CHAPTER III

FUNDAMENTAL TECHNIQUES FOR MOBILE INSPECTION DEVICES

This chapter provides an introduction to the theory and application of fundamental techniques for mobile inspection devices. The data requirements and procedures of mobile inspection are described in the first part of this chapter. Secondly, data modeling for data collection methods of the road and bridge inventory and condition in remote field location will be elaborated. The third part of this chapter will explain about data capture theory of the road inventory and condition to measure parameters of road inventory and condition attributes data. Data transfer and base map will be described in the last part of this chapter.

3.1 Data Requirements and Procedures

3.1.1 Data Collection Consideration

Data requirements and capture procedure consist of road inventory data collection issues and deciding what data to be collected. Each data item collection requires time, effort and money to collect, store, retrieve, and use. This section will address a number of issues that road management system faced when determining exactly what their data requirements are how to selected appropriate data-collection technologies that could meet those requirements (Peterson, W.D.O. and Scullion, T, 1990).

3.1.2 Deciding What to Collect

Regarding road management data for monitoring road network, the first question usually asked by road management system is "what data should we collect?" As the literature review of road monitoring and management system, many agencies started by asking an internal team to compile a "data wish list". Other agencies first

take inventory of currently available data and try to implement road management systems using that data. Both of these approaches should be avoided (Paterson, W.D.O. and Scullion, T, 1990). The questions for data need in items to assess of road management system that should be asked are:

- What decisions do we need to make regarding our road management system to manage the network?
- What data are needed to support these decisions?
- Can we afford to collect these data initially?
- Can we afford to keep the data current over a long time period?

To avoid these misperceptions, Paterson and Scullion (1990) have provided approaches for deciding what data should be collected and how it should be collected:

- Collect only data needed
- Collect data to the lowest level of detail sufficient to make appropriate decision; and
- Collect data only when the RMS is needed

According to inspection and monitoring of road and bridge inventories and conditions, the elements below provide some guideline for each type of data, (Paterson, W.D.O. and Scullion, T, 1990).

- Road inventory data: will be consisted of the geometric data of road network. It is common to verify/update the data every five years. The road inventory data comprises point feature and inventory data. The point features need to be described before the inventory data.

- Pavement and road element condition data: will consist of pavement and road element predominance defect. These are usually collected at different frequencies, depending on the road classification. Main roads are monitored at frequently interval, often 1-2 years, while minor roads may be monitored at 2-5 years intervals. The frequency needs to be sufficient to identify major changes, which will influence road maintenance decision.

- Bridge inventory data: will consist of bridge elements component facilities to ensure proper bridge use.

- Bridge condition data: Bridge condition data tends to be done in two cycles. Regular surveys are conducted at 1-2 year intervals for collecting general data on bridge conditions. More intensive investigations are done at long intervals, typically on the order of five years.

Data collection may be considered as belong to one of the following three levels:

- Network-level data collection should answer the general planning, programming, and policy decisions supported by the network-level RMS.

- Project-level data collection should support decisions about the best treatment to apply to a selected section of road. As that data are collected, they can be store to create a more complete database over time. However, a method must be established to keep the data current; and

- Research-level data collection should be established to collect detail data on specific attributes to answer selected questions.

This study focuses on develop mobile inspection and ArcPad application with GPS receiver to collect roadway inventory and roadway condition. Inventory data can be described as the geometric elements of road system such as road classification, road name, lane, surface type, shoulder, no of lanes, lane width, length, etc. It should

be noted that inventory data is the static data that do not change markedly over time. The roadway condition data describes the condition of pavement and road elements such as pavement defect, shoulder defect, culvert defect, side drain defect, right of way defect, etc. This type of data is dynamic data that can be expected to change over time.

3.1.3 Information Quality Levels (IQL)

According to a description in Bennett and Peterson (2000), Information Quality Levels (IQL) helps structure road management information into different levels that correlate to the degree of sophistication required for decision making and methods for collecting and processing data. In IQL theory, very detailed data (low-level data) can be condensed or aggregated into progressively simpler forms (higher-level data), as shown in Figure 3.1.

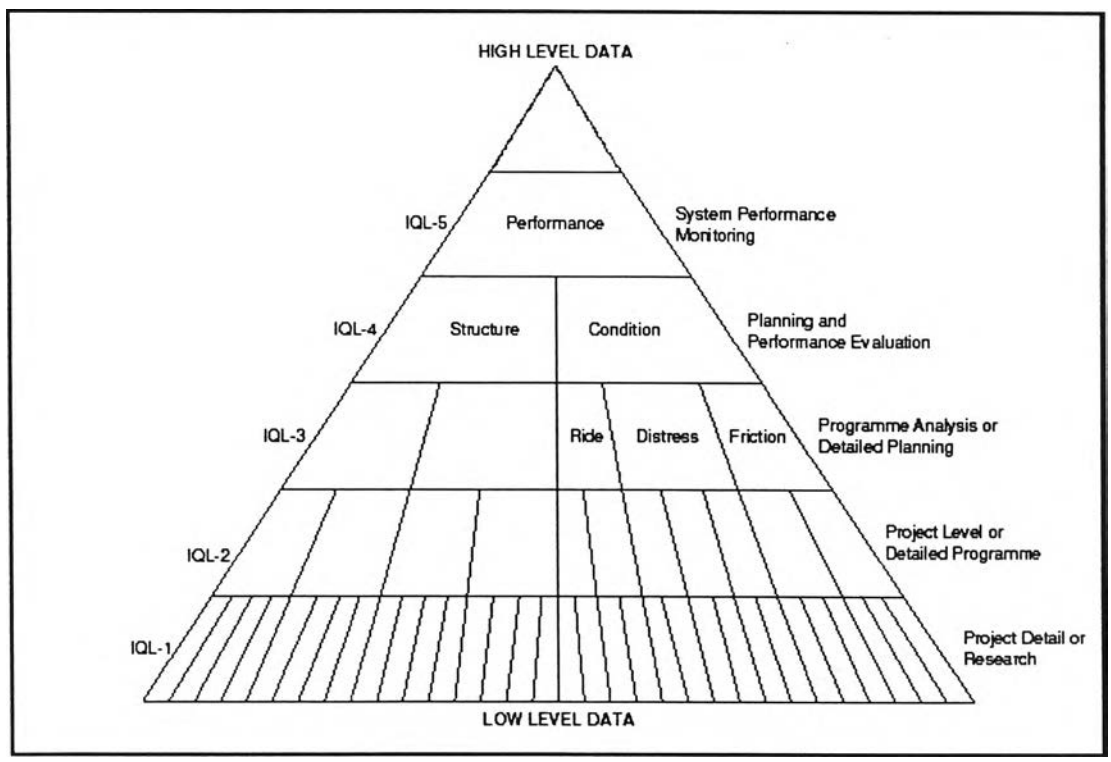


Figure 3.1 Information Quality Level Concept
Source: Bennett and Paterson (2000)

In road management, five levels have been identified for general use, defined in Table 3.1. IQL-1 represents fundamental, research, laboratory, theoretical, or electronic data types, where numerous attributes may be measured or identified. IQL-2 represents a level of detail typical of many engineering analyses for a project-level decision. IQL-3 is a simpler level of detail, typically two or three attributes, which might be used for large production uses like network-level survey or where simpler data collection methods are appropriate. IQL-4 is a summary or key attribute which has use in planning, senior management reports, or in low effort data collection. IQL-5 represents top level data such as key performance indicators, which typically might combine key attributes from several pieces of information. (Bennett and Paterson, 2000)

Table 3.1 Classification of Information by Quality and Detail

IQL	Amount of Details
1	Most comprehensive level of detail, such as that which would be used as a reference benchmark for other measurement methods or in fundamental research. Would also be used in detailed field investigations for an in-depth diagnosis of problems, and for high-class project design. Normally used at project-level in special cases and unlikely to be used for network monitoring. Requires high level skill and institutional resources to support and utilize collection methods.
2	A level of detail sufficient for comprehensive programming models and for standard design methods. For planning, would be used only on sample coverage. Sufficient to distinguish the performance and economic returns of different technical options with practical differences in dimensions or materials. Standard acquisition methods for project-level data collection. Would usually require automated acquisition methods for network surveys and use for network-level programming. Requires reliable institutional support and resources.
3	Sufficient detail for planning models and standard programming models for full network coverage. For project design, would suit elementary methods such as catalogue-type with meager data needs and low-volume road/bridge design methods. Can be collected in network surveys by semi-automated methods or combined automated and manual methods.
4	The basic summary statistics of inventory, performance and utilization that are of interest to providers and users. Suitable for the simplest planning and programming models, but for projects is suitable only for standardized designs of very low-volume roads. The simplest, most basic collection methods, either entirely manual or entirely semi-automated, provide direct but approximate measures and suit small or resource-poor agencies. Alternatively, the statistics may be computed from more detailed data.

