residential

A rehabilitation decision tree specifies multi-levels of decision making. Each decision node in each level may specify a logical expression defining a decision criterion. At each decision node, the section is evaluated against the decision criterion. If the section meets the criterion, the section proceeds down the tree toward the right. If the section does not meet the criterion, the section proceeds down the tree toward the left. Each section in the network 'navigates' through the decision tree in this fashion and eventually reaches one of the result nodes at the bottom of the tree.

Each results node was assigned technically feasible rehabilitation strategies, based on the established criteria. The strategies specified at the result node are included in the 'pool' of potential rehabilitation strategies for the section. The decision trees defined for the City of Amarillo are illustrated on the following pages.

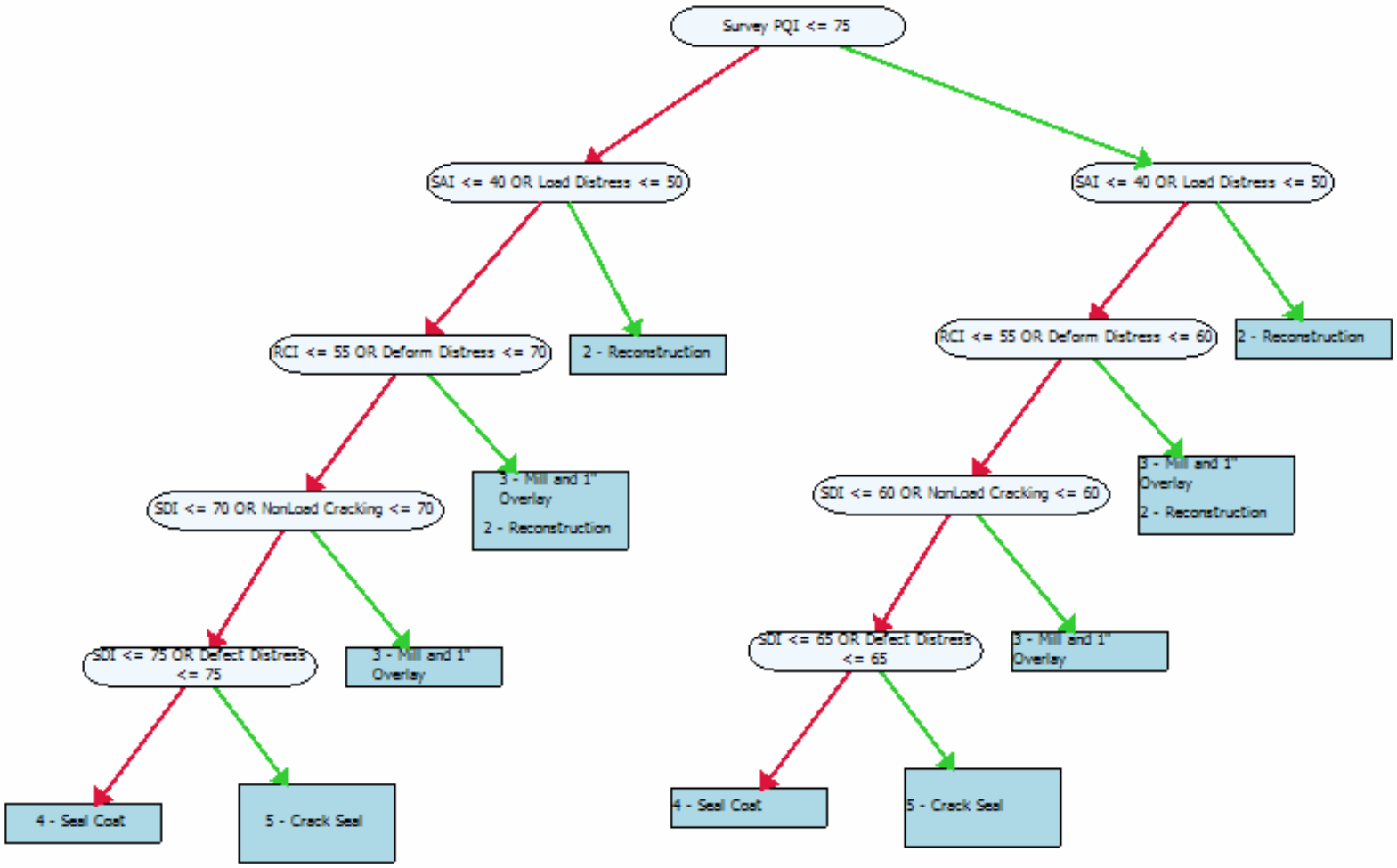

