Transportation Asset Management:

The Use of GIS to Create a Heavy Vehicle (Bus) Index for the NYC LION File

By

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Abstract

The New York City Department of Transportation seeks to improve its street maintenance program by using innovative information systems technology to improve scheduling of proactive maintenance. This research looks into how Transportation Asset Management (TAM) via a preventive maintenance strategy can improve roadway management. A key component of TAM is the establishment of an information system. This thesis describes the theory and methods used in establishing a frequency based index for scheduling street maintenance for heavy vehicles (buses), as a preventive maintenance tool. It synthesizes the research results, provides supporting maps and graphs, and presents an instruction guide for implementing a frequency-based index.

Chapter 1 Introduction

The New York City Transit system carries over one hundred and fourteen million people annually through a mix of local and express bus service provided by seven private, franchised bus companies (NYCDOT 2004). The Department of Transportation is responsible for the roadways on which the buses travel, and roadway pavement maintenance is a key function. Currently, NYCDOT prioritizes maintenance and rehabilitation work based on functional classifications of streets – Primary, Secondary or Local Street -- as well as based on transit complaints filed by private citizens, community boards, elected officials, and DOT staff. However, in light of new information technology, changes in accounting requirements, and budget challenges, NYCDOT wishes to improve on its current maintenance approach by creating a Heavy Duty Vehicle Index for the NYC LION File (Street centerlines).

This research looks into the concept of pavement management, a subsystem of Transportation Asset Management. It focuses on a preventive maintenance approach in the management of transportation infrastructure in New York City. Preventive maintenance involves a scheduled and planned program of surface treatments on existing roadways before they deteriorate to a point where reconstruction and rehabilitation activity are necessary. NYCDOT's goal is to preserve and extend the service life of roadways and maintain roadways at an established level. Since wear and tear on the roadways by heavy vehicles is a major concern, the Department desires an accurate index or indicator that will aid in scheduling maintenance on roadways traversed by heavy vehicles.

The research goal was to develop an Asset Management tool consistent with preventive maintenance methods that would enable NYCDOT to set up a proactive street maintenance schedule. The design objective involved data maintenance, a challenge that entails linking data from disparate sources and integrating them by some common parameter. A related concern was the need to create a mechanism for future updates and upgrades from a variety of ever-changing data sources. A relational database model was used to execute certain management tasks, such as managing, archiving, manipulating, retrieving, and housing the data. The index is a composite index that is a simple accumulation of scores assigned to individual indicators such as pavement width, pavement type, bus frequency, and truck type. Each indicator is scaled and scored according to its internal response, which describes individual characteristics within each parameter.

This research is presented in five chapters. Chapter 1 gives an introduction to the topic. Chapter 2 provides a review of the literature on asset management concepts, definitions, historical development, and various asset management approaches in other transportation departments. Chapter 3 has three sections: the first describes the data used, the second describes methods and procedures, and the third describes in detail how the research was carried out. Discussion and results are found in Chapter 4, followed by concluding remarks in Chapter 5.

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Chapter 2 Literature Review

Asset management is practiced in the private sector and has recently been introduced and implemented in the public sector. Transportation Asset Management (TAM) and pavement management practices are business methodologies that assist managers to organize and strategize planning and implementation of goals and objectives through the use of economic, accounting, and engineering analytical tools. This literature review defines the emerging concept of TAM, discusses changes in TAM paradigms and approaches, and highlights the factors that have influenced its general acceptance and implementation. The chapter ends with a description of pavement methodologies and explains pavement practices of three State Departments of Transportation.

Transportation Asset Management is a relatively new terminology that came into use during the mid-90s (Switzer & McNeil, 2004). Its application in the private sector is well advanced and fully integrated into private business practices. TAM was seen as a better alternative to the other management approaches it replaced, such as Zero-based budgeting (ZBB), Management-by-Objectives (MBO), Total Quality Management (TQM), Business Process Reengineering (BPR), and in particular Infrastructural Science.

While there are competing definitions of TAM, they all stress the need for efficient management of physical assets, using sound decision-making tools. The American Public Works Association Asset Management Task Force has defined it as *"…a methodology needed by those who are responsible for efficiently allocating generally insufficient funds amongst valid and competing needs"* (Asset Management Primer, p. 8).The above definition focuses on efficient use of resources, or allocation decisions. Another slightly different definition emphasizes asset performance as it applies to the provision of extended benefits for the community. Here, asset management is defined as

"...a comprehensive and structured approach to the long-term management of assets as tools for the efficient delivery of community benefits" (Strategy for Improving Asset Management Practice, AUSTROADS, 1997, p. 4), and includes extended benefits such as accessibility, mobility, economic development, and social and environmental justice. Still others like the Organization for European Cooperation and Development Working Group, Asset Management System, Project Description, 1999, assert that

> *"…asset management goes beyond the traditional management practice of examining singular systems within the road networks, i.e., pavements, bridges, etc., and looks at the universal system of a network of roads and all of its components to allow comprehensive management of limited resources. Through proper asset management, government can improve program and infrastructure quality, increase information accessibility and use, enhance and sharpen decision-making, make more effective investments and decrease overall costs, including the social and economic impacts of road crashes"* (Asset Management Primer, p. 8)

The above definition views the concept of asset management as a holistic economic, environmental, and social process, directed toward roadways. A more complex and comprehensive definition from a Blueprint for Developing and Implementing as Asset Management System, by the Asset management Task force, New York State Department of Transportation, April 22, 1998, defines asset management as a

> *"…systematic process of operating, maintaining, and upgrading transportation assets cost-effectively. ……….. Asset management systems are goal driven and, like the traditional planning process, include components for data collection, strategy evaluation, program development, and feedback. The asset management model explicitly addresses integration of decisions made across all program areas. Its purpose is simple—to maximize benefits of a transportation program to its*

customers and users, based on well-defined goals and with available resources." (Asset Management Primer, p. 8)

This definition emphasizes analysis of transportation assets at a network level rather than at the level of a single system and advocates an interdisciplinary approach to solving transportation infrastructure problems.

A simple definition - "*systematic process of maintaining, upgrading, and operating physical assets cost effectivel*y"[1] is widely accepted. Generally, the asset management concept simply represents a shift in traditional management practices to those of a private sector business model, based on a decision making paradigm that is holistic, objective and highly driven by the principle of maximum return on investments. The business model used relies heavily on economic, social, political and environmental factors to make sound decision about transportation infrastructure development.

2.1 Geographic Information System and Transportation Asset Management

The use of geographic information systems (GIS) and other spatial technology has long been in practice in planning and managing transportation assets. Its principal applications are in the areas of data collection, integration, management, cleaning, dissemination, map generation, and spatial analysis. Some state transportation agencies are averse to its use, despite its usefulness as a tool. But all this has changed since the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and General Accounting Standards Board GASB Statement 34 Regulation. While ISTEA mandated that recipients of federal funding develop and establish information management systems integrated with other transportation subsystems, Statement 34 under the General

[1] Definition used be ASSHTO and FHWA and credited to Commissioner Karen Miller, Boone County, Missouri during the Fourth TRANSPORATATION ASSET MANAGEMENT Workshop 2002

Accounting Principles required public agencies to report their assets in their Comprehensive Annual Financial Report (CAFR).

GIS brings to fruition the immense and extensive data needs required during asset inventory. There are a variety of GIS platforms with the capabilities to collate and integrate information from disparate sources, which are sometimes located within and external to the department concerned. Sources may include but are not to limited satellites, spreadsheets (digital formats), legacy maps, and aerial photographs (hardcopy formats). Such voluminous data requires a database management system with the ability to house and integrate these disparate datasets. And since transportation facilities have an explicit spatial relationship, transportation managers will benefit from the use of GIS.

In addition to their data collection and integration abilities, GIS and other spatial technologies are also suitable for analysis and display of information. Digital maps can show and predict future road conditions, required treatment levels, or maintenance schedules, along with charts and graphs showing cost and benefit analyses of various programs. Spatial analysis tools are important for decision support systems that will help managers better allocate resources.

2.2 Pavement Management Systems (PMS)

The Intermodal Surface Transportation Efficiency Act (ISTEA 1991) originally mandated recipients of federal transportation funding to implement a variety of transportation management system - Bridges, Pavements, Safety, Traffic Congestion, Public Transportation and Inter-modal Transportation. Each of these subsystems is integral to the entire transportation asset management process. The oldest of these systems is the pavement management system. Pavement management began in earnest with AASHO road tests from 1956 to 1960, with the goal of creating a universal application for describing pavement condition. Since then pavement systems have gradually evolved with increasing complexity and understanding of pavement performance. One process fostering this position is the insistence of transport managers' implementation of a "silos" system that has undergone the necessary business processes required to implement the system; rather than a complete asset management system that will be prohibitively costly (Falls & Tighe 2004).