Source: Bennett and Paterson (2000).

3.2 Data Attributes of Road and Bridge Inventory

To operate road management system application and to extract road and bridge statistic, a number of data need to be collected. The data collection includes location referencing data, inventory data, and condition data. This study creates GIS shape files, separating into four types of shape files: Location referencing point (LRP), road inventory, road condition, and bridge inventory and condition. The roadway inventory attributes desired by the MCTPC's Planning Technical Division (PTD) (RAMBOLL; September; 2003) are divided into three primary categories, i.e., core attributes, critical attributes and desirable attributes.

3.2.1 Core Attributes

Core attributes data indicates primarily road and bridge inventory, location referencing (GPS coordinate), type of roadway, roadway condition, and inspection maintenance history. This information assists in the development of the roadway inventory database. More specifically, they are identified road inventory as follows.

3.2.2 Critical Attributes

Critical attributes provide more specific information about roadway inventory, roadway conditions, and the asset itself. This information is valuable in keeping proper inventory in database and can provide additional information that supports the county in liability issues.

3.2.3 Desirable Attributes

Desirable attributes provide additional information about the roadway that can assist with maintenance activities. They include the following:

- Register needs for maintenance and repair works and assign corresponding cost estimates

- Register needs for special inspection where the condition survey is not sufficient to determine the right method and quantity of repair
- Monitor changes in the condition of the roadway inventories and thereby evaluate the adequacy of the maintenance activities (and the size of the maintenance budget)

The description of the condition of each individual road element is done by assigning a condition rating/score. The condition rating will be used as an indication of the level of maintenance needs (no maintenance, minor maintenance, rehabilitation etc.).

3.2.3.1 Point Feature

Point feature set up is given road information for each survey section. The surveyor can be tabbing the point features along the roadway. For the topography only one selection per segment can be chosen. The point feature is given by:

- StartingLRP: is the LRP from where the inventory is referenced to. The total length of the segment is shown to the right.
- PFId: is the number of the point feature in ascending order
- Chainage (km): is the offset of the point feature
- PFType: is the type of the point feature
- Description: is a description of the point feature
- LRP: is a registration whether the point feature is also a Location Referencing Point

3.2.3.2 Road Inventory Data

The inventory data is given for each survey section. The survey sections can very between the types of inventory data. When the form has been completed the inspector shall submit it. The form can only be submitted if inventory data for the

whole link has been entered. For the topography only one selection per segment can be chosen. The following information needs to be entered:

- Road number: is the road for which the survey has been carried out
- Link Id: in the link for which the survey has been carried out
- Survey Id: is the reference to the campaign of the particular survey
- Province: is the province in which the road is present
- District: is the district in which the road is present
- RoadName: is the name of the road
- Link start: is a description of the start of the link
- Link end: is a description of the end of the link
- Road class: is the road classification
- Surface: is the surface type
- Surface width: is the width of the carriageway
- Shoulder: is the type of shoulder
- Shoulder width: is the width of the shoulder
- Topography: is the terrain along the road
- Maintenance: is the timing and type of last maintenance
- SPerformed: is the date on which the survey has been carried out
- SPerformedBy: are the initials of the surveyor

Table 3.2 Road Inventory Attribute Data

Attribute Field	Description
ROADID	Street Identified Number
NODEID	Node Identified Number
LINKID	Link Identified Number
SEGMENTID	Segment Identified Number
SURVEYID	Survey Identified Number
ROAD_NAME	Road/Street Name
DATE_INSPE	Date of Data Collection
INSPECTOR	Person Collecting Data
PROVINCE	Name of Province
DISTRICT	Name of District
STA1	Station Start to record Road Inventory
STA2	Station End to record Road Inventory

LRP1	Beginning of Location Referencing Point
LRP2	Ending of Location Referencing Point
DIRECTION	Direction of Traveling on Road
ROAD_NO	Road Number
ROAD_CLASS	Function Class (National, Provincial, District, Urban, Rural…)
NO_LANE	Number of Lanes
LANE_WID	Lane Width (2, 5; 3, 00; 3, 50; 4, 00 ;…)
SUR_TYPE	Surface Type (Asphalt, Surface Treatment, Penetration Macadam)
SUR_WIDDTH	Surface Width (5, 00; 6, 00; 7, 00; 8, 00…)
SH_TYPE	Shoulder Types (Hard, Soft, None)
SH_WIDTH	Shoulder Width (0,5; 1,00; 1,5; None)
RD_TOPO	Road Topography (Flat, Rolling, Hilly, Mountainous)
HISTORY	History of maintenance
ACCESS_LEV	Accessibility Level (Accessibility, Good, Fair, Low, Inadequate)
ACCESS_CON	Access Constraint (Bridge collapse, road Collapse…)
RD_BUDGET	Road Budget (ADB, World Bank, Financial, Foreigner)
CONSTRCT_YE	Road Construction Year
RECONST_YE	Road Reconstruction Year
CONSTRC_BY	Constructed By (French, China, Malaysian, Vietnamese…)
PHOTO	Picture Capture the Environment of Roadway

Source: Location Referencing & Inventory Manual, RAMBOLL, 2003. (MCTPC)

3.2.3.3 Bridge Inventory Data

The attributes of bridge inventory data need to be described. This description includes the location of the bridge and the element of the bridges for the bridge some overall data needs to be given the location of the bridge is given by:

- Road Id.: is the road on which the bridge is located
- Chainage: is the chainage of the middle of the bridge (in km)
- Survey Id: is the reference to the campaign of the particular survey
- Bridge Nb: is the number of the bridge, numbered in succession
- River Name: is the name of the river
- Bridge Name: is the name of the bridge
- SPerformed: is the data on which the survey has been carried out
- SPerformedBy is the initial of the surveyor
- SuperstructureLength: is the length of the superstructure (in m)
- CarriagewayWidth: is the width of the bridge carriageway (in m)

- Spans: is the number of spans of the bridge
- MinSpanLength: is the length of the smallest span (in m)
- MaxSpanLength: is the length of the longest span (in m)
- MaxVehicleLoadPosted: is the load limit posted at the bridge (in tons)
- YearConstruction: is the year of construction of the bridge
- YearReconstruction: is the year of the last reconstruction of the bridge
- Bridge Type: is the type of the bridge
- Wearing Surface: is the type of wearing course on the bridge
- Photo: is the path to the photo.
- Description: is a description of the photo

Table 3.3 Bridge Inventory Attributes Data

Attribute Field	Description
ROADID	Road Identified Number
LINKID	Link Identified Number
BIDATE	Bridge Inspection Date
STA1	Station Start to record Bridge Inventory
STA2	Station End to record Bridge Inventory
RIVERNAME	River Name
BRIDGEID	Bridge Identified Number
BRIDEGNAME	Bridge Name
BRIDGETYPE	Bridge Types (Concrete Slap, Concrete T-Beam...)
NOSPAN	Number of Span
BAILEY	Bailey Design
WEARING	Wearing Course
YRCONS	Year of Construction
YRRECONS	Year of Reconstruction
DONORS	Donors
REMARK	Remarks (Massage short description about bridge)
BRIDGESU	Bridge Super Structure
PARAPET	Parapet on bridge
GUADRIAL	Guardrail on bridge
DRAINAGE	Drainage on bridge
EXPANJOINT	Expansion Joint
SUPERSTRS	Superstructure
ABUMENT	Abutments
PIERS	Piers
BEARING	Bearing
EMBANKMENT	Embankment
RIVERBED	Width of River bed
BRIDGEGEN	Bridge Generation

Attribute Field	Description
WIDTH	Width of Bridge
LENGTH	Length of Bridge
MAXSPAN	Maximum Span
MINSPAN	Minimum Span
MAXLOADPOST	Maximum Load Post
MAXLOADASS	Maximum Load Associate
PHOTO	Photo Capture the Environment of Bridge
INSPECTN	Inspection Name
TEMPER	Temperature in Degree
WEATHER	Weather Condition
INSPECTOR	Inspector
BCREMARK	Bridge Condition Remark
BISURVEYID	Bridge Inventory Survey Identified Number
BCSURVEY	Bridge Condition Survey

Source: Bridge Inventory and Condition Manual, RAMBOLL, October, 2003, (MCTPC)

3.2.3.4 Road Element Condition

Road element condition focuses on the road condition and is defined by seven elements of road defects such as pavement, shoulder, side drain, culvert, slope, road furniture and right of way. For each of road elements, a condition and predominant defect need to be registered during the annual visual inspections and then evaluate and give the score rating in field. For the sealed roads the condition and predominant defect follows the surface Integrity Index, (RAMBOLL, October, 2003).