Figure E.1: Arterial Flexible Decision Tree

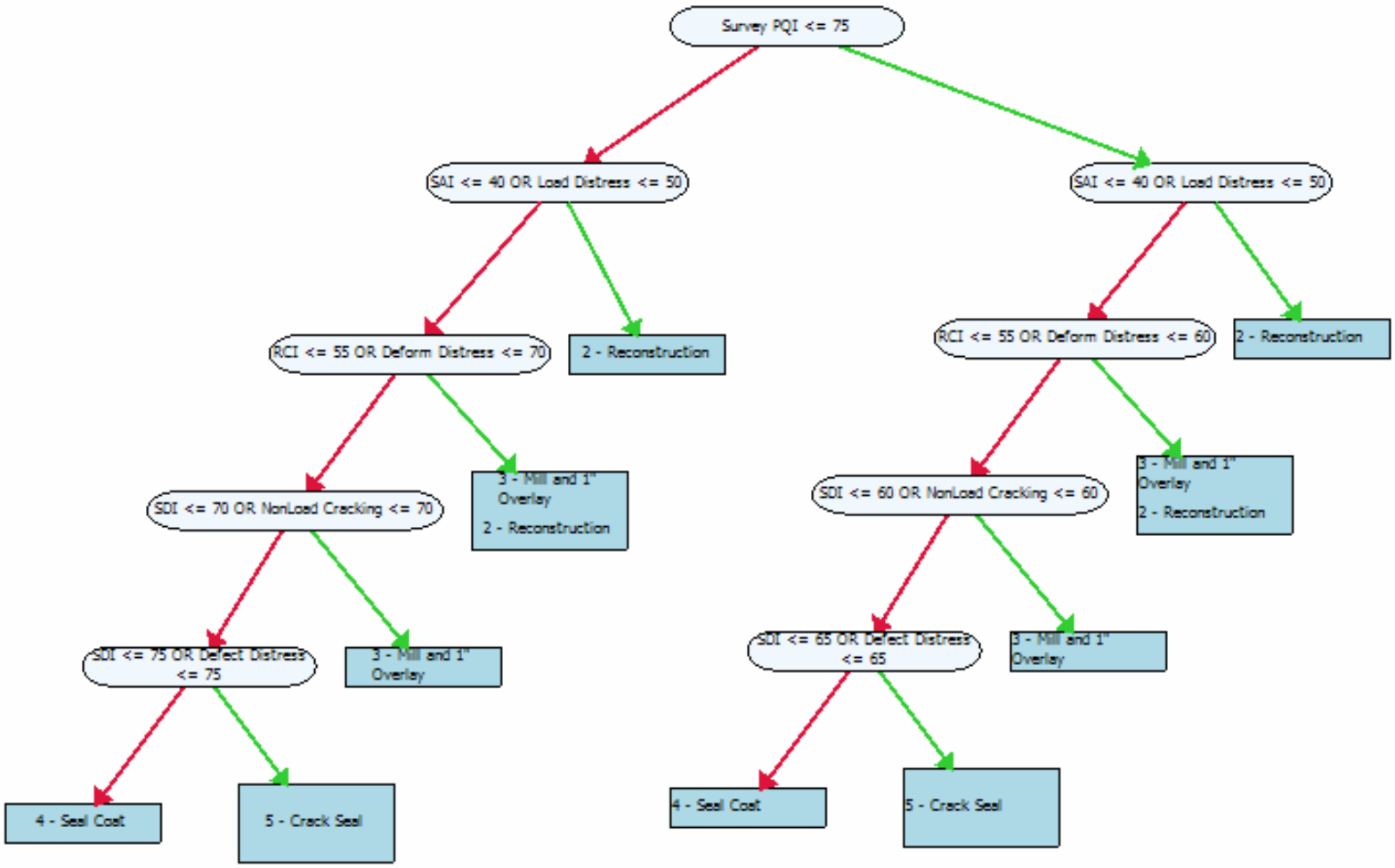

Figure E.2: Collector Flexible Decision Tree

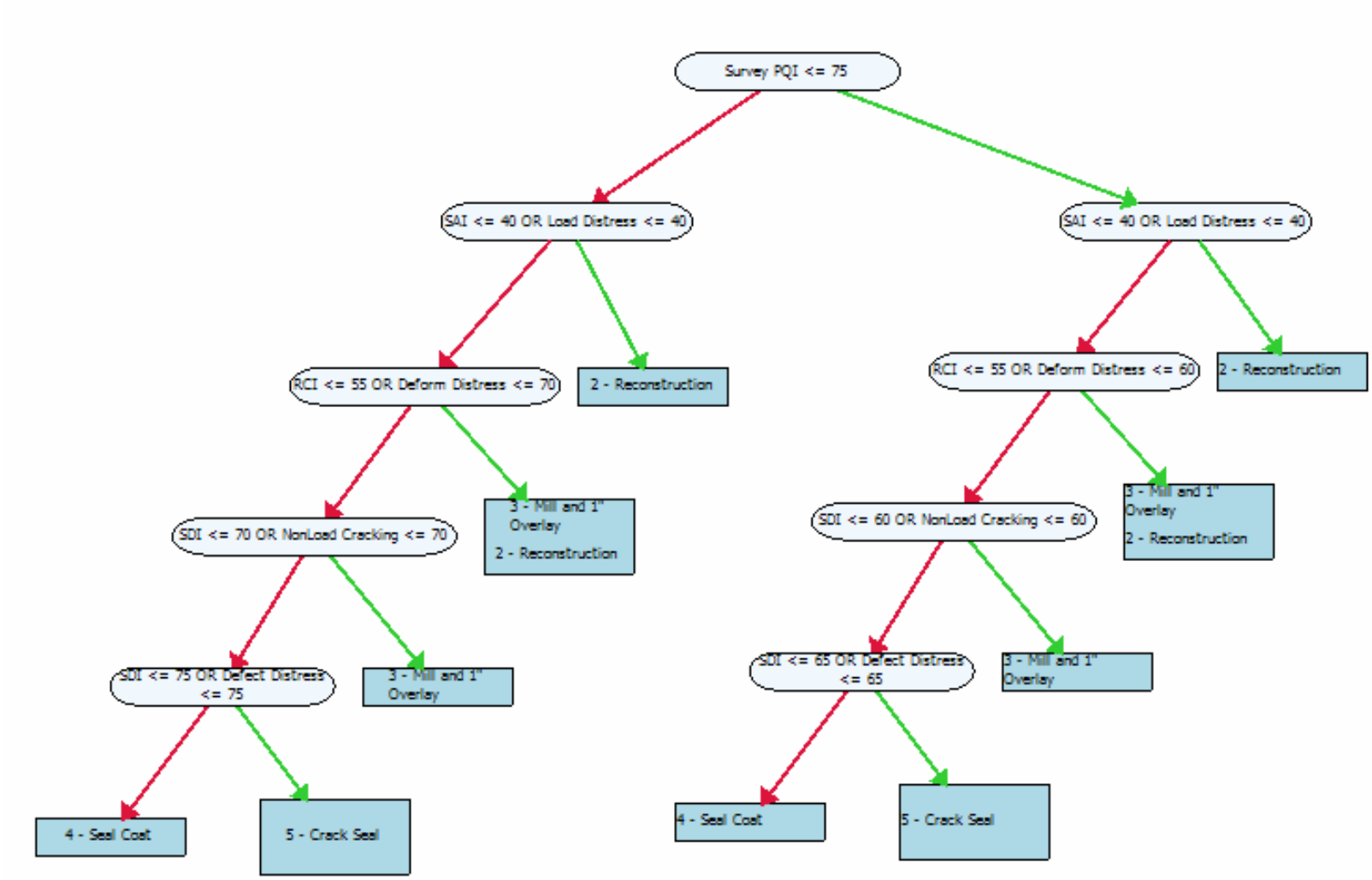

Figure E.3: Local – Residential Flexible Decision Tree

Appendix F

Functional Class Performance Distribution