The concept of pavement management conjures some uncertainties in definition as there always are when exploring new concepts but a working definition developed during the National Workshop on Pavement Management 1980 and used by the Federal Highway Authority (FHWA) defines it "as a system which involves the identification of optimum strategies at various management levels and maintains pavement at an adequate level of serviceability. These include, but are not limited to, systemic procedures for scheduling maintenance and rehabilitation activities based in optimization of benefits and minimization of costs".

Others describe it as "*a programming tool used to collect and monitor information on current pavement condition, forecast future condition and evaluate and prioritize alternative reconstruction, rehabilitation and maintenance strategies to a achieve a 'steady state' of system preservation at a predetermined level of performance* (e.g. a goal)"[2]. Although both definitions emphasize maintenance of pavement surfaces at an established level, they deviate in their approach. While the former uses a strategic system approach that maximizes outputs and minimizes inputs, the latter views pavement management as a management tool that relates to economic and engineering principles.

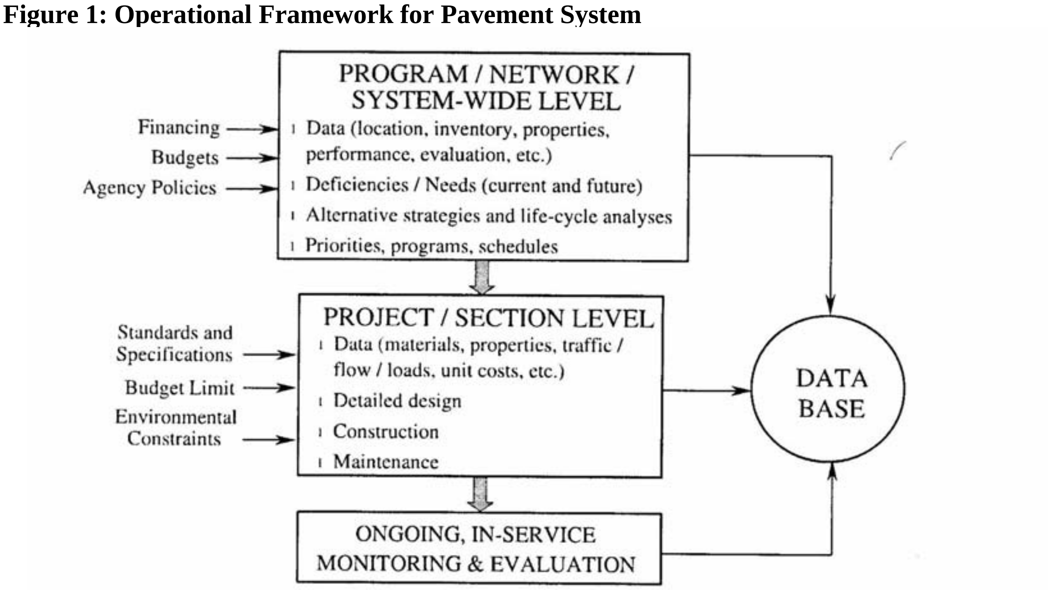
[2] USDOT Asset Management Primer 1999

What is important to know is that pavement management systems consist of a variety of planning, economic, and engineering functions that generally involve tracking and rating the current pavement conditions, forecasting future network pavement conditions, estimating costs associated with different pavement rehabilitation strategies, and defining what long-term investment level is required for maintenance at an established level.

The development of pavement management systems is centered on three principle components: data collection and management; analysis, and a feedback process. The data component involves inventoried information and the supporting hardware and software components that will hold information about the pavement's physical condition - faulting, rutting, cracking, potholes; pavement material, history, traffic load (LOS - Level of Service), pavement grade, roadway curvature, and gradient. These data aid in calculating the service life of the pavement and other indices that rate the pavement condition.

According to Falls & Tighe (2004) and Haas, Hudson, and Zaniewski (1994), pavement management systems operate in three categorical frameworks or levels:

Figure 1: Operational Framework for Pavement System



Source: Falls & Tighe 2004

network, project, and ongoing evaluation. This is illustrated in Figure 1. PMS analysis applications occur at the network level and the project level. The network level analysis takes a holistic view of the entire pavement system. It supports planning and programming decisions by optimizing and prioritizing projects based on cost–benefit analysis, identifying appropriate maintenance and rehabilitation projects, conducting network needs analysis, and assessing impacts of alternative funding decisions. It generally focuses on developing a multi-year program for rehabilitation, reconstruction, and maintenance projects.

At the project level, a detailed workflow of designs and construction and maintenance schedules is developed with a short to medium term planning range. Efforts are focused on selecting final alternatives to plans, projects designs, and viable repair strategies based on engineering and economic expedience. The benefit that accrues at this level includes innovation in building designs, materials, and methods aimed at decreasing construction time. Benefits that accrue at the network level for both the agency and the road users include reduction in cost, improved decision-making as a result of long-term planning, and smoother roads. The final component – On-going evaluation, provides an annual evaluation and a feedback mechanism for the pavement management system.

2.3 Pavement Management Approaches

2.3.1 Deferred Maintenance, Preservation and Preventive Maintenance

The development of transportation infrastructure in the United States beginning from the Eisenhower administration witnessed massive increases in mobility, economic stimulus, and population decentralization. Various legislative and fiscal policies increased -federal funding and investment decisions, favored capacity expansion and new construction over maintenance and rehabilitative work. This set the tone toward the development of a deferred maintenance culture that caused the deterioration of transportation infrastructure over the past twenty to thirty years.

The general approach to maintenance and rehabilitation was planning, programming, and monitoring of projects under a “Worst First” policy. The traditional approach to PMS, in terms of resource allocation, was tactical, concentrating only on immediate conditions rather then strategic and systematic concerns. A worst-first mentality ensured that maintenance was deferred to some later period. Deferred maintenance is simply a postponement of maintenance and replacement activities on capital assets. Deferred maintenance practices, especially during recessionary times, has had negative long-term effects on roadways and other capital management assets, leading to continual asset deterioration, increased replacement costs, and safety hazards to users.

In recognition of the continual deterioration of infrastructural assets, Congress enacted laws (3R and 4R) in pursuit of resurfacing, restoration, replacement, and rehabilitation activities. Over the past decade maintenance philosophies have shifted from being of a do-nothing and reactive nature to more of a proactive stance on pavement preservation. As the asset management concept gains more acceptance among transportation planners, technical innovation in computers and analytical tools develop, improvements in automated data collection and testing equipment advances, and as design procedure progresses, investment decisions will increasingly be focused on asset preservation.

Asset preservation is a program focused on activities undertaken to provide and maintain serviceable roadways. Infrastructural preservation encompasses rehabilitation, reconstruction, and preventive maintenance activities with a goal of cost-effective and efficient improvements in asset performance, as measured by ride quality, safety, and service life. It is a concept gradually gaining acceptance with agencies, marking a departure from traditional, more reactive approaches to maintenance. Preservation, through preventive maintenance, seeks to cost effectively reduce deficiencies in roadways before they degrade beyond their designed service life.

2.3.2 Preventive Maintenance

There are varying definitions used to describe preventive maintenance. Some describe the concept in fairly broad terms while others in rather short but conclusive manner. The leading definition used by the American Association of State Highway and Traffic Officials (ASSHTO) defines preventive maintenance as "…… *the planned strategy of cost effective treatments to an existing roadway system and its appurtenances that preserve the system, retards future deterioration, and maintains or improves the functional conditions of the system without increasing structural capacity*"(Capital Preventive Maintenance 2004, p17).