- Pavement surface condition and predominant defect (sealed)
- Shoulder condition and predominant defect
- Drainage condition and predominant defect
- Culvert condition and predominant defect
- Slope condition and predominant defect
- Furniture condition and predominant defect
- Right-off-Way condition and predominant defect

The inspector will input the road information to each segment. For the sealed roads the condition and predominant defect follows the surface Integrity Index. For the other elements a similar system building on same principles and general information is given by:

- Road number: is the road for which the survey has been carried out
- Link Id: is the link for which the survey has been carried out
- Survey Id: is the reference to the campaign of the particular survey
- SPerformed: is the date on which the survey has been carried out
- SPerformed By: are the initials of the surveyor
- Starting LRP: is the starting point (given as a one of the location referencing points) of the survey.

Table 3.4 Road Condition Attribute Data

Attribute Field	Description
ROADID	Road Identified Number
LINKID	Link Identified Number
SEGMENTID	Segment Identified Number
STA1	Station Start to record Road Condition (200m/segment)
STA2	Station End to record Road Condition (200m/segment)
LRP1	Beginning of Location Referencing Point
LRP2	Ending of Location Referencing Point
RCSURVEY	Road Condition Survey
INSPECDATE	Date of Data Collection
INSPECTOR	Person Collecting Data
ROADELEMENT	Road Elements defects (pavement, shoulder, side drained...)
PAVEMENT_DEF	Pavement defect type(bleeding, cracking, patching, reveling)
BLEDD_AR	Bleeding Area
BLEED_CR	Condition Rating of Bleeding (Excellent, good, fair, poor...)
PATCH_AR	Percent Area of patching
PATCH_CR	Condition Rating of Patching (Excellent, good, fair, poor...)
REVEL_AR	Percent Area of Reveling
REVEL_CR	Condition Rating of Reveling (Excellent, good, fair, poor...)
CRACK_AR	Percent Area of Cracking
CRACK_CR	Condition Rating of Cracking (Excellent, good, fair, poor...)
POTH_AR	Percent Area of Potholes
POTH_CR	Condition Rating of Potholes (Excellent, good, fair, poor...)
DIS_AR	Percent Area of Disintegration
DIS_CR	Condition Rating of Disintegration (Excellent, good, fair...)
TOTALAREA	Total Area Defect

Attribute Field	Description
MNAREA	Minor Area Defect
MJAREA	Percent Major Area Defect
P_MNAREA	Percent Minor Area Defect
P_MJAREA	Percent Major Area Defect
MN_CR	Minor Condition Rating
MJ_CR	Major Condition Rating
SHDEFECT_TYPE	Shoulder Defect Types (drop off, transverse erosion…)
SHDEFECT_AR	Shoulder Defect Area
SHDEFECT_CR	Condition Rating of Shoulder Defect
SDDEFECT_TYPE	Side drains Defect Types (drain needed, block, eroded…)
SDDEFECT_AR	Side drain Defect Area
SDDEFECT_CR	Condition Rating of Side drain Defect
CVDEFECT_TYPE	Culvert Defect Types (silt/block, inlet/outlet, pipe damage...)
CVDEFECT_AR	Culvert Defect Area
CVDEFECT_CR	Condition Rating of Side drain of Culvert Defect
SLDEFECT_TYPE	Slope Defect Types (slip up hill, slip down hill, erosion)
SLDEFECT_AR	Slope Defect Area
SLDEFECT_CR	Condition Rating of Slope Defect
RFDEFECT_TYPE	Road Furniture Defect Types (guardrail, sign, marking)
RFDEFECT_AR	Road Furniture Defect Area
RFDEFECT_CR	Condition Rating of Slope of Road Furniture Defect
ROWDEFECT_TYP	Right Of Way Defect Types (short grass, long grass, brush..)
ROWDEFECT_AR	Right Of Way Defect Area
ROWDEFECT_CR	Condition Rating of Right Of Way Defect
ACCESS_CONST	Accessibility Constraints (bridge collapse, road collapse…)
ACCESS_LEVEL	Accessibility Level (Accessibility, Good, Fair, Inadequate)
PHOTO	Picture Capture the Condition of Roadway defect

Source: Road Inventory and Condition Manual, RAMBOLL, October, 2003. (MCTPC)

3.2.4 Road Element Condition Rating Criteria

This study applies the condition rating to evaluate the predominance condition defect of road elements. The condition rating is given on a scale from 0 to 5, depending on the severity and density of the pavement defects. The ratings are given in Table 3.6. Pavement conditions are divided into six levels (Excellent, Good, Fair, Poor, Bad and Failure) and other elements will be divided into four levels (Good, Fair, Poor and Bad).

Table 3.5 Maintenance Rating Program – Condition Standards

Distress Characteristic	Condition Standard
Pavement	Flushing/Breeding, Patching, Raveling/Scabbing, Potholes, Cracking, Disintegration
Shoulder	Drop-off (paved carriageway only), Transverse erosion, Crossfall, and Vegetation
Side Drain	Drainage needed, Drain blocked, and Drain eroded.
Culverts	Silted/Blocked, Inlet/Outlet and Pipe damage
Slopes	Slips uphill side, Slips downhill side, and Erosion
Road Furniture	Guardrails, Traffic signs, and Making (sealed roads only)
Right-of-ways	Short grass, long grass (thick vegetation), bushes and trees

Source: Road Inventory and Condition Manual, RAMBOLL, October, 2003. (MCPTC)

Level of Importance Factors for Characteristics by Roadway Classification

Pavement element	**Condition Rating**
Flushing/Bleeding	0 1 2 3 4 5
Patching	0 1 2 3 4 5
Revelling/Scabbing	0 1 2 3 4 5
Potholes	0 1 2 3 4 5
Cracking	0 1 2 3 4 5
Disintegration	0 1 2 3 4 5
Shoulder Elements	
Drop-Off	0 1 2 3
Transverse Erosion	0 1 2 3
Crossfall	0 1 2 3
Vegetation	0 1 2 3
Side Drain Elements	
Drainage Needed	0 1 2 3
Blockage	0 1 2 3
Erosion	0 1 2 3

Culvert Elements	**Condition Rating**
Blockage	0 1 2 3
Inlet & Outlet Damage	0 1 2 3
Pipe/ Conduct Damage	0 1 2 3
Slope Element	
Slips Uphill Side	0 1 2 3
Slips Downhill Side	0 1 2 3
Erosion	0 1 2 3
Road Furniture	
Guard Post Damage	0 1 2 3
Guardrail Damage	0 1 2 3
Traffic Sign Damage	0 1 2 3
Marking Damage	0 1 2 3
Right-of-ways	
Short Grass	0 1 2 3
Long Grass	0 1 2 3
Bushes, Trees	0 1 2 3

(1) Pavement Condition

The condition rating is given on a scale on 0 to 5, depending on the severity and density of the pavement defects. The defects included are given in Table 3.6.