Appendix F: Functional Class Performance Distribution

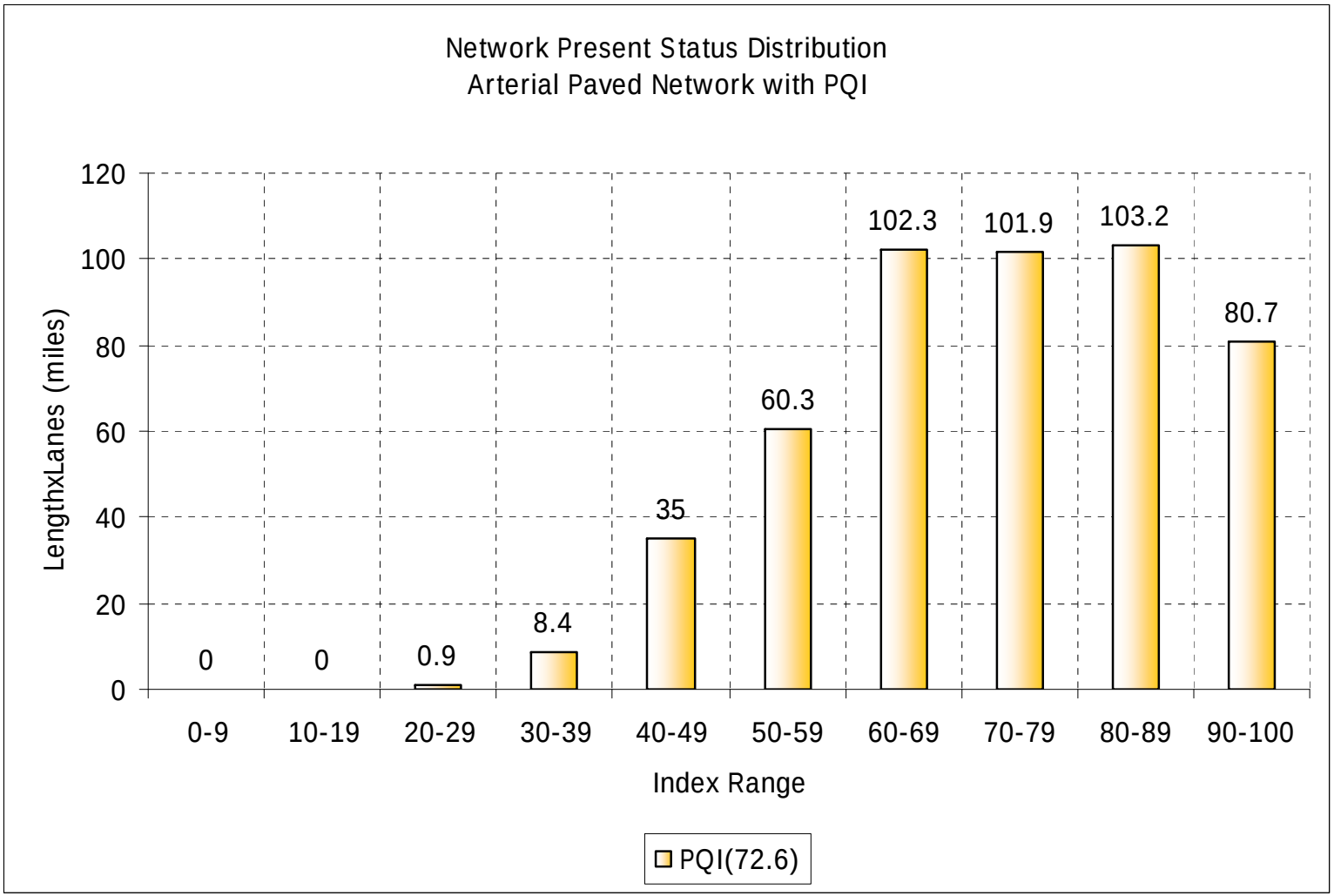

Figure F.1: PQI Distribution for Arterial Paved Network

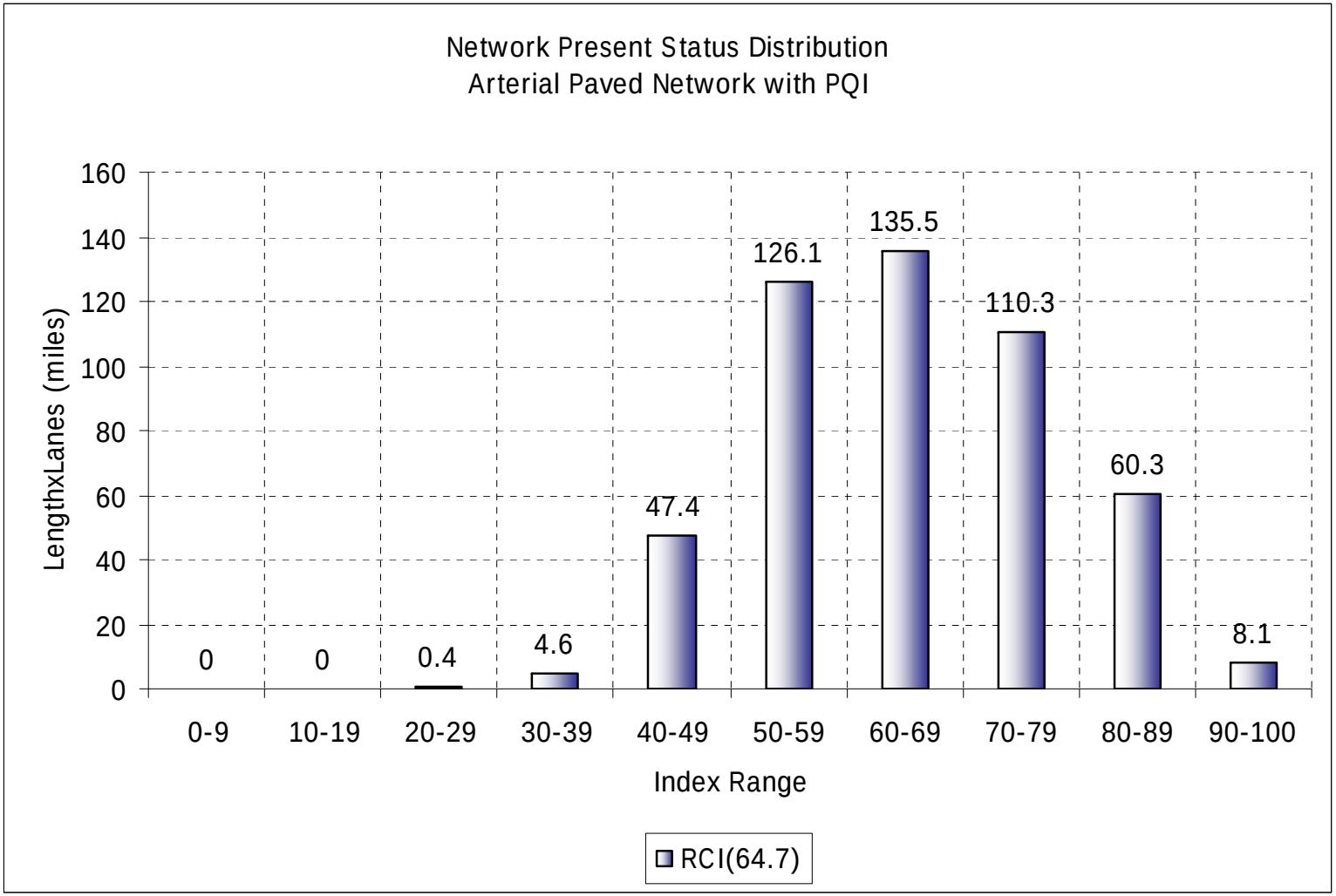

Figure F.2: RCI Distribution for Arterial Paved Network

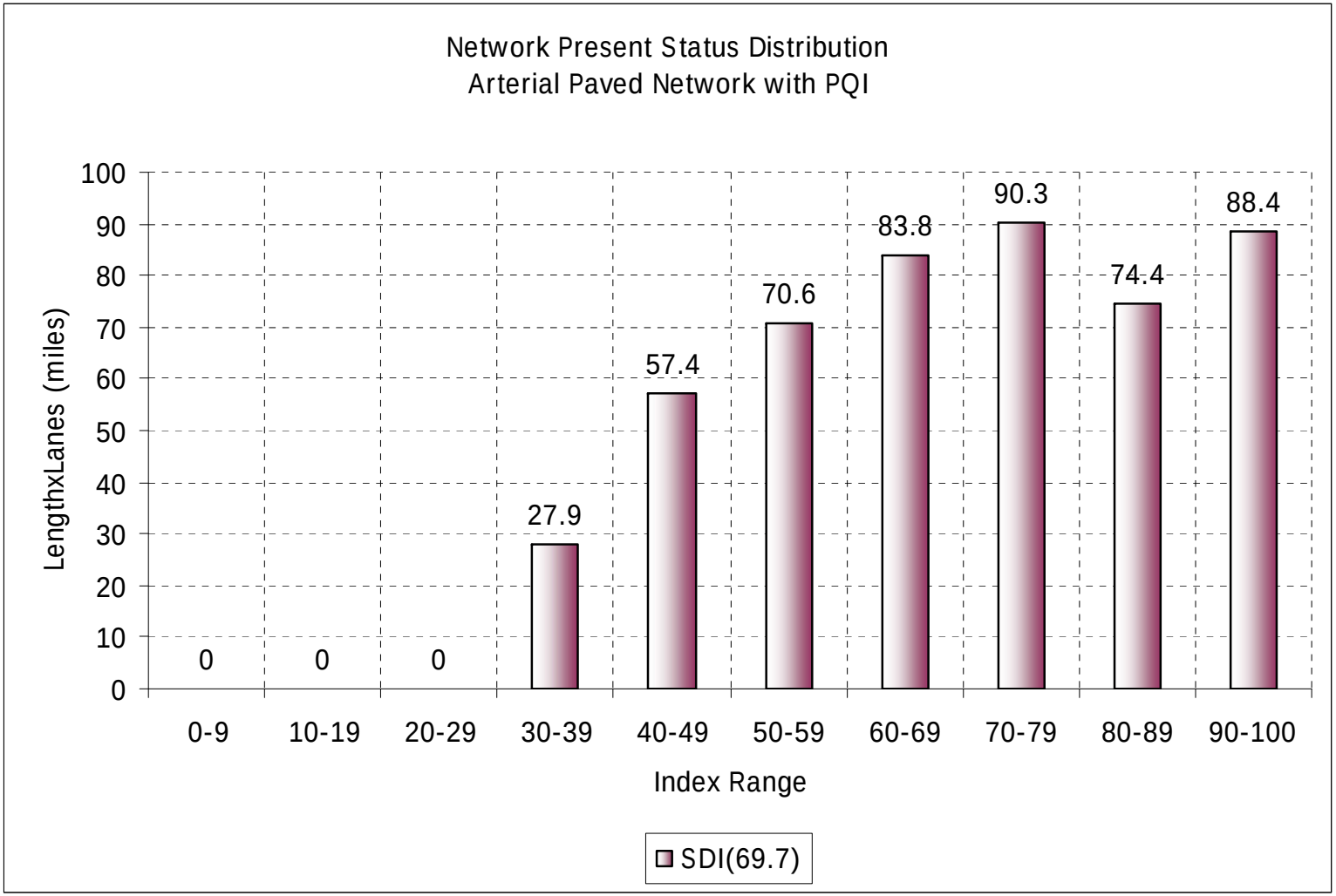

Figure F.3: SDI Distribution for Arterial Paved Network