The Federal Highway Authority (FHWA) in its Asset Management Prime defines preventive maintenance *"as a systematic process of applying a series of preventive maintenance treatments over the life of the pavement to maintain a good condition, extend pavement life, and minimize life-cycle costs"*(Asset Primer 2001, p7). The first two definitions are somewhat similar, in that they highlight the preventive aspect of the strategy and cost-saving goals. They deviate in that ASSHTO emphasizes preventive maintenance with the possibility or goal of reducing the need for future infrastructure expansion while the later emphasizes preventive maintenance with the capability of reducing maintenance and rehabilitation costs altogether. The ASSHTO definition is somewhat optimistic about the ability of preventive maintenance to preserve assets. A more narrow definition by O'Brien (1989) suggests that a preventive maintenance program will reduce the need for further routine maintenance. He defines preventive maintenance as "*.a program strategy intended to arrest light deterioration, retard progressive failure, and reduce the need for routine maintenance and service activities*."(Carroll et al., 2004, p. 18)

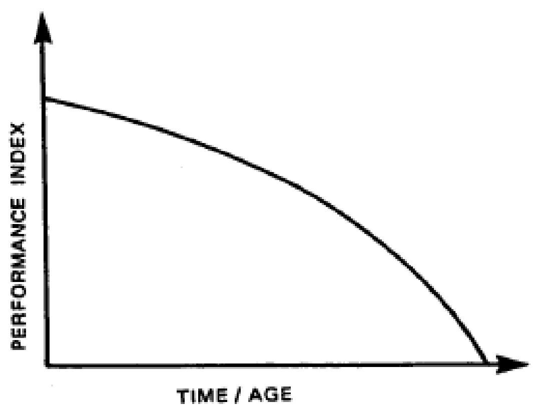
The lack of a well-defined concept of preventive maintenance presents a significant barrier to the implementation of preventive maintenance as an asset management tool. According to Carroll et al (2004), any proposed definition should emphasize the cost-effective benefits, the potential for expanding the life of infrastructural assets, and set appropriate benchmarks to measure asset performance. They define preventive maintenance as "… *a planned program of cost-effective treatments to existing roadway systems and appurtenances that functions to limit deterioration, retard progressive failures, reduces the amount of routine maintenance and other service activities required to maintain the functional conditions of the system."* (Carroll et al., 2004, p. 18) This definition integrates preventive maintenance goals with asset performance measures and stresses the importance of preventive maintenance as a means to prolong replacement of assets.

2.4 Pavement Performance

Newly constructed pavement surfaces are designed to provide excellent performance. Pavement performance should reflect a safe and smooth ride to the traveling public, among other things. Unfortunately, pavement surfaces start to deteriorate after construction ends and the road opens to the public. The rate of deterioration increases with usage, which include continual loading due to vehicular traffic, with age, time, and varying environmental conditions such as oxidation of asphalt, repeated freezing and thawing. Along with such deterioration comes a decrease in the service level until the roadway finally becomes unusable.

Maintenance and rehabilitative work are needed to preserve the level of service and reduce further deterioration. The longer a pavement remains without rehabilitation or maintenance, the greater its rate of deterioration and the dollar amount spent for rehabilitation. This is easily represented by the pavement performance graph in Figure 2. A performance index is used to assess the quality and condition of transportation infrastructure as it deteriorates with time, usage, and aging.

Figure: 2 Pavement Performance Graph.

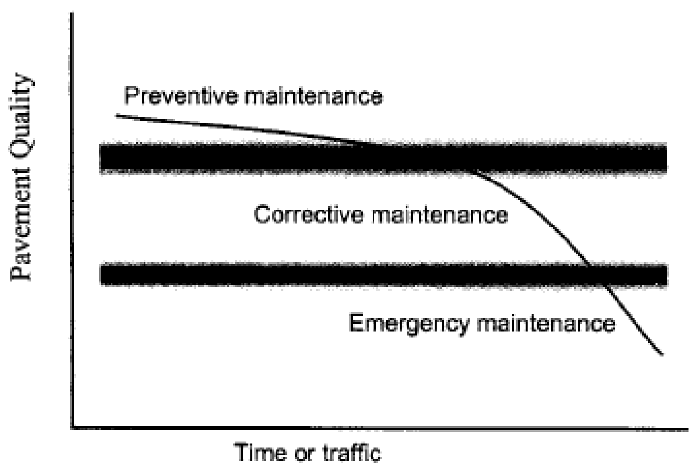


Source: Capital Preventive Management Project 03 – 01 MRUTCCE

Here, pavement performance is measured in an index called the Pavement Condition Index (PCI) or Pavement Condition Serviceability (PCS). While the PCI scale ranges from zero for poor pavement condition to 100 for excellent road condition, the PCS ranges from zero for very poor pavement to 5 for pavement in excellent condition. Usually plotted as a linear or a curved line, a graph is obtained through a regression analysis of the actual condition-time data for a pavement section.

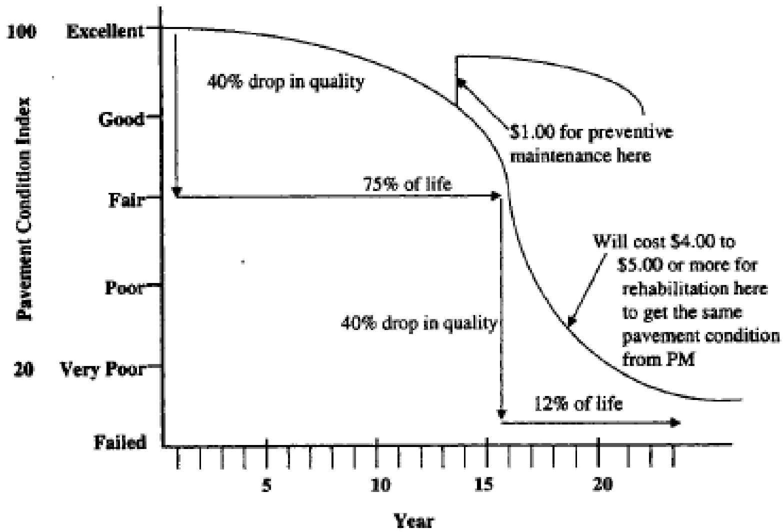
Thus, preventive maintenance tends to arrest minor deterioration before the need for more aggressive and costly maintenance measures, such as reactive and emergency measures. Currently the DOT uses a reactive approach to maintenance and this has been shown to be costly and time-consuming. Figures 3, 4 and 5 illustrate the benefits of a comprehensive program for the timely application of maintenance measures. It reveals that it requires only $1.00 to maintain the performance level of a pavement using timely preventive maintenance measures. This represents a savings of $3.00 to $4.00 for future corrective maintenance. Based on this research, some have suggested (Carroll et al, 2004) that funding be channeled toward preventive treatment at the right time as opposed to being channeled toward reactive (corrective) maintenance.

Figure: 3 Conceptual Performance of Pavement Maintenance



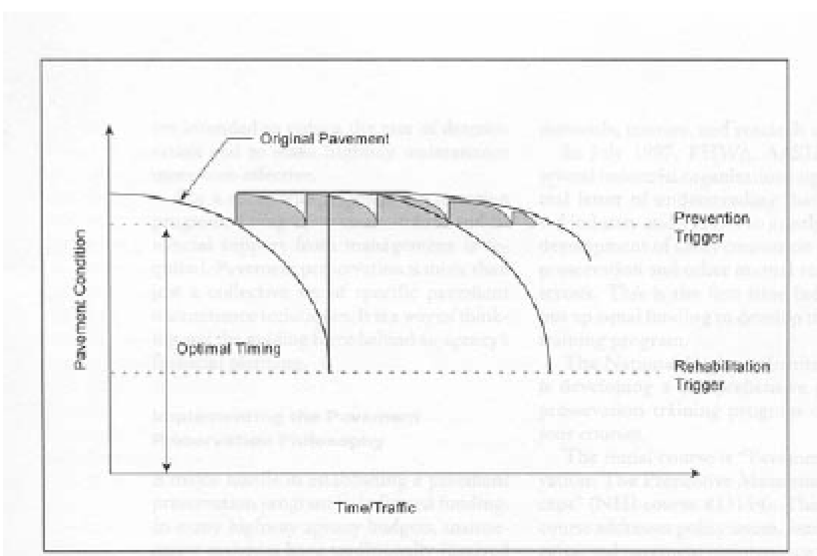
Source: Capital Preventive Management Project 03 – 01 MRUTCCE

Figure: 4 Typical Variation in pavement Condition as a Function of Time



Source: Capital Preventive Management Project 03 – 01 MRUTCCE

Figure: 5 Optimal Timing of Pavement Treatment Applications.



Source: Capital Preventive Management Project 03 – 01 MRUTCCE

2.5 Pavement Management System: The State Approach

2.5.1 The Michigan State DOT

MDOT focuses on short and long-term pavement strategies. Although the Michigan DOT uses a PMS that is not fully operational, it does require a series of engineering and planning functions to plan evaluate, present, and forecast future pavement conditions through the most cost-effective means.

MDOT evaluates pavement in two ways. The first is an annual rating system called sufficiency rating. It is a subjective approach also called *"windshield survey"*[3] that gives an excellent sense of what road users experience on the road network. This rates streets on a scale of one to five with one being the best condition. Ratings are based on the observed amount and severity of distress (cracking, faulting, wheel tracking, and patching). The second involves a bi-annual rating system called PMS rating. A distress index is computed from data (measurement of rutting, friction, ride quality, cracking, raveling, flushing, spalling[4] and road curvature) collected from detailed inspection of pavement conditions, in order to calculate the remaining service life (RSL). The RSL measures the years left before reconstruction or major rehabilitation is required for the road. These rating systems are obtained through a periodic survey of MDOT's 13,000 street centerlines and the national highway system (MDOT 2001).