Table 3.6 Surface Integrity Defect

Minor Defect	Major Defect
Patches	Wide Surface Cracks and crocodile cracking (>3mm)
Shallow/Ravelling (<2mm depth)	Ravelling
Bleeding (Texture depth<1mm)	Potholes (> 75mm)
Surface Cracking (<3mm)	Disintegration

Source: Paterson, W.D.O. Internal paper, World Bank 1993

Based on the visual inspection of the pavement surface the surveyor indicates which of the six rating levels is most appropriate, in accordance with the guidance given in Table 3.7.

Table 3.7 Classifications of Minor or Major Defects /Surface Integrity Index

Pavement Condition Index:(PCI)	Surface condition	Description	
		Minor Defects	Major Defects
0	Excellence	None	None
1	Good	Up to 20 m2 per 100m	1 occurrence per 100 m
2	Fair	< 50 % of the area	up to 4 occurrences per 100 m
3	Poor	> 50 % of the area	< 30 % of the area
4	Bad	N/A	≥ 30 % of the area, or potholes on < 20 % of area
5	Failed	N/A	≥ 30 % of the area, or potholes on ≥ 20 % of area

Source: Paterson, W.D.O. Internal paper, World Bank 1993

For the pavement condition rating is given on a scale of 0-5, where 0 indicates an excellent pavement without any defects, while 5 indicates a failed pavement, where most of pavement is disintegrated.

The pavement condition rating is given on a scale of 0 to 5, where 0 indicates an excellent pavement without any defects and 5 indicates a failed pavement, where most of pavement is disintegrated. The pavement condition can be determined by using these criteria:

Condition Rating		Description
0	*Excellent:*	No damage, element as new
1	*Good:*	Insignificant damage, no repair needed
2	*Fair:*	Minor damage, repair when convenient
3	*Poor:*	Damage, repair soon
4	*Bad:*	Severe damage, repair immediately
5	*Failure:*	Ultimate damage, element has failed

(2) Shoulder Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the shoulder defects. The defects included are:

- Drop-off (paved carriageway only)
- Transverse erosion
- Crossfall
- Vegetation

Based on the visual inspection of the shoulder the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.8. The condition is given as the average of the shoulders of each side of the road.

Table 3.8 Shoulder Condition Ratting

Shoulder Condition Index:(PCI)	shoulder condition	Description
1	Good	The shoulder has sufficient crossfall and is clean of vegetation. No drop-off (paved carriageway only).
2	Fair	The crossfall is less than desired. Some vegetation and erosion (up to 20 m/100 m). No drop-off (paved carriageway only).
3	Poor	Vegetation and/or erosion common (up to 50 m/100 m). If paved carriageway the drop-off is up to 10 cm.
4	Bad	Erosion is dominant (more than 50 m/100 m). If paved carriageway the drop-off exceeds 10 cm.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

(3) Side Drain Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the drainage defects. The defects included are:

- Drainage needed
- Drain blocked
- Drain eroded

Based on the visual inspection of the drainage system the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.9. The condition is given as the average of the drainage system of each side of the road.

Table 3.9 Side Drain Condition Ratting

Side drain Condition Index:(PCI)	Side drian condition	Description
1	Good	The ditch is deep4 (30-50 cm). Only minor erosion (up to 10 m/100m). The ditch is not blocked.
2	Fair	The ditch is relatively deep (>20 cm). Some erosion might be seen (up to 25 m/100m). The ditch might be blocked up to 10 m/100 m.
3	Poor	The ditch depth is less than 20 cm. Erosion is common (up to 50m/100 m). The ditch is blocked up to 40 m/100 m.
4	Bad	The ditch depth is less than 20 cm. Erosion is common (up to 50 m/100 m). The ditch is blocked up to 40 m/100 m.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

(4) Culvert Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the culvert defects. The defects included are:

- Silted/Blocked
- Inlet/outlet
- Pipe damage

Based on the visual inspection of the culverts the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.10. The condition is given as the average of the culverts on the road section surveyed.

Table 3.10 Side Drain Condition Ratting

Culvert Condition Index:(PCI)	Culvert condition	Description
1	Good	Only negligibly silted. No damage to pipe or inlet/outlet.
2	Fair	Culvert partly silted, but open area to at least 75%. No pipe damage, but inlet/outlet could have minor damage.
3	Poor	Less than 50% open area. Inlet/outlet partly damaged/eroded. Pipe not damaged.
4	Bad	The pipe is severely damaged (maybe collapsed) and the culvert does not function.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

(5) Slope Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the slope defects. The defects included are:

- Slips uphill side
- Slips downhill side
- Erosion

Based on the visual inspection of the slopes the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.12. The condition is given as the average of the slope condition on each side of the road.

Table 3.11 Slope Condition Rating

Slope Condition Index:(PCI)	Slope condition	Description
1	Good	Only minor slope erosion is present (< 10 m/100 m). No slips.
2	Fair	Some erosion is present (<30 m/100 m). Minor slips only (<10 m/100m)
3	Poor	Erosion is common (<50 m/100 m). Some slips (<20 m/100 m)
4	Bad	The slope has slipped on several locations.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

(6) Road Furniture Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the furniture defects. The defects included are:

- Guardrails
- Traffic signs
- Marking (sealed roads only)

Based on the visual inspection of the road furniture the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.12. The condition of the road furniture is given as an average for the total number of the road furniture within the section surveyed.

Table 3.12 Road Furniture Condition Rating

Road Furniture Condition Index:(PCI)	Road Furniture condition	Description
1	Good	The marking is clear. Few traffic signs have minor damage. Guardrails are undamaged.
2	Fair	The marking is indistinct. Some traffic signs have minor damage. Only minor damage on guardrails.
3	Poor	The marking is indistinct. Many traffic signs have some damage. Only minor damage on guardrails.
4	Bad	Guardrails and traffic signs are severely damaged or missing. Marking is nonexistent.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

(7) Right of way Condition

The condition rating is denoted by: Good, Fair, Poor or Bad, depending on the severity and density of the right-off-way defects. The defects included are:

- Short grass
- Long grass (thick vegetation)
- Bushes
- Trees

Based on the visual inspection of the right-of-way the surveyor indicates which of the four rating levels is most appropriate, in accordance with the guidance given in Table 3.13.

Table 3.13 Right-of-Way Condition Rating

Right-of-way Condition Index:(PCI)	Right-of-way condition	Description
1	Good	Only insignificant obstruction of the visibility of the road users from grass and bushes. No trees.
2	Fair	Only short sections with obstructions of the visibility of the road users from grass and bushes. No trees.
3	Poor	Visibility lost on longer sections (up to 50 m/100 m), due to high grass and bushes. Only few trees along the road.
4	Bad	The shoulders and slopes are overgrown with thick vegetation (long grass and bushes). Trees are close to the road. Visibility lost on most of the section.

Source: Road Condition Survey Manual, RAMBOLL, October, 2003. (MCTPC)

Other elements for road condition is given on a scale of 0 to 3, where 0 indicates that the element has a good condition with only insignificant defects, and 3 indicates that the element has a bad condition, and has failed in several locations. The road elements condition can be determined by using these criteria:

Condition Rating		**Description**
0	*Good:*	Insignificant damage, no repair needed
1	*Fair:*	Minor damage, repair when convenient
2	*Poor:*	Damage, repair soon
3	*Bad:*	Severe damage, failed in several locations.

Condition rating of bridge elements is similar to the evaluation of the predominance defect elements. The condition rating is an expression of the urgency of repair, and it can assume the values listed in Table 3.7. The condition data is entered for each bridge element. Only bridge elements appropriate for the particular bridge chosen will be shown in the form. For each of the bridge element a condition rating is

given on a scale from 0 to 5 (no damage, element is new to ultimate damage, element has failed). Table 8 provides a full description of the condition ratings.

3.2.5 Bridge Condition Data

Bridge condition data requires the assessed routine maintenance (maintenance activities) and condition rating for each individual bridge element (condition data).