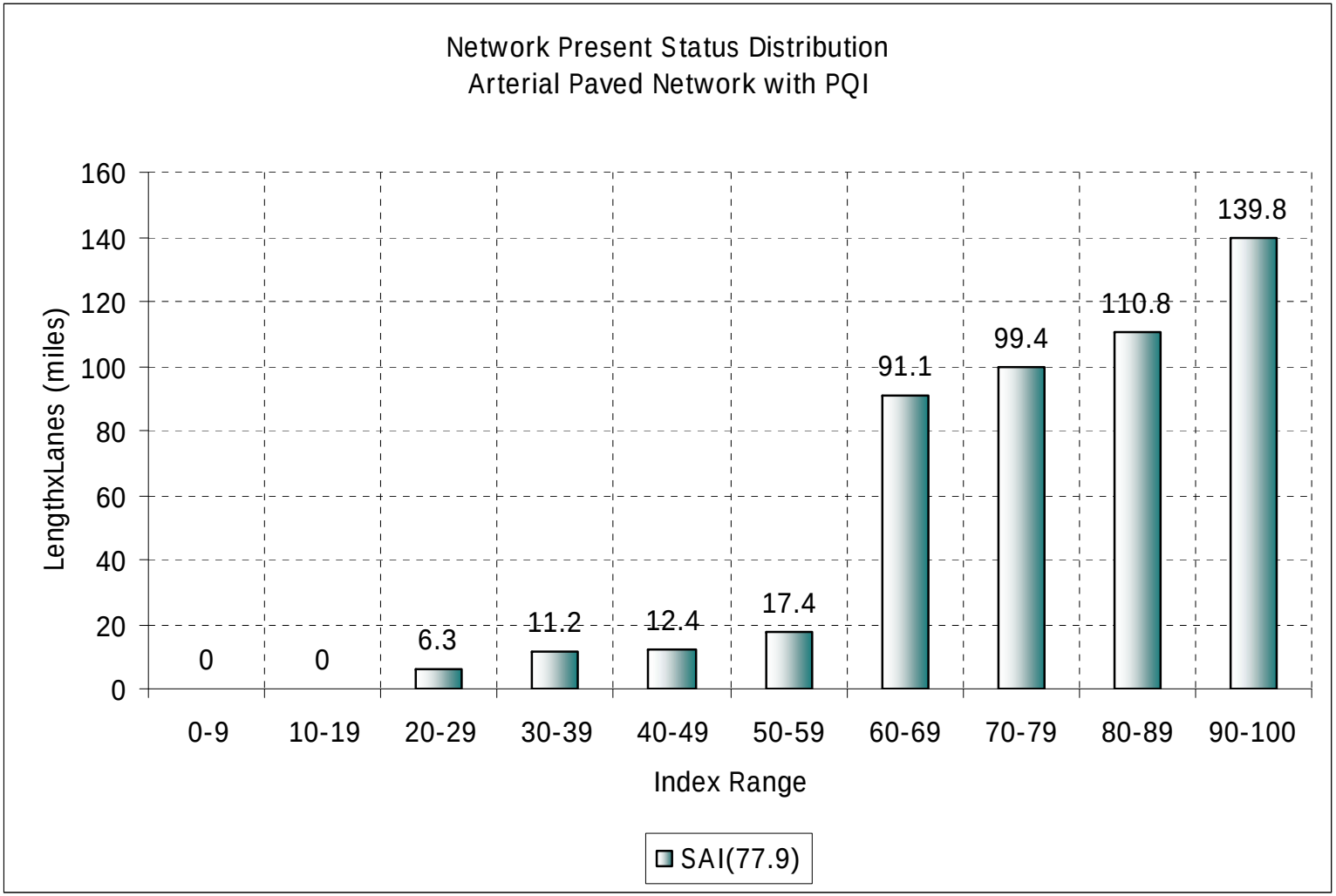

Figure F.5: SAI Distribution for Arterial Paved Network

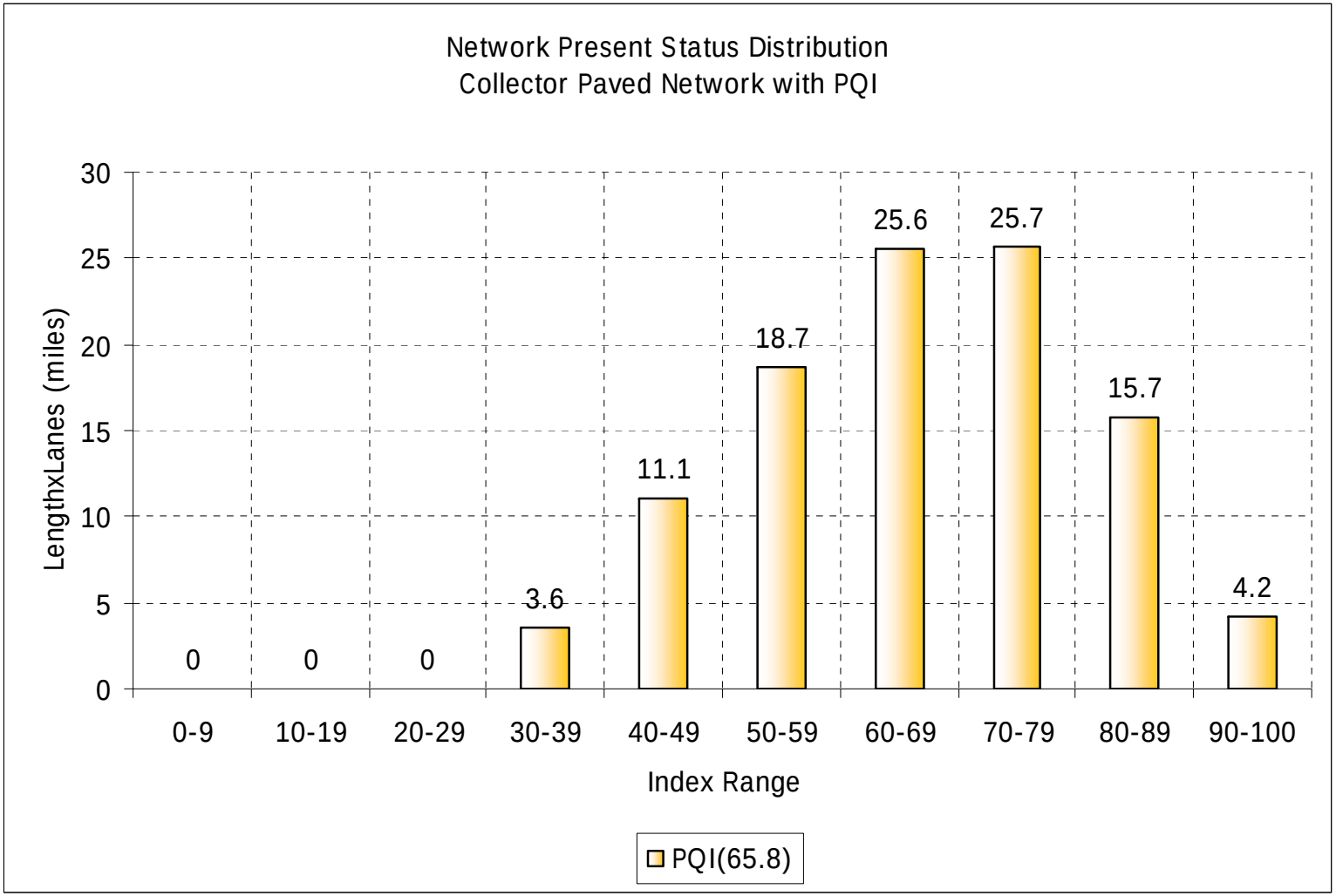

Figure F.5: PQI Distribution for Collector Paved Network

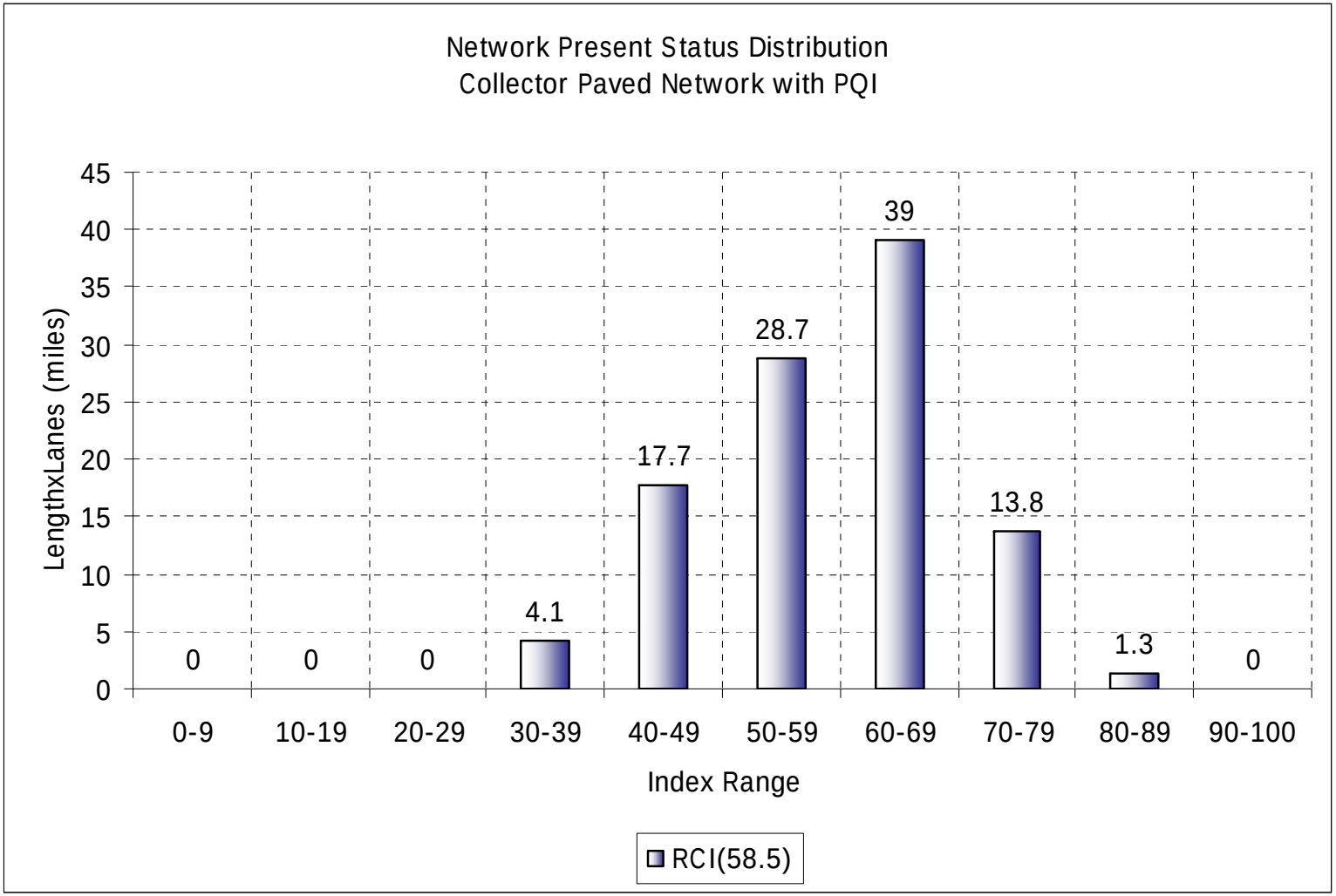

Figure F.6: RCI Distribution for Collector Paved Network

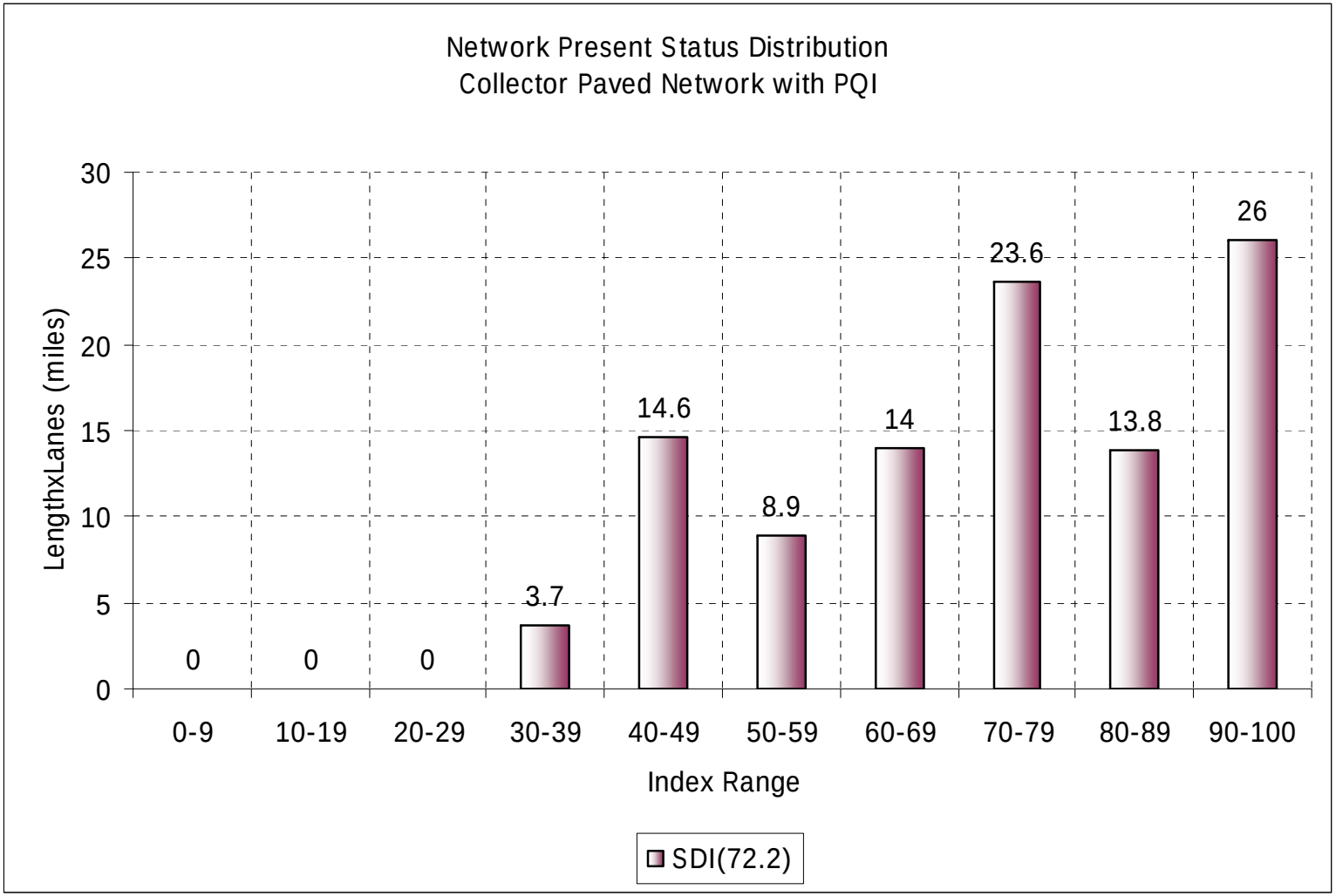