MDOT uses a three type approach to Pavement Preservation Management that includes Reconstruction and Rehabilitation (R&R), Capital Preventive Maintenance (CPM), and Reactive Maintenance. The use of any of these approaches depends on the Remaining Service Life (RSL) of the pavement. Pavement with RSL of two years

[3] "Windshield survey" represent survey conducted by a staff from a drive by perspective usually though the window of a car.
[4] Chipping away of surface due to extreme temperatures

requires R&R while pavement with RSL greater than two years requires a CPM approach. Based on cost and savings per network mileage, CPM is relatively inexpensive when compared to R&R (MDOT 2001). It is typically performed on pavement surfaces with minor distress and can increase pavement performance and service life for more than five years. The costs are relatively cheaper than R&R. R&R operations involve a complete removal and replacement of the pavement's internal structure (base course and subgrade). R&R increases the service life of pavement to ten years. Reactive maintenance is only used to mitigate unforeseen circumstance needing urgent attention.

2.5.2 Oregon DOT Pavement Management System

The Oregon Department of Transportation conducts an annual pavement condition survey of it 8,200 mile road network (Brophy 1998). The information obtained provides the department with the current health of the state's highway system that aids in determining funding needs and tracking pavement rehabilitation work. Two distinct pavement rating systems are employed to gather pavement condition data. The first is an objective rating system used by the National Highway System. Here information usually obtained from the outer lane roadbed (truck lane) is collected to calculate index values. Because the outer roadbeds are the most severely distressed lanes, they are used to categorize the general condition of the highways. The indices used to rate the pavement include rut, patch, raveling, and fatigue.

Once the index is developed they are then used to determine the pavement conditions and the type of maintenance or rehabilitative work to be performed. Table 1 describes the rating value:

Table 1: Index Category

Overall Section Index	Condition Category
99-100	Very Good
76-98	Good
46-75	Fair
11-45	Poor
0-10	Very Poor

Source: Oregon Department of Transportation October 1998

The Good-Fair-Poor rating method is used to assign rating scores for state jurisdiction highways (non NHS highways). The method as shown in Table 2 has been in operation since 1970 and is conducted by a two man crew. Visual inspections are made while driving along the pavement surface. Rating scores range from one to five based on the ride quality and surface distress. Surface distresses are obtained by assigning a single condition on a road segment based on its observed distress and are recorded in a tenth of a point. Although no distress data are recorded, its rating scores are determined by specific criteria. The condition surveys are usually conducted in a span of five months (Brophy 1998).

Table 2: Good-Fair-Poor (GFP) Condition

Overall Section	Condition Category
1.0-1.9	Very Good
2.0-2.9	Good
3.0-3.9	Fair
4.0-4.9	Poor
5.0	Very Poor

Source: Oregon Department of Transportation October 1998

2.5.3 California DOT Pavement Management System

The California Department of Transportation conducts an annual pavement condition survey (PSC) of it 15,000 centerline and 49,000 lane miles (California State of the Pavement Report 2003). Their pavement management systems began in the 1970s and have grown to be one of the most advanced pavement systems in the country. A rating crew conducts visual inspections on pavement surfaces and in addition, a van equipped with laser sensors collects the surface profile. The information obtained (structural deficiencies or ride quality) provides detailed inventory, identifies project needs, prioritizes pavement distress, and summarizes the condition of the system (California State of the Pavement Report 2003). See Table 3.

Table 3: Pavement Deficiency Classification

Deficiency	2002			2003		
	Lane Miles	% of Deficiency	% of System	Lane Miles	% of Deficiency	% of System
Major Structural Deficiency	7,670	68%	16%	8,938	76%	18%
Minor Structural Deficiency	2,976	26%	%	2,410	20%	5%
Poor Ride Quality	710	6%	%	476	4%	1%
Total	11,356	100%	%	11,824	100%	24%
Total System Lane Miles	49,249			49,319		

Source: California State of the Pavement Report 2003

The Department also uses a ride quality scale that determines the performance measurement of the state's pavement surface. The measuring scale is based on a standard scale called the International Roughness Index. The scale measures the up and down movement as a vehicle traverses a pavement. Five inches per mile is considered a smooth road while any value greater than 175 inches per mile is considered a rough road. Table 4 shows a typical California ride quality.

Table 4: California Ride Quality

Condition Category	International Roughness Index (IRI)
Excellent	0 - 75
Good	76 - 125
Fair	126 - 175
Poor	176 - 200
Unacceptable	200 +

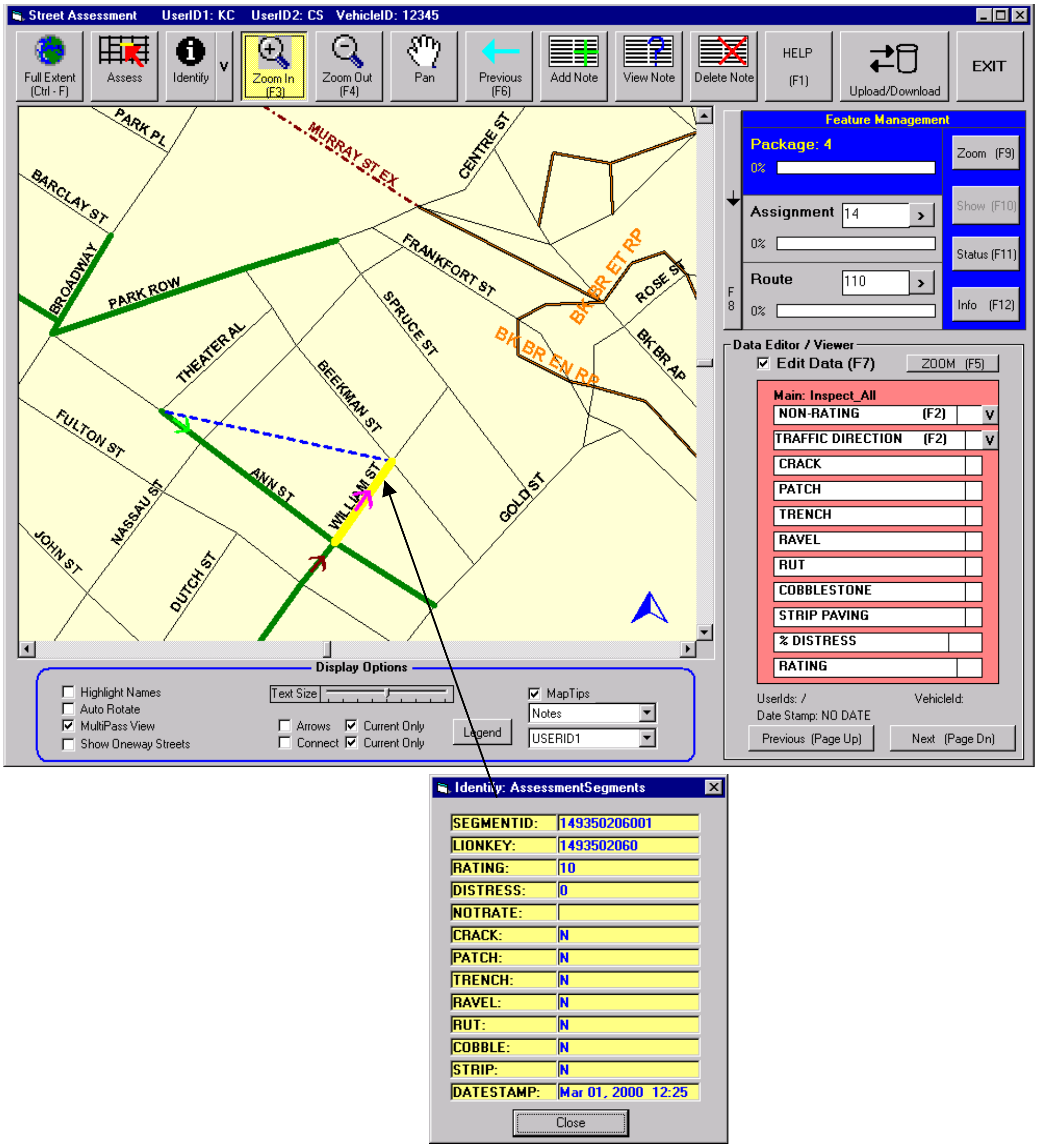
Source: California State of the Pavement Report 2003

2.5.4 NYC DOT Pavement Management System

The New York City Department of Transportation's pavement management system is not as advanced as the states discussed above. Like other states they have a well developed street assessment and data collection systems that are used to collect and transfer field data to a master assessment database. Assessment is mostly carried out through a windshield survey, where teams of assessors periodically pass through each street for evaluation. The process is designed such that each street condition is recorded to the street segment's unique identifier. The street identifier contains attributes such as the street name, type direction, and From and To nodes.