- Road number: is the road for which the survey has been carried out
- Link Id: is the link for which the survey has been carried out
- Bridge Chainage: is the bridge for which the survey has been carried out for
- Survey Id.: is the reference to the campaign of the particular survey
- SPerformed: is the date on which the survey has been carried out
- SPerformedBy: is the initial of the surveyor

Table 3.14 Bridge Condition Attribute Data

Code	Element
1	Bridge Surface and Footpaths
2	Parapets on Bridge
3	Guard Rails at Bridge Approach
4	Drainage
5	Expansion Joints
6	Superstructure
7	Abutments, Wing Walls and Retaining Walls
8	Piers
9	Bearings
10	Embankments and fill in front of abutments
11	River Bed
12	Bridge in general (The bridge seen as a whole)

Source: Bridge Condition Manual, RAMBOLL, October, 2003. (MCTPC)

Table 3.15 Condition Ratings

Code	Description
0	No damage, element as new
1	Insignificant damage, no repair needed
2	Minor damage, repair when convenient
3	Damage, repair soon
4	Severe damage, repair immediately
5	Ultimate damage, element has failed
?	The condition could not be determined at the inspection

Source: Road Inventory and Condition Manual, RAMBOLL, October, 2003.

Table 3.16 Description of Condition Ratings

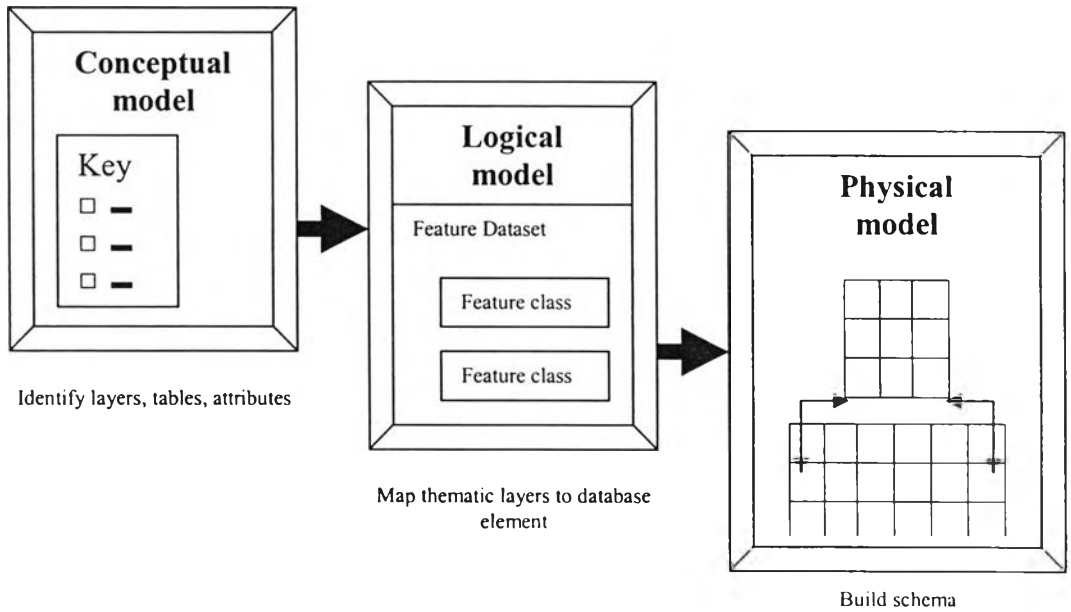
Code	Description
0	**No damage, element as new** No signs of damage or deterioration
1	**Insignificant damage, no repair needed** Minor popouts or hairline cracks in concrete surfaces. Superficial spalling, scaling or other deterioration that is not expected to develop into need for repair within 10 years or more. Superficial corrosion and wear of painting that does not justify any treatment within 10 years or more.
2	**Minor damage, repair when convenient** Damage that is not assumed to be of immediate importance, but may develop into more serious damage: Fine or medium cracks in concrete surfaces (without structural implications), scaling and spalling of concrete, local corrosion of secondary reinforcement, superficial corrosion of steel components, wear of painting, superficial erosion of embankments and river bed.
3	**Damage, repair soon** Damage that is expected to develop into something more serious and/or expensive unless action is taken within a very few years: Coarse cracks indicating structural deficiencies, severe spalling and scaling exposing reinforcement, significant corrosion of reinforcement or steel components, significant erosion and scour (that has not yet affected the structures themselves). Minor settlements and displacements that do not imply immediate danger of getting worse.
4	**Severe damage, repair immediately** Damage that has a significant risk of developing into failure of the component unless action is taken within about a year: Local failure/fracture that has not yet lead to failure of the whole component. Cracks, spalling, corrosion or other deterioration that has significantly reduced the structural capacity of the component. Erosion and scour that implies a significant risk of the stability of piers and abutments.
5	**Ultimate damage, element has failed**

	Damage that has already caused the component to fail or that has an extent that may lead to failure any time under normal loads: Fracture of primary components, severe settlements of piers and abutments, missing panel pins or other primary components of Bailey Bridges. Significant deformation of truss members in compression. If an important element is not present, it is also rated 5, even if it has never been there. E.g.: At one-lane bridges on two-lane roads guard rails at bridge approaches are considered important for the safety of the road users and for the bridge. If they are not present, the element is rated 5.
?	**The condition could not be determined at the inspection** Piers, abutments, bearings and superstructure can be impossible to inspect at high water levels.

Source: Bridge Condition Manual, RAMBOLL, October, 2003. (MCTPC)

3.3 Data Modeling

The main purpose of data modeling process is to implementation a system that makes information more useable and effective. Data modeling as applied to database system is a language that allows the definition of the structures that will be used to store the base data and integrity constraints that the store data has to obey at all times (Johnson, 1998). The process of data modeling is usually represented in 4 different levels (Figure 3.2). These are transformations that facilitate representation of real word phenomena in a computer environment by capturing object that interest and their characteristic (Lupe, 2002).



Explore data models at http://support.esri.com

Figure 3.2 Phases in Database Design

The conceptual model is the concept and representation of important entities essential to application, attributes and relationships. In the case of elements at road mapping, entities are the general roadway information and roadway characteristics. The logical model is the step toward particular database system, where entities and relationships are converted into tables that can be implemented into a computer database. The computer data model is the actual implementation of the valid data model or entity of data into the computer in the field. To generate road and bridge inventory and condition mentioned, a data model is necessary to describe the objects of interests.

Transportation data model was developed by a group of ESRI transportation industrial users, consultants, and academics. This study will examine the essential of implementing data model in particular for support mobile handheld inspection to collect road inventory and condition data in remote field location, as well as for road management organizations and transportation agencies including road network topology, road inventory system, linear referencing system, dynamic event

representation and management (NJDOT, 2003). The proposed transportation data model has several components or layers as shown below:

- Base layers contain background mapping information such as orthophotography, features, and road network lines. For this study, these layers can be obtained from the MCTPC in Lao PDR.

- Routing layers contain the individual route feature classes that contain the data relative to the road network.

- Cartographic layers contain other cartographic elements such as annotation requirements and/or route shields. Separate cartographic layer give the MCTPC the liberty to move symbols to make mapping products more attractive.

This study implements data model that contains five different object packages of essential object that can benefit data model for mobile inspection. Each package contains a set of object, feature classes and relationship between those classes. Each object class consists of a descriptive name and a set of attributes that defined the object that occurred in the segments. All object classes inherit properties from one of the basic object type. The object packages of transportation data model considered in this study are assets, domains, location referencing, reference network and relationships.

(1) Asset objects are transportation network features that include roadway inventory, roadway condition, bridges, point features, pavement and roadway systems. Assets can be both point and linear features. For example, bridge and culvert or sign are represented by points, while street and segment are represented by linear.

(2) Domains are table objects that contain allowable sets of value for other event objects that occurred in the road network. An example of domain would be the list of district code in the road network by municipal code number.

(3) Location referencing objects are those table that are required to assign route point feature and/or km-post information to the road network. The assign route point feature/km-post information for each route segment is used to calculate the spatial position of a segment that is linear referenced with route number and km-post information.

(4) Reference network are used to measure the location of segments along the roadway. The methodology for locating segments along the transportation network is typically referred to as linear referencing. The reference network comprises the physical entities form of linear objects.

(5) The relationships objects dictate how the other data model objects interact with each other. Relationship describes behavior and properties of segments i.e. a relationship called "Road_Idnumb" would be dictated the one-to-many relationship between records in the road table and the address range table.