Figure F.7: SDI Distribution for Collector Paved Network

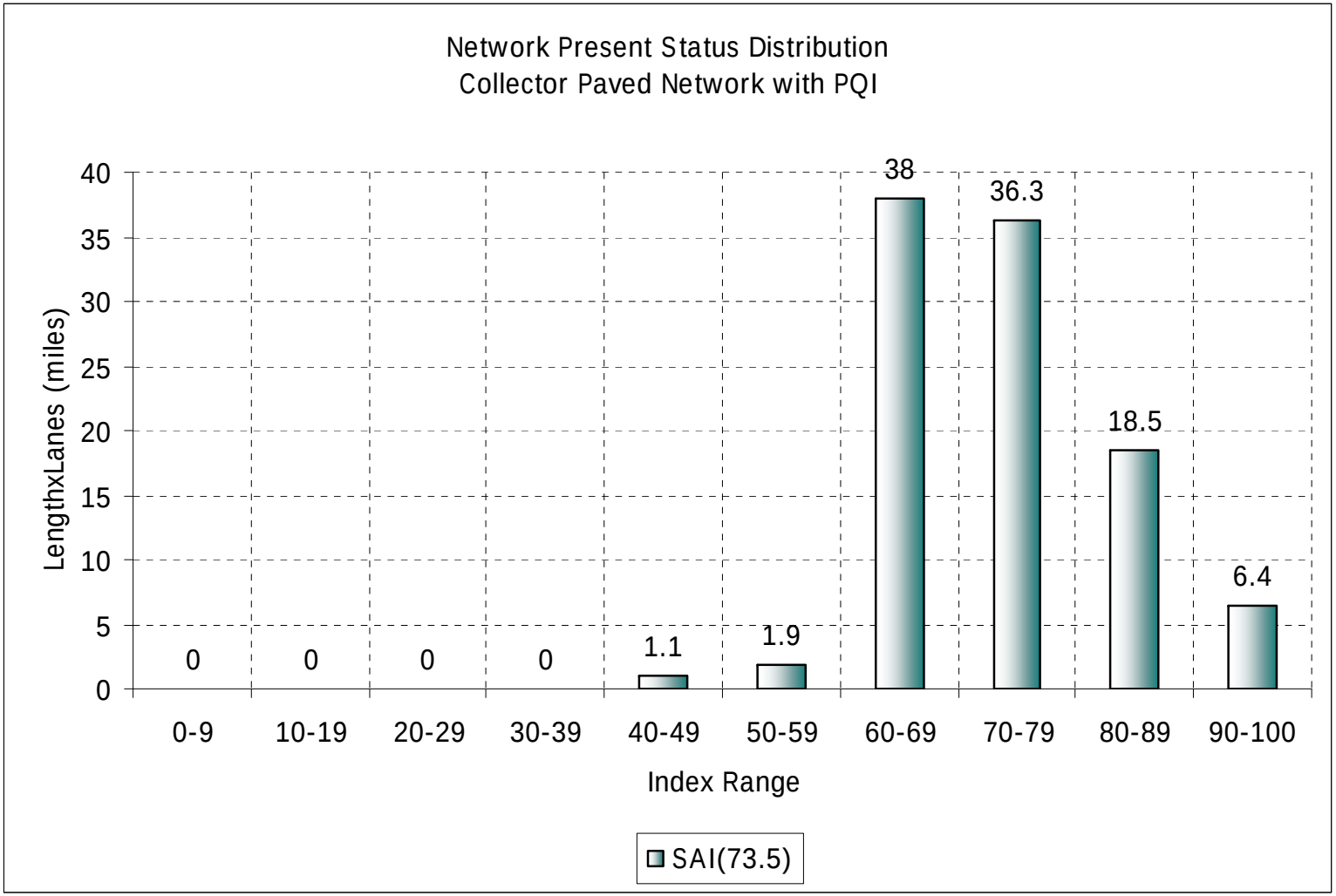

Figure F.7: SAI Distribution for Collector Paved Network

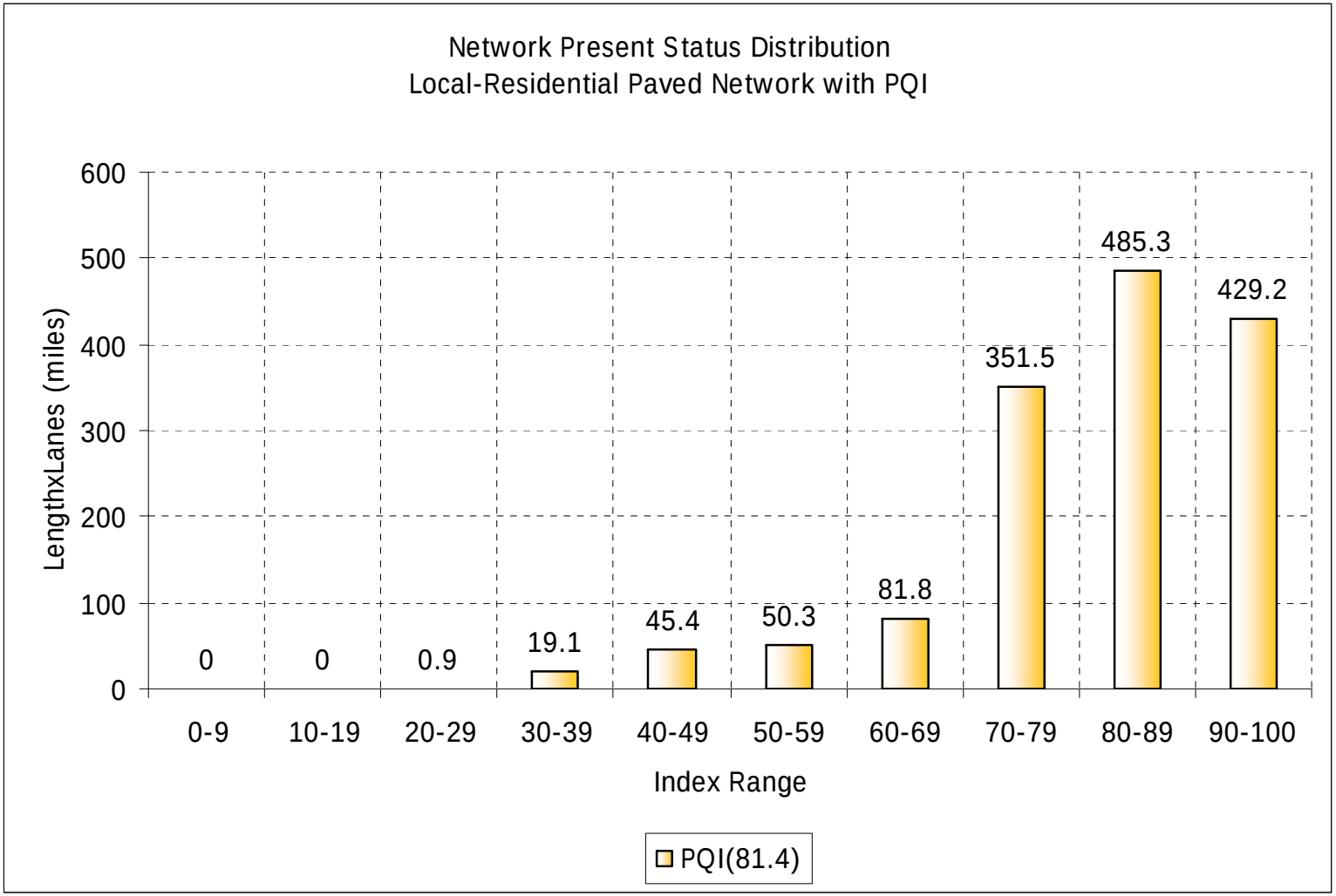

Figure F.9: PQI Distribution for Local-Residential Paved Network

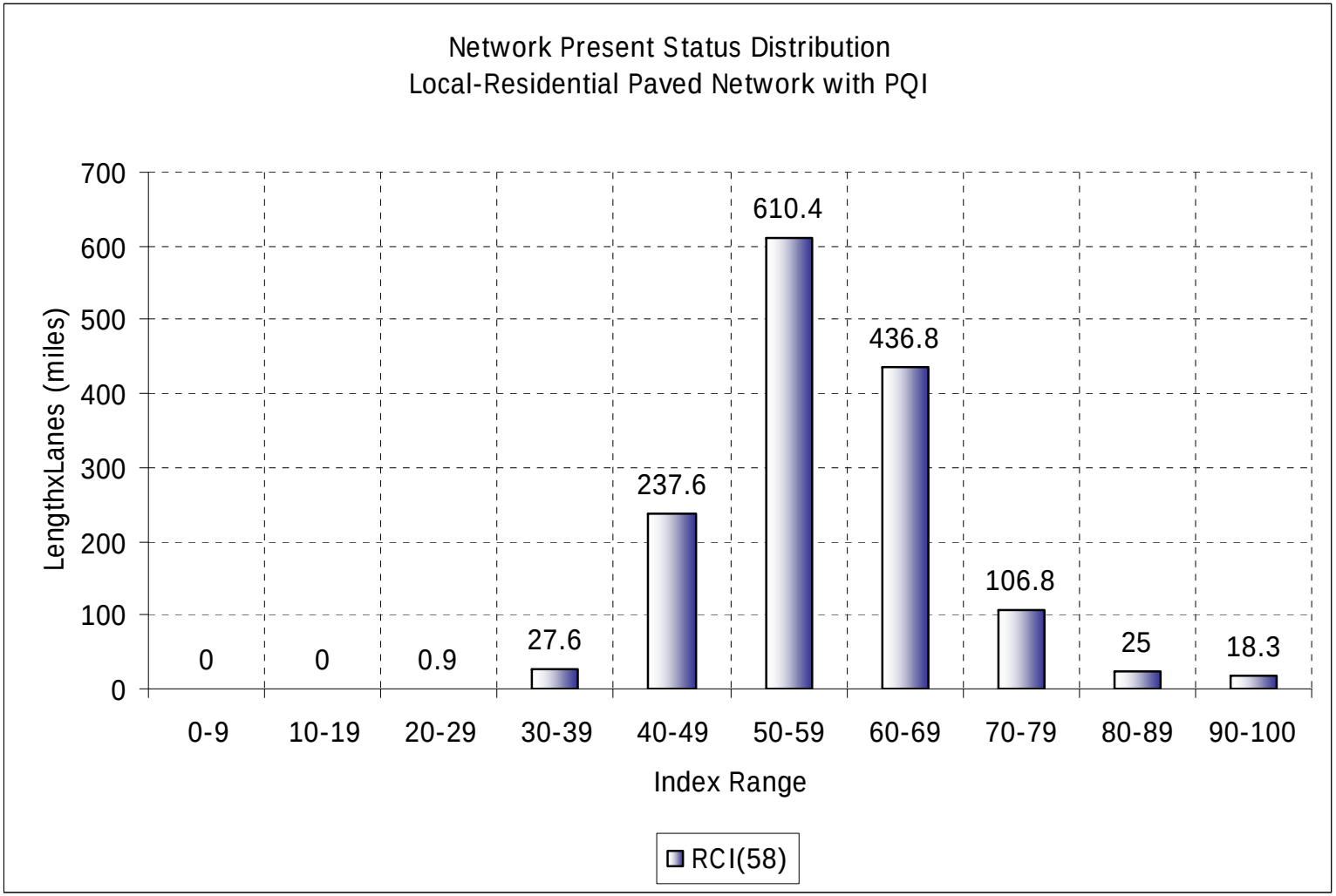