The information obtained in the field is uploaded to a master database where each street segment is attributed with field values such as traffic direction, cracks, patches, trenches, ravel rating, and distress percentages. The data is then used to support a host of agency applications such as Street Smart. Street Smart is a mapping application used to query, map, and generate reports on street conditions throughout New York City. Figure 6 shows the Street Smart Interface.

Figure 6: Street Smart Interface



Source: NYCDOT Street Assessment Data Collection and Mapping Application 2002

The New York City Department of Transportation uses two types of rating systems: non-rating and rating. Both systems are based on the NYCDOT assessment guidelines. Once a non-rating code is selected no other assessment value can be entered.

Non-rating values are assigned to non-street segments or streets that do not exist (rail line/ boundary line). Under the rating system, street segments can be assigned a rating value ranging from 1 – 10. Each rating code should be consistent with the distress value (See Table 5).The distress rating depends on the type of surface defects, such as cracking, patches, trench, etc. A dialog box provides a space where an assessor can enter Yes or No for each type of distress seen on the surface during inspection (See Figure 6).

Chapter 3 DATA AND METHODOLOGY

The following chapter is divided in three sections. The first section describes the data and certain limitations associated with its use. The second section discusses in general terms different methods that can and have been used to implement a maintenance program. Finally the last section describes the techniques implemented in this study.

3.1 Data

This project required that several sources of information be acquired and integrated in order to enhance the ability of the New York City Department of Transportation to calendar a proactive maintenance schedule. The two primary data sources are the LION of Department of City Planning and Bus route of New York City Transit Authority.

3.1.2 Data Description

There are two types of data used in this project. The first is the Linear Integrated Ordered Network (LION) file. The LION is a schematic map that contains street centerlines, address ranges, street names and intersection identifiers. Street centerlines consist of lines or tics that combine to form routes and networks. The LION acts as the base map and frame to which all ancillary data (bus route name, headway) will be registered. The LION is projected on the New York Long Island State Plane Coordinate System (NAD83). The reference coordinates are in decimal degrees of longitude and latitude and their measurements are in feet. The accuracy of this base map will determine how the other data layers would look in relation to each other as well as your base map.

The LION suffers from several defects, including its lack of ancillary data and low level of accuracy. Spatial accuracy was not of primary concern in its creation. A limited set of control points were used to loosely fit the lines to the NAD83. The primary mapping goal of the LION is geocoding. Recent versions of the LION have improved its spatial accuracy, especially as it is being aligned to the more accurate aerial precision photograph from the New York City MAP (NYCMAP).

The second data type is the Bus route file provided by New York City Transit (NYCT). This file is a polyline layer containing attribute information for all buses (Metropolitan Transportation Authority (MTA) and seven other private bus companies) that travel on NYC streets. Its main function is purely cartographic and thus lacks topology that would have made it more useful for spatial analysis. The bus route data contain ancillary information such as bus route, operator type, and headways. The headway data   is used to create the index. The bus route has the same projection as the LION. The polyline layer was digitized by snapping or aligning the bus route to the 1996 NYCMAP centerline.

3.1.3 Data Projection And Alignment

Although both the LION and the Bus route data have the same NAD83 projection, their spatial accuracies differ slightly. The route data digitized by NYCT was snapped to the 1996 NYCMAP centerline and this appears to be more spatially accurate due to the use of aerial photography. NYCMAP are a representation of current street positions as they are seen from airplane. On the other hand the LION centerlines were mainly developed for geocoding application; spatial accuracy was not a priority.

Such spatial inaccuracies result in misalignment between the two datasets. The degree of distortion may be anywhere from 30 feet to 250 feet. The degree of misalignment varies over each borough, and is the smallest in Manhattan. Misalignment could lead to mismatching of both polyline features and their corresponding attributes.

3.2 Part I : Methodology

This section describes some general techniques for implementing a pavement maintenance system. It focuses on methods of spatial and data integration, and excludes discussion of data collection and inventory processes. Techniques such as conflation, dynamic segmentation, and spatial adjustment are explained together with the database system designed to store the data. This section also reviews applications of maintenance methodology to preventive maintenance. Lastly it describes the methods used to update the base map and develop a frequency based index, with an objective of preventive maintenance.

3.2.1 Spatial Integration

The discipline of geography observes entity occurrences and their physical distribution or patterns in space. Every instance of a phenomenon, be it a car, a building, pavements, and potholes; can be represented by their geographic coordinates and descriptive information. Each representation in association with others forms an inherent relationship – explicitly or implicitly, between or amongst objects due to their proximity and coincidence in time. In the same vein, transportation infrastructure can be spatially referenced and do exist in relationship with other objects. The ability to reference objects and exploit their relationships facilitates transportation planning, analysis, design, data management and integration. Spatial technology like a Geographic Information System is particularly appropriate for accomplishing these goals.

3.2.2 Linear Referencing VS Geographic Coordinates

A Linear Reference System is a one-dimensional referencing model used by most transportation agencies for facilities management. The system helps locate, place and position processes, objects and events on roadways based on a set of known points and distances on a network (NCHRP Report 506, 2003). It also provides a convenient way to associate attributes or events to locations or portions of a linear feature. Attributes are associated by using only one parameter usually known as the m value (measure) along a linear feature.

Current methods of linear referencing in use by some DOTs include the route number, milepost, offset and links, and node measures. There are differences in measurement techniques across various linear referencing methods, but all methods have in common identification of a known point, measurement from a known point and direction of measure. The type of reference method used affects the system's utility. This becomes an issue when integration occurs between systems using different referencing systems or location systems of varying accuracy.

3.3 Spatial Integration Techniques

Dynamic segmentation, conflation technology, and spatial adjustment are a few examples of spatial integration techniques. The best technique for extracting any relationship depends on software application and the nature of the problem. Some application link spatial and non-spatial attributes through the use of topological operators whereas others solve problems through network analysis.

3.3.1 Dynamic Segmentation

Dynamic segmentation is the process of transforming linearly referenced data (commonly called events) that is stored in a table, into a feature that can be displayed on a map. The segmentation process allows multiple sets of attributes to be associated with any portion of a linear feature. Linear features are modeled using routes and route events.

Each route and route event must have both a unique identifier and a measurement system and measured positioned along the linear feature.

A route is simply one or more linear features whose attributes can be defined and assigned using a unique identifier (Cadkin, 2002 p. 40). Route locations or events describe a discrete location on a section along a linear feature. Discrete or linear events which can be organized into tabular themes–pavement structure, conditional rating, etc, – are called route event tables. There are two types of events: point and linear route events. An event occurring at a discrete location, requiring only a single measure for referencing, is called a point event, e.g., potholes instances at Kilometer 6 on route I–95. An event that is referenced by two measured values–from and to along a linear feature–is called a linear event, e.g., pavement types located between kilometer 6 and kilometer 12 on 1–95.

The key to dynamic segmentation is that linear features are not actually segmented. Rather they are symbolized using thematic descriptive attributes, which describe some characteristics specific to each linear segment. The segmenting process is not static but occurs on the fly, hence the term dynamic. Transportation events stored in tables do not have feature classes such as geometric shapes. Their generation for mapping display occurs as needed and will change once their descriptive information or measured positions are different from the event table.

3.3.2 Conflation

Conflation is a technique used to update and enhance geographic data, by merging or conflating information from multiple vector datasets into one master dataset. Conflating usually supports the transfer of attributes from one data set of lower positional accuracy to a dataset of higher spatial accuracy and precision. It is a commonly used technique used in a variety of projects, ranging from upgrading land base maps and updating street centerlines, to managing utility companies' facilities. A variety of conflation software technologies – ESEA MapMerger, Digital Engineering Corporation ConfleX, and bd Systems GIS/T-conflate–are available in the market. Below is a discussion of ESEA MapMerger's modus operandus.

The MapMerger automated conflation system works as an extension within ESRI ArcGIS. Conflation usually begins with a pre-processing stage where unwanted attributes or features are cleaned to ensure data usability and similarity. Similarity ensures that the data are in compatible formats. In cases where the number of arcs to be conflated exceeds 50,000, it may be necessary to split the arcs into groups of 50,000. Such subdivision increases processing performance and speed of the conflation process. In MapMerger, the dataset is designated as either the target and source data depending on the transfer direction. The target layer is the layer with the best coordinates while the source layer is the layer with additional attributes.

The matching process goes through a series of match cycles to determine the best possible node and line match. Each match cycle has a match setting option that sets the geometry and match strategy. While the geometry setting determines the maximum separating distance vital for a match to occur between each candidate feature in both source and target data, the match strategy specifies some common field by which the matching will occur, thereby increasing the confidence of matching. Weighted values can be applied to assist identification of possible matches. At the end of each matching cycle, a displacement link is inserted to indicate all potential matches between source and target. The process continues iteratively until all possible associations have been found. The datasets may be rubber sheeted if need be before the attribute transfer process begins.