For national road class in Lao PDR, the data model may include a single feature class, combining feature class for all route information. The study includes the creation of spatial views, one for each route type. The actual feature classes are identified based on required attributes by route type. The key feature for these order route types are:

- Route Centerline: route centerline graphic representation of divide roadways by fixed length segment will be implemented. The modeling of route within the roadway inventory uses street centerline representation for roads. The feature class contains separate segments for each carriageway. Each carriageway of divided street will have its own number and be identified as separate route.

- Road Identified Numbers: every route of the road network must have a unique of road identified (ID) number for ease of inspection. The longer streets will be divided by point (nodes) connected by line (links) from one intersection to

next intersection. A segment ID number will contain Road ID number and is a primary key in the entity diagram relationship in database.

- Segmentation: the number of segments includes the feature class for each of the route types. A single line segment without gaps or branches represents a stretch of road between two points.
- Street Identifies Numbers: the data model will continue to utilize the street route identifier format for all routes.
- Road Name: The common name for each route will continue to be carried in the feature table.
- Beginning and End Points: The beginning and end point are where the segment of a street begins and ends. It is very important to begin and end the segment at intersection or other point features along the street and geographical features.
- Km-post and Km-end: the measure starting and ending km-post of the route segment will be explicitly stated as well as is carried in the route segment.
- Activation: Activation is a status field called "Active" as well as activation and retirement dates, "Year_Active" and "Year_Retired" respectively, will be maintained for each segment.
- Network topology: The network topology is the relationship between spatial object in the GIS. The relationships established in a GIS dictate the interaction between the objects.

3.3.1 Conceptual Data Model

The purpose of elements in road and bridge inventory mapping is to establish a database that will be used for loss estimation due to possible road and bridge conditions. In this case, location, roadway inventory, and roadway condition, bridge inventory and condition have been considered. For loss estimation, generally roadway

information, roadway characteristics, and roadway condition have been considered important entities linked to a certain road network.

The general roadway information entity has information describing the road number, street name, district, province, and date of survey and the identity of surveyor. The roadway characteristics entity describes information on use, road classification, surface type, surface width, shoulder type, shoulder width, number of lane, lane width, road topology, etc. that will indicate the degree of vulnerability to a certain road network. The roadway condition entity which describes about the road elements defect on the road network has fields describing the defection of pavement, shoulder, side drain, culvert, slope, road furniture and right of way that will be used to derive the road management system. In a roadway condition there will be general more than one element, which implies to a one to many relationship. Another entity types is the bridge in which attributes described are the number, type, width, length and photo taken. More than one bridge could be found in one road hence a many to one relationship.

3.3.2 Data Structure

The database designed for elements in road inventory consists of attributes tables each describing the entities in dbf tables. The road number is the unique identifier of each roadway and servers as the primary key in the general information and road characteristic tables. The unique identifier in the table road condition is the segment number and the secondary key stored in this table is the road number, which then link to the general information and roadway characteristic tables. The road number is the primary field relating to road inventory tables and bridge inventory tables. The bridge number is the primary field in the bridge inventory table and stores the road number, as the secondary key.

3.3.3 Database Profile

Look up tables for some fields in roadway inventory table have been defined into suitable classes that will be used for elements defect classification, vulnerability study and road assessment. These profiles are used as a look up table for field data collection to improve efficiency in field data acquisition. In this study, the classification by Ministry of Communication Transportation Post and Construction (MCTPC) has been used. The roadway type defined for the look up table is according to MCTPC classification of roadway types (Federal Emergency Management Agency, 1999). For roadway condition, the profiles have been defined and classes or values will be assigned to the fields where they apply.

3.4 Mobile Inspection Data Collection

The first step in preparing for field data collection is to compile the data sets that include administrative, campaign, mobile inspection, GPS receiver, photos and road network base map, which will be used for elements at roadway mapping. Interpretation of images of the study route is done with desktop GIS and screen digitizing to create vector layers. This can be done using any suitable GIS software that can convert the vector files to .SHP file format.

Point and linear shape files are created in ArcPad. The attributes of the tables (Figure 3.3) are defined as the fields of new layers. The new layer generates 4 files, i.e., .dbf, .shp, .shx and apl files. The database file stores the attributes of the defined fields and the .apl allows for creation of custom forms for data capture.

The feature class contains a single record for each route and the route will contain database tables are either event tables (both point and linear) that contain attributes, domain tables that include lookup value for event tables, or system table used to control the operation of the straight linear diagram application. And each shape file contains the attribute fields of road inventory which are described below:

Table 3.17 Road Inventory Data Entities

ENTITY	DEFINITION
Administrator	An entity that consists of road network planning
Point Feature	An entity that provides identifiable element of transportation system, location and information.
Point Event	An entity that consists of a component or attributes at a single location
Location Referencing Point (LRP)	An entity that provides that specific location
Campaign	An entity provides a methodology for road inventory and condition
Road Inventory	An entities that consists of road geometric and physical information
Road Condition	An entity that consists of road elements defects and condition
Road Condition Photo	An entity that provides inspector evaluated score ratting for road survey
Bridge Inventory	An entity that consists of physical information of bridge
Bridge Condition	An entity that consists of bridge element defects and condition
Bridge Photo	An entity that provides inspector evaluated score ratting for bridge survey
Fixed Length Segment	An entity that provides a direct line between two points
Linear Event	An entity that provides attributes of distinct beginning and ending event point

To create a relation data model in ArcPAd GIS, specialized script writing is required. However where one has limited knowledge on script writing using visual basic programming language, creation of different shape files for each database table is used as an option so that one can establish relational links in a desktop PC

environment. This will be advantage in the field and any other time when one want to edit the attributes since one has to keep on navigating between the three layers. However when creating the custom forms, the general information of roadway is assigned the first page, a different layer is created for roadway condition of each segment.