Figure F.10: RCI Distribution for Local-Residential Paved Network

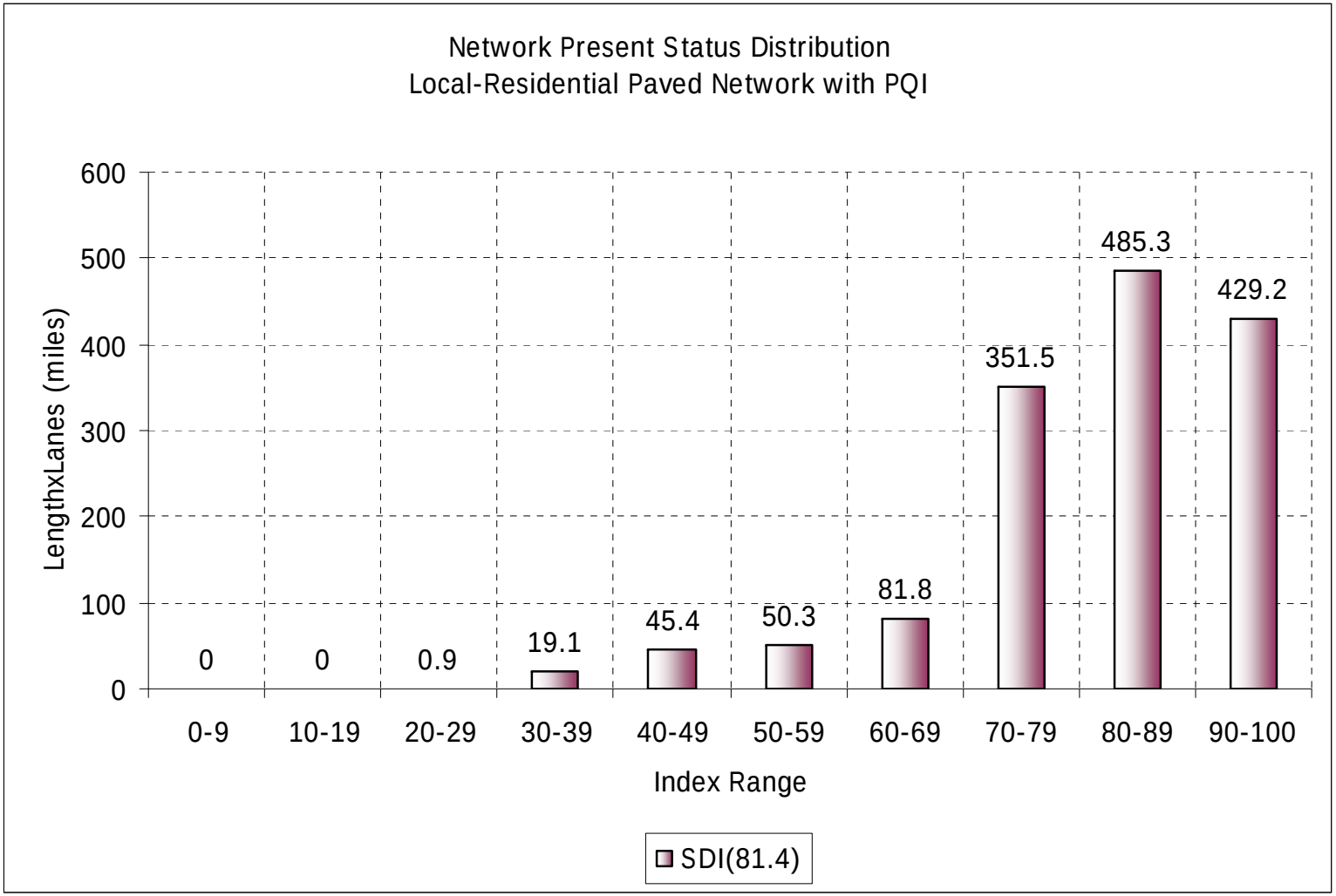

Figure F.11: SDI Distribution for Local-Residential Paved Network

Appendix G

10 Year Program Based on ‘Maintain PQI=80’ Funding Scenario

Appendix G: 10 Year Program Based on 'Maintain PQI=80' Funding Scenario