Once the node matching process ends, the line matching process can begin. The process is somewhat similar except that the matching process could become complex. This is especially the case where many linear associations exist– many to many, one to many and many to one. When relationships are complex, nodes and arcs may be added as needed to ensure that the features actually represent the real world. The software allows for manual matching and visual inspection of the automated matching process to verify the accuracy of each matching episode.

The attribute transfer process follows the matching of nodes and arcs. Selections are made as to the number, type and destination of transfer. A single attribute or a combination of attributes can be chosen for the transfer. After conflation, a series of validation checks is performed to assess the accuracy of results. The final map product is converted from MapMerger internal format to a geodatabase format for use in ArcMap.

3.3.3 Spatial Adjustment

Another merging and updating technique is the Spatial Adjustment tool provided in ESRI ArcGIS software. The adjustment tool enables the user to transform, rubbersheet, and edgematch objects in a map. The objective of these tools is to maximize accuracy and increase the potential for attribute matching by registering the source and destination layer in close proximity. The operation is available only within an ArcMap Editor session and provides a variety of adjustment methods and tools, such as snapping, to enhance adjustments. Within the adjustment environment, an attribute transfer tool aids in the transfer of attributes between different objects. Attribution is only possible when matching common fields between two layers.

The spatial adjustment environment begins with some pre-processing procedures that make certain the data to be updated are cleaned. Transformation is one such procedure that requires the conversion of different datasets into one common coordinate and measurement system. The ArcMap spatial adjustment tool supports three types of transformation functions: Affine, Similarity, and Projective. Each transformation interactively selects and insert control points on the source and destination source using a displacement link. The function creates a residual and root mean square (RMS) whose values determine the best-fit function or how well the transformation represents the true location. Standard practice requires a lower value of the residual and root mean error because they reflect the minimum difference between the source and destination control points.

Another pre-processing tool is rubbersheeting and edgematching. Rubbersheeting corrects geometric distortions in source maps that arise from the digitizing process by inserting a displacement link or control points to physically tack down and warp features to more accurate positions. Edgematching aligns and ensures that adjacent features extending across a two or more tile boundary sustain a correct match. While rubbersheeting is best for preserving straight lines within a layer, edgematching is useful for preserving edge accuracy.

3.4 Data Integration

Transport planning and management is a data intensive process that involves the gathering, sharing, retrieving and analysis of information from varying sources. Analysis and decision support systems are most effective when internal and external information exchanges are readily available and accessible. Sharing and exchange of disparate data is facilitated through a data integration process. Within a pavement management system (PMS), the data integration process is a comprehensive procedure involving the accumulation of information from road inventory, pavement structure and functional conditions, traffic (volume and weight), and maintenance and rehabilitation history. The data varies not only in their structure, but also in the standards and referencing methods used in their collection and storage; and in the business unit responsible for data gathering, recording and processing.

Data integration is the process of combining, linking or merging two or more data sets to facilitate data sharing, analysis, decision support, and overall information management activity in an organization. Integration improves information processing and decision making capabilities by organizing and merging disparate information into one easily accessible format or platform. The incentives for integration are improved accuracy, timeliness, availability and accessibility of the information collected. On a larger enterprise scale, the integration process begins with a needs analysis to understand the requirements of the organization, including the agency's business processes, structural characteristics, pre-existing data requirements and database systems, and workflow models. The next phase involves the selection and evaluation of alternative database architectures and various risk and cost assessments. Lastly the database design, data specifications, development, testing and system implementation ensure that the system works to specification. Integration occurs in two phases: the first phase determines the general database architecture while the second phase establishes detailed plans and methods of implementing the proposed database architecture.

3.4.1 Integration Approach

There are several approaches to data integration but the two most recommended approaches are fused and interoperable databases (Data Integration Prime 2001). The fused data approach requires a one-time integration of information from multiple sources, while the interoperable data approach involves a collection of separate databases connected through a computer network. Both approaches require and promote information sharing between the databases as the primary point of integration.

Within the fused environment, merged data exist in a centralized database that is a replica of the previous database. Replication simplifies the conversion process. It allows a merge of the different data structures and schema in each dataset into a new organized structure. This replication process is possible because a layer of software, middleware, is placed between the databases, facilitating data transfer between source and target databases. Once completed, the new database provides an enterprise view of all merged datasets with a common user interface.

The interoperable (also known as federate) approach promotes a single data view by linking numerous databases through a computer network. As in the fused approach, middleware is placed between all databases and the application that views the data. This approach maps each physical database to the virtual database model that reflects a federated view of the entire network. The view is distributive, facilitating multiple means of information access between dissimilar formats, data structures and transaction language.

Various transportation departments have used either of these alternatives. Maine DOT uses a geographically linked warehouse database called Transportation Information for Decision Enhanced (TIDE). The fused or warehouse approach has the advantage of simplicity, low cost, and data security. The simplicity of fusion has its advantages. The conversion of databases results in a single fused application within the new environment, simplifying infrastructure and maintenance needs. However, its major disincentives are that the data is generally static and viewing is possible only in readable formats. Highly compartmentalized environments would benefit from a federated approach because it would be preferable to run an agency wide maintenance program with access to several databases such as pavements and bridges (Data Integration Primer 2001).

In terms of cost, the federated approach is higher but the long term benefits are cost effective and other advantages such as information access through a network, local control, and preservation of legacy data are guaranteed. Another disincentive is that it requires rigorous procedures for database access and updates, and persistent changes to export protocols once the database needs to be rebuilt.

3.4.2 Database Design

Once the general database architecture has been selected, the next phase is selection of a database design model and a specific approach to database development. The database model is required regardless of the approach chosen. It is essential to ensuring database integrity and reliability throughout the life of the project design, along with standards and reference systems; metadata and data dictionary; computer communication requirements, software, hardware, staffing and data management requirements.

The data model determines the structure and configuration of the database. A variety of structures–flat file, hierarchical, network, relational, and objected-oriented models–have been developed and each has its advantages. The type of model chosen is determined by how information flows between different agency units. The database design also entails developing data standards and a set referencing method. Standards define the type of storage formats, SQL protocols, and transfer and export protocols.

3.5 Indexing Methods and Approaches

Engineering, economic and behavioral models are key considerations in designing and implementing a pavement index. A model enables the conversion of detailed data into distress information or indices (pavement condition rating, visual condition survey, or International Roughness index). Upon inception of a pavement management system most agencies adapt one of the pavement indicators or develop their own based on similar characteristics such as weather and climate conditions, geography, traffic, and soil amongst others (Falls & Tighe 2004). The following sections discuss various indicators (ride quality, roughness, distress index, dynamic loading index) used to determine pavement conditions.

Many pavement indicators utilize the smoothness parameter and its affects on ride quality. Road users and the owner agency view road smoothness as an important quality that makes for safe roads, lowers dynamic loading on pavement, extends the pavement's remaining life cycle, and decreases overall vehicle maintenance cost and fuel consumption cost. In addition, various research results and pavement design models by ASSHTO support the idea that smoother roads with higher serviceability ratings tend to last longer than rougher surfaces (NCHRP Web Doc1: Final Report 1997). Smoothness is given high priority during initial road construction. Most transportation agencies specify initial smoothness tolerance levels to ensure a uniform, planar surface profile. The parameter is also a means to gauge a contractor's workmanship and overall construction quality.

Roughness, or the absence of smoothness, is an important indicator that determines the ride quality and comfort of a pavement surface. The quality of a surface greatly affects vehicle speed, operating cost, wear and tear, and pavement performance. Rehabilitation activities are also determined by ride quality because a vast majority of highway users are sensitive to the quality of movement. Roughness is defined as the vertical accelerated movement felt from a passenger seat. It could also be defined as the summary of variation in surface profile that induces vibrations to the traversing vehicles and is defines over a length of the road (Sayers, 1990 p.106-111). The objective of the roughness indicator is to define a single parameter or a series of parameters that indicate characteristic roughness for a given stretch of roadway.

3.5.2 Roughness Index

Roughness indexes are based on measuring the surface characteristic over a road two dimensional profile. Profile measurements are obtained by gauging the elevation difference between relative location and some reference point, along an imaginary line on two wheel roadbed. The instrument used to gauge and produce a series of numbers that represent the surface is called Profilers. A number of roughness indicators exist and all have the same principle governing their application: a defined reference elevation, height relative to the reference and longitudinal distance. Once roughness information has been obtained from a profile measure, an algorithm equation extracts this information to obtain the desired index.