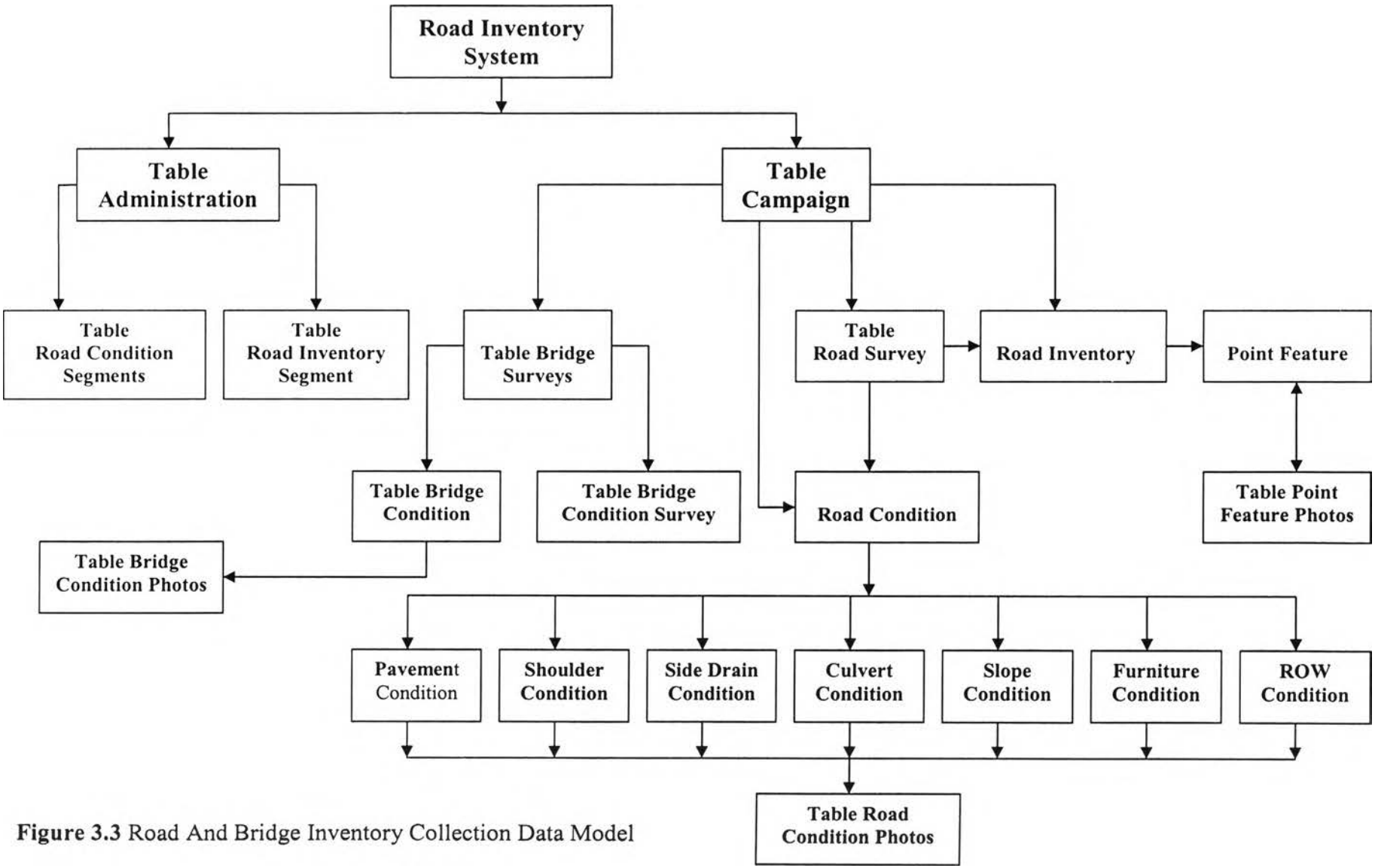
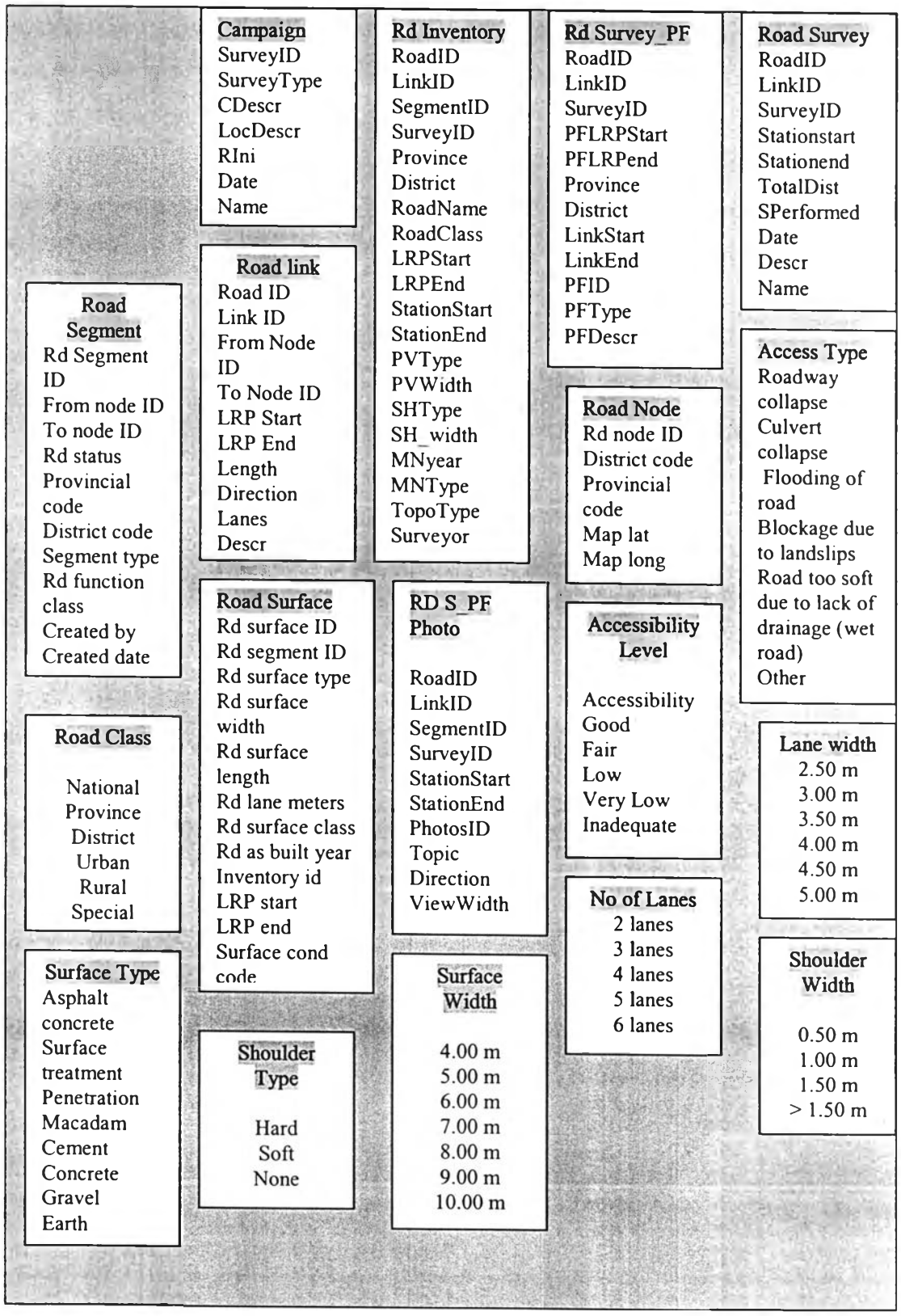


Figure 3.3 Road And Bridge Inventory Collection Data Model


Campaign
SurveyID
SurveyType
CDescr
LocDescr
RIni
Date
Name
Rd Inventory
RoadID
LinkID
SegmentID
SurveyID
Province
District
RoadName
RoadClass
LRPStart
LRPEnd
StationStart
StationEnd
PVType
PVWidth
SHType
SH_width
MNyear
MNType
TopoType
Surveyor
Rd Survey_PF
RoadID
LinkID
SurveyID
PFLRPStart
PFLRPend
Province
District
LinkStart
LinkEnd
PFID
PFType
PFDescr
Road Survey
RoadID
LinkID
SurveyID
Stationstart
Stationend
TotalDist
SPerformed
Date
Descr
Name
Road link
Road ID
Link ID
From Node ID
To Node ID
LRP Start
LRP End
Length
Direction
Lanes
Descr
Road Segment
Rd Segment ID
From node ID
To node ID
Rd status
Provincial code
District code
Segment type
Rd function class
Created by
Created date
Road Node
Rd node ID
District code
Provincial code
Map lat
Map long
Access Type
Roadway collapse
Culvert collapse
Flooding of road
Blockage due to landslips
Road too soft due to lack of drainage (wet road)
Other
Road Surface
Rd surface ID
Rd segment ID
Rd surface type
Rd surface width
Rd surface length
Rd lane meters
Rd surface class
Rd as built year
Inventory id
LRP start
LRP end
Surface cond code
RD S_PF Photo
RoadID
LinkID
SegmentID
SurveyID
StationStart
StationEnd
PhotosID
Topic
Direction
ViewWidth
Accessibility Level
Accessibility
Good
Fair
Low
Very Low
Inadequate
Lane width
2.50 m
3.00 m
3.50 m
4.00 m
4.50 m
5.00 m
Road Class
National
Province
District
Urban
Rural
Special
Surface Width
4.00 m
5.00 m
6.00 m
7.00 m
8.00 m
9.00 m
10.00 m
No of Lanes
2 lanes
3 lanes
4 lanes
5 lanes
6 lanes
Shoulder Width
0.50 m
1.00 m
1.50 m
> 1.50 m
Surface Type
Asphalt concrete
Surface treatment
Penetration Macadam
Cement Concrete
Gravel
Earth
Shoulder Type
Hard
Soft
None

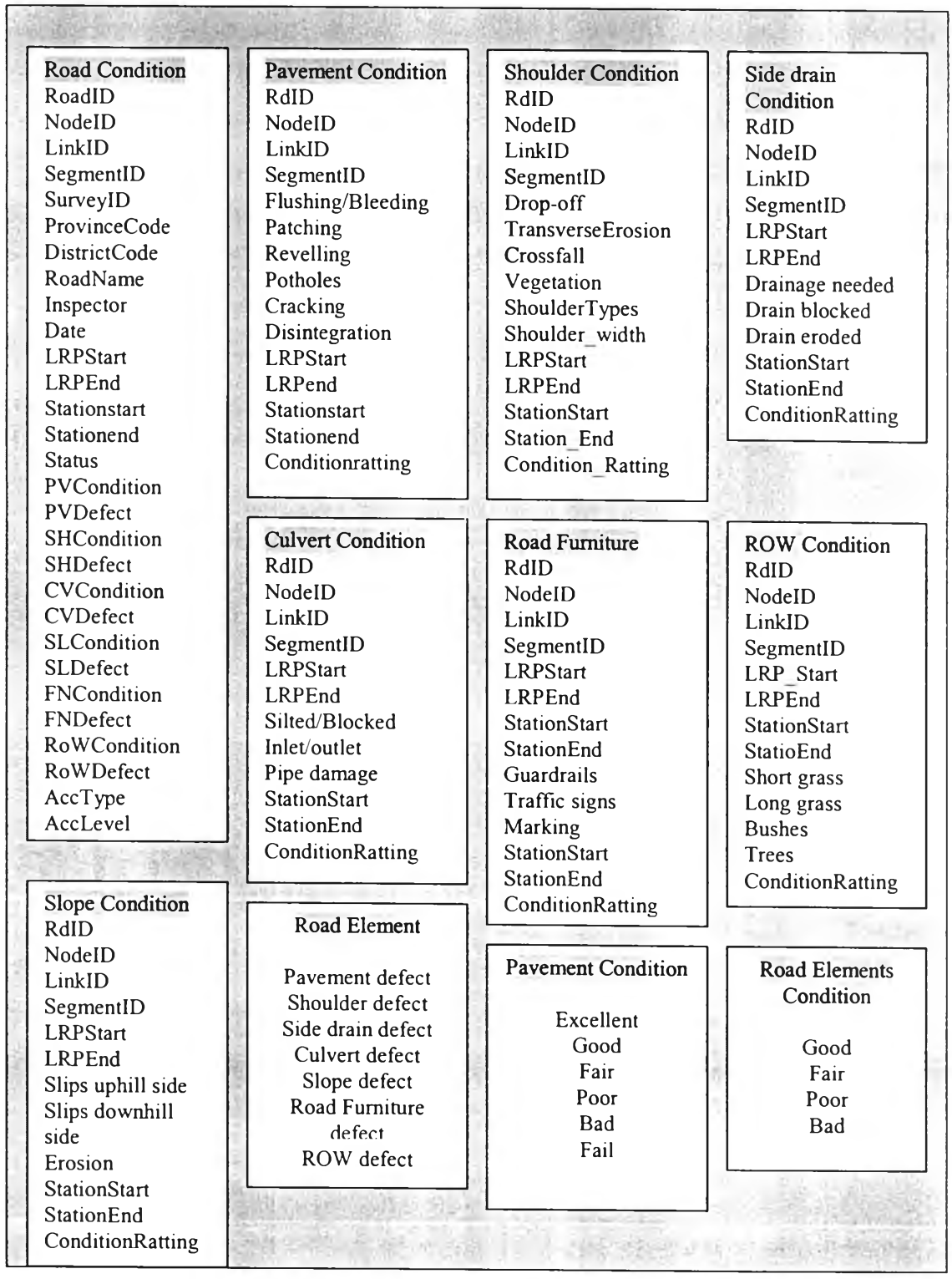


Figure 3.4 Road and Bridge Inventory and Condition Look up tables

3.4.1 Tools

A number of tools can be used for various functions in a digital capture system, as shown in Table 3.10. Hardware to be used includes a laptop and Ipaq Pocket PC. The laptop is used for data backup and to make any adaptations in the custom forms since the application builder can only run on a desktop computer. Software used for data capture is ArcPad 6.0 mobile GIS, ArcPad Application Builder (ArcPad Studio), ArcView3.2 and GIS software.

Table 3.18 Mobile Inspection Data Capture Tools

Tool	Type	Function
ArcView Software	GIS	• Data preparation for ArcPad (Images Screenshots) • Visualization in field • Editing dbf files
ArcPad Software	Mobile GIS	• Creation of custom forms (desktop) • Field point data capturing • Vector map editing
ActiveSyne (Software)	Interface Software	• Synchronization of pocket PC and desktop computer/laptop
Compaq Ipaq (Hardware)	Pocket PC	• Field data collection using mobile GIS
Laptop (Hardware)	Desktop PC	• Downloading data • Backup • Data visualization
GPS	GPS	• Navigation

Source: Jacob Kanwaria Njagih, March, 2003

3.4.2 Custom Forms

The inclusion of data collection forms in a mobile inspection data capture system is of optimal importance since point and line data entry are done in the systematic way from one attribute to the other. The customization is done in ArcPad 6.0 application builder, Forms are designed for each of shape files corresponding to tables defined in the data collection forms store data in a dbf file, which is linked to the corresponding shape files.

3.4.3 Form Page

Data collection forms for elements at road inventory mapping are designed with different data collection pages to aid data entry and utilize the limited screen size of pocket PC. For roadway characteristics layer, data collection pages were created due to long number of attribute in table. Descriptions of the roadway characteristics are given in Figure 3.5.

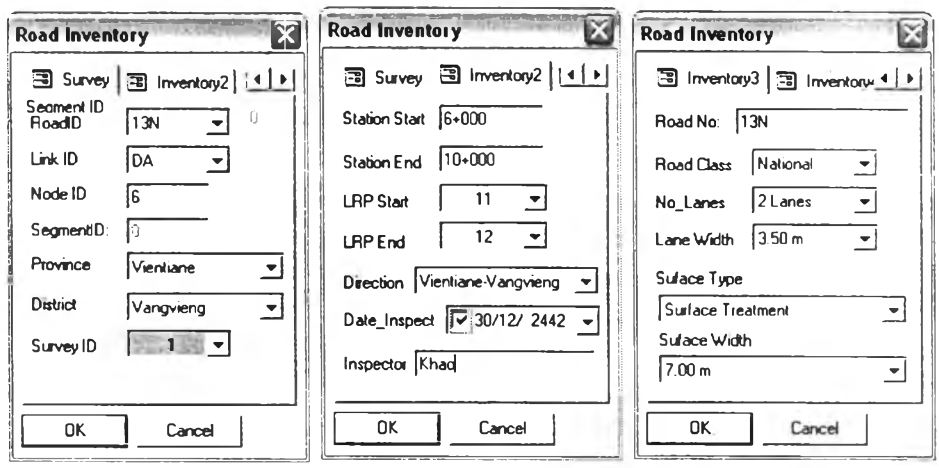


Figure3.5 Illustratation of Road Inventory Data Entry

3.4.4 Form Controls

The various kinds of data and their entry design on each field are defined by the use of the different controls available in ArcPad Studio. The control help define look up tables by the use of combo box or the list box. Database files have been created for the look up tables to be linked to the combo box for use as popup list in the field. However, these two controls do not necessarily limit one to the list not unless specified. One has a chance to input new classes arising from observations in the field. One the other hand, limitation can be applied where only a certain range of terminology is to be applied, thus applying consistency checks. An example is where one would want to stick to the seven general function of roadway (Figure3.4). Other types of controls are the label, date, and checkboxes. The checkboxes are used for inspection type of fields.

3.5 Data Transfer

Data is exchanged between mobile device and desktop computer by establishing a link between them. The primary software for establishing the link is the ActiveSync, which serves the purpose of file management, file backup and program installation. After create a serial connection on handheld computer, the ActiveSync connection will automatically establish a link to desktop and data can be copied and pasted from one folder to the other.

3.6 Base Map

A base map for mapping elements at roadway inventory can be either a base map with administrative boundaries or geo-coded imagery. The boundaries of roadway are mapped using digital versions of the center line base map created in the office. The system support usage of a geo-coded image, which has the same coordinates system as the new layer to be edited. To maintain the geo-reference of the images, use ArcPad extension tools in Arcview. The image is exported to ArcPad and saved as GeoPEG file, which is a compressed format. The study of roadway inventory can be divided into several fixed length segmentations and screen shots created for each segment. One will be load the screen shots for the particular part being mapped for that day. The vector layer is overlain on the base map image screen shots during data collection in order to match polyline with fixed length segmentation on the ground.