One of the earliest indices was the Mean Panel rating developed by the ASSHTO in the 1950s. The Mean panel rating was subjective because the rating criteria depended on the psychophysical principles and pre-instructions given to the panels of those characteristic to be evaluated. A scale from one to five was the standard range; with five representing a good road and one the worst. The rating system was statistically computed after a panel of pavement experts had traversed a given roadway. This result was an average of the mean panel rating called the Present Serviceability Rating (PSR) for that road segment.

The subjective nature of the mean panel and present serviceability rating lead to the development of an objective analysis called the Present Serviceability Index. It involved a regression analysis between the mean panel rating, distress and roughness indices that correlated users' opinion with measurements of road roughness, cracking, patching and rutting (NCHRP Web Doc1: Final Report 1997).

The three most common roughness indices are the International Roughness Index (IRI), Ride Number (RN), and Profiles Index (PI). The International Roughness Index developed by the World Bank is the most common of the three. It is a mathematical model whose calculation is based on the response of a quarter car model (one tire represented with a vertical spring, axe mass, tire, suspense and damper) as it relates to a passenger car. The simulation model divides vertical vibration (at a fixed speed of 80 km per hour) by the distance traversed to obtain an index. The International Roughness Index and the Profile Index are similar with the exception of the instruments used (profilograph) and the ratios between the masses, spring constants and damping coefficient (Awasthi, G. et al 2003).

3.5.3 Distress Index

A variety of distress indices is used to identify, forecast and prioritize existing and future pavement conditions and rehabilitation work. This is accomplished through a visual inspection of the pavement surfaces. The Michigan Department of Transportation quantifies its pavement distress using an index called Surface Rating (SR) (MDOT 2003). Pavement distresses are those deformities visible on the pavement surface such as cracking – alligator cracking, multiple cracking, D-Cracked Panels, rutting, raveling and weathering, potholes, patched panels, and cracked panel longitudinal joint distress. The surface is rated using a series of cameras and computers to record and compute data. The resulting analyses produce a distress rating value for that particular road section.

The rating value for a give road length varies according to the preferences of individual state highway agencies, but typically ranges between 0 – 5 or 0 – 10. Higher values indicate no distress, as in a newly constructed highway, whereas lower values indicate the converse. Generally, the distress index contains numeric values with descriptive information that corresponds to each rating value. The index values are a function of distress type, distress severity and distress quantity. Table 2 shows an example of a numeric rating and the descriptors.

3.5.4 Dynamic Loading Index

The dynamic loading index is an indicator that measures the repetitive traffic loading or continuous bounce of vehicle suspensions as they can distress and increase roughness over a section of pavement surface. The concept of dynamic loading looks at the relationship and interaction between truck/heavy loading, surface roughness, and pavement damage to plan better pavement preventive maintenance. The concept is based on the premise that roadway roughness leads to a cycle of increasing deterioration with increasing roughness severity.

The goal of the index is to prevent this cycle of deterioration by performing preventive maintenance before the road becomes too rough. This is done by locating a hot spot of roughness that marks the threshold where the deterioration rate rapidly increases. Identifying a threshold enables the scheduling of maintenance and rehabilitation activity to extend pavement life and continued smoothness. (C&T Research Records MDOT 2002).

An important component of roughness is the frequency at which roughness is measured. Most roughness indicators (International Roughness Index and Ride Quality) represent roughness by the sensation felt by a passenger in a moving vehicle. This manner of representation produces a broad frequency response range with reduced sensitivity. The frequency response range is used in understanding profile analysis and enables users to describe the response behavior of the system (Sayers W.M. & Karamihas M. S. 1998).

3.6 Part II: Methodology

The research methodology had two dimensions: the development of an index had a spatial and management component as well as an engineering and mathematical component. The former involved data integration; which presented the challenge of linking and merging data from disparate sources by some common parameter. There was also the need to create a mechanism for future data maintenance from these disparate, ever changing sources. A relational database model was created to execute management tasks such as archiving, manipulating, and retrieving data. The latter component involved developing an indexing application for scheduling maintenance. The index was to be determined by the number of buses per hour per route on each segment. The index was to establish a certain threshold or upper limit at which maintenance would be required.

3.7 Spatial Component

The goal of the spatial component was to integrate the ancillary data (NYCT bus route) with the base map (NYCDOT LION), to create an improved dataset that would enhance the decision support system at the New York City Department of Transportation. ESRI (Environmental Systems Research Institute) ArcGIS 8.3/9.0 software and Microsoft Access were the working environment for the spatial component.

The introduction of the data into ArcGIS 8.3/9.0 prompted the need to ensure data compatibility within the new environment. This required a simple conversion of shape files and tables to feature classes and object classes in a geodatabase. A feature class is a conceptual representation of a geographic feature. Object classes are the non-spatial component in the database. The bus route (NYCT) attribute table contains 908 records, which represent the total number of New York City bus routes that traverse the city streets. Each record is split to create 908 linear feature classes. Each new linear feature class represented a record instance containing pertinent information of the bus route, unique identifier, route name and route number (e.g., ID 39, M66, and M66_W, respectively).

Once the data organization and compatibility issue was resolved, a spatial join was used to append each bus route feature class to the LION feature class. A spatial join is a spatial analysis technique in which the attributes of features in two different layers are joined together based on the relative locations of the features. The join technique exploits the spatial coincidence between two layers, by appending the attributes of the bus route layer to the LION layer. The use of a spatial join was necessary because neither shared a common attribute field geodatabase format nor unique identifier.

Each bus route feature was adjoined to the LION data by the selected join option. The join option allows you to summarizing the data in your table before you join it to a layer. When you summarize a table, Arc Map creates a new table containing summary statistics - count, average, sum, minimum, and maximum. The new information can be used to symbolize, label, or query the layer's features based on their values for the summary statistics.

The product of the join provided a more permanent association between the two layers because it created a new layer containing both sets of attributes. All newly created layers were named and saved by their route name, because the selected join option excluded all string attribute fields or alphanumeric values,. For instance, a bus with ID 39 would have a layer name that corresponded to its route name, M66_W.

After a series of edits to ensure quality control, each feature class attribute was imported into Microsoft Access as a table. A union query was then performed (see Appendix B for sample query) on the tables to extract and aggregate information based on the segment ID and Bus ID attribute field. Each query was performed in batch within the individual boroughs, as Access only permitted a limited number of queries to be performed at an instance.

A relational database system was developed to manage the newly created data. A relational database is a method of structuring data as a collection of tables that are logically associated to each other by shared attributes. ESRI Arc View 8.3 personal geodatabase was selected to store all pertinent data. A geodatabase is an object-oriented model that provides certain functionalities – validation rules, relationships, and topological associations. These functions facilitate managing and maintaining the integrity of geographic data.

Relationships are association or link between two objects in a database. Relationships can exist between spatial objects (features in feature classes), nonspatial objects (rows in a table), or between spatial and nonspatial objects. They are usually stored in a relationship class. Each relationship formed has a primary and foreign key in the origin and destination layers, as well as certain cardinality. Cardinality characterizes the relationship by describing each associated event. Relationships can be either one-to-many, one-to-one, one-to-many, and many-to-many cardinalities. Each relationship maintained a virtual rather than a permanent association between the layers. This is especially important when the data is managed by different units and requires constant updates.

3.8 Indexing

The computation of an index application required the creation of a composite measure that summarized and rank-ordered several observations. Each individual summary indicator (pavement width, bus route frequency, truck type, and pavement structure type) forming the composite measure was scored and rated separately. Each measure within the composite was scaled such that it accounted for differences in intensity among attributes within the same variable that are usually obscured by the computation of the composite index. While the composite index was based on a score of 100, the individual scores were reported on a tenth of a point numeric rating. The rating depicted the relative condition within a general condition category and was further assigned a descriptive term indicative of its condition.

Certain assumptions were made to arrive at comprehensive bus route schedules. These assumptions ensured that all missing values were populated to obtain scheduling information (AM and PM) with acceptable accuracy. Each indicator (pavement width, bus route frequency) score was based on the standard deviation of their respective mean score. The composite index had a maximum value of 100 and was computed based on the assumption that each variable was equally weighted in affecting the outcome. Chapter Four discusses further the computation of the index.

Table 5: Distress and Rating Value

Rating	% Distress
1	76 – 100
2	76 – 100
3	50 – 75
4	25 – 49
5	25 – 49
6	10 – 24
7	5 – 0
8	1 – 4
9	0
10	0

Source: NYCDOT Street Assessment Data Collection and Mapping Application 2002

Currently the New York City Department of Transportation uses a prioritization method for maintenance and rehabilitation of city streets. Maintenance scheduling is prioritized based on the street functional classification, of either Primary, Secondary, or Local Street. Primary streets receive the highest priority because they have higher car volumes. In some instances, maintenance and rehabilitation considerations can be influenced by transit complaints and requests by private citizens, community boards, elected officials, and DOT staffs. As each complaint or request is received, it is compared with pavement assessment records of the streets in question to ascertain the severity of the street condition before any action is taken.

Thus far we have discussed the developing concepts and definitions of asset and pavement systems in transportation management. Its historical development was described from varying perspectives - policy, legislative, planning, and fiscal - with the aim of explaining the driving force behind its implementation. The discussion illustrated and explained the necessary components of an asset system, presented the concept of preventive maintenance as a means for preservation of infrastructure, and reviewed its practice within selected department of transportation. The next chapter, Data and Methodology, explains some of these components in detail. It attempts to generalize the various techniques in use and then deal more specifically with the procedure used to achieve the final outcome of this research.

Chatper 4 IMPLEMENTATION

Presentation and discussion of results comprise the following two sections. The first discusses integration techniques and the mechanism used to execute certain management tasks. The second describes the composite index that was used as an indicator and the mathematical formulation of the Heavy Duty Vehicle Index.

4.1 Spatial Integration and Database Methodology

The spatial operation began with disintegration of the bus route layer into separate bus route entities. Disintegration is a pre-processing requirement that separates several polyline layers (bus routes) into individual polylines (individual bus routes). This made each bus route a singular entity rather than a composite entity of several buses. Route feature class entities were created by selecting and exporting records of the input layer. This process created 908 bus route features with the coordinate system of the input layer. Each bus route was organized into feature datasets based on the location of its traversing segments. For instance, buses designated as M66_W, Q45, and BX 27 indicated that these buses traverse the streets of Manhattan, Queens, and Bronx, respectively. This nomenclature allowed for easy updates and adjustments (change management) when routes change.

After disintegration, each individual route entity and LION (NYCDOT) feature class layer was joined spatially. The default layer (LION) were summarized by average and count statistics. While the average statistic ensured that each route entity’s instance coincident to the LION was captured, the count statistic simply tallied each instance of a bus route traversing a LION segment. A shortcoming of the average statistic was that it only appended numeric attribute values of each route (e.g., bus ID) while excluding string attribute values. To prevent information loss during the join process, each route entity had a name that corresponded to their route name.

The product of the join created new feature classes with the desired attribute field (bus ID). An inspection of each joined layer found that the join operation resulted in some error, approximately 5- 7%. Errors were bound to occur because the process selected adjacent and intersecting segments as possible matches. An edit session was initiated to fix incorrect matches. Those without traversing bus routes were deselected while those that had traversing bus routes were selected. The layers were symbolized differently to make comparison easier. Unwanted segments were then discarded while newly selected segment were stored. Each newly selected street segments created during the edit session were then interactively populated with their corresponding unique identifiers (bus route ID) using the field calculator under the attribute table.

Another edit session was also necessary to limit the number of non-street segments selected in the process (approximately 214). Non-street segments include other linear features designated as boundary, shoreline, rail line etc. An arbitrary number of 200[5] non-street segments was the allowable number permissible in the data (see Appendix A for a list of non-street segments). Most of these non-street segments had a subtype of 3, 4, 6, 8, and 9. The NYCT Bus Map helped determine the appropriate street traversed by a bus. In other instances, a buffer (10-20 feet) was created around these non-street segments to find the best possible corresponding streets. Through visual inspection and buffering techniques, this number was reduced to 70 non-street segments.

[5] This figure was set by DOT to limit the number of non-street segment flagged as bus routes.

4.2 Database Structure and Management

A geodatabase is a relational database, whose internal design is proprietary to Environmental Systems research Institute (ESRI). They are capable of storing spatial objects (feature classes) and non-spatial objects (tables) within its structure. The LION street centerline and all bus route entities were linear feature classes while the truck, LION width, and pavement types existed as object classes (tables).

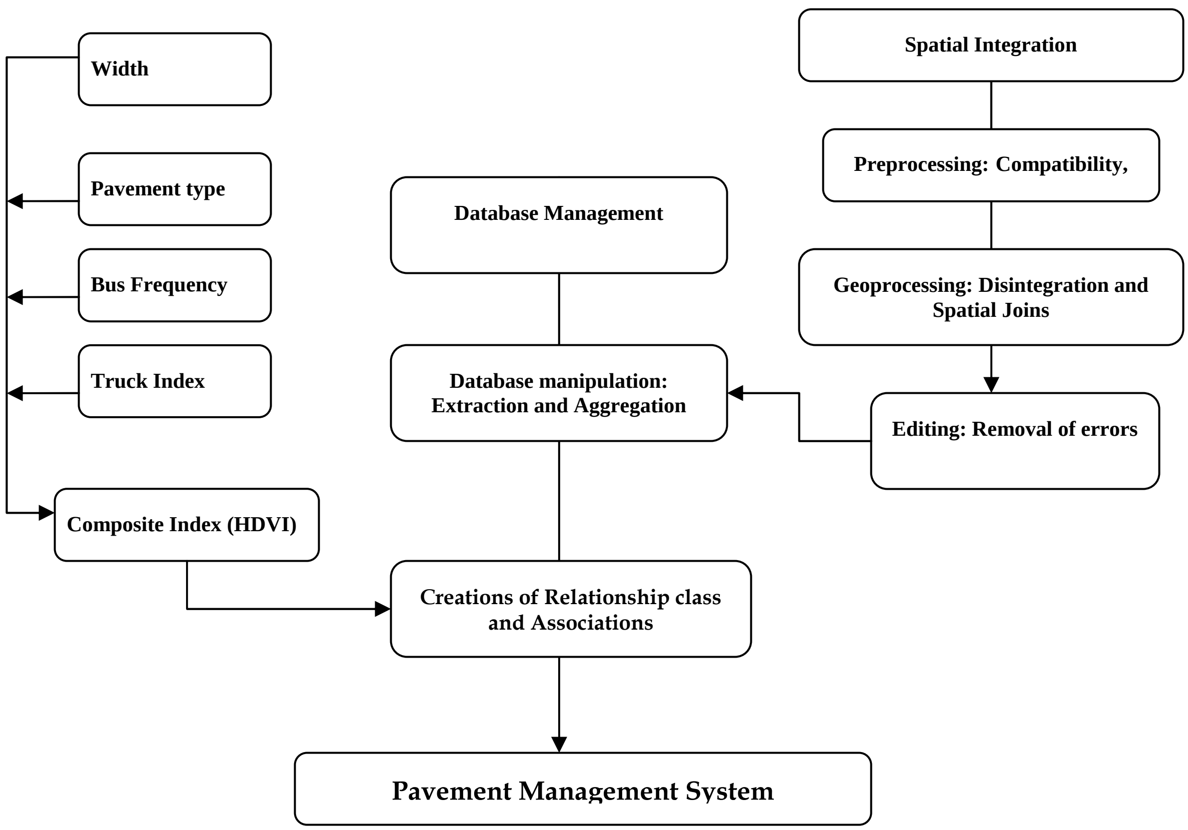
The data management task began by querying the LION feature class with appended bus route attribute. See Figure 7 for the flow chart. The query (see Appendix B extracted and aggregated segment ID and bus ID fields from each layer that was created from the spatial join operation. The objective was to create a table (segment_ bus_ID) with segment ID and the associated traversing bus ID. For instance, bus routes, M66_W, M66_E, M103, M100, M77, and M86 all traversed segment ID 189787. The segment_bus_ID table was another example of an object class within the geodatabase See table 6 and Figure 7b (Entity-Relationship Design). 23,478 LION segments had their segments traversed by at least a single instance of a bus.

Table 6: Segment_bus ID

RID	SegmentID	BusID
1	65	1891
2	65	1802
3	65	2275
4	65	2282
5	67	1891
6	67	1802
7	67	2275
8	67	2282
9	70	1891
10	70	1802

Table 6 provided a means to associate the LION with bus route layers. Associations were formed using a relationship class, which had the advantage of maintaining referential integrity (duplication and redundancy) between objects, as they were modified, deleted, and created. Where additional attribute information was important (street-smart distress indicator and heavy duty vehicle index), an attribute relationship class was created.

Figure 7: Operational Flow Chart



Each relationship formed had a primary and foreign key in the origin and destination layers, as well as certain cardinality. The cardinalities expressed in this thesis are many-to-many and one-to-many. For example, many buses can traverse a street segment and many buses could traverse many street segment. The bus route layer and LION layer were associated using a simple relationship class. Table 7 show the cardinality and Figure 8a and 8b database design structure and Entity-Relationship. Each relationship maintained a virtual rather than a permanent association between the layers. This is especially important when the data is managed by different units and requires constant updates.

Figure 8a: Entity - Relationship Diagram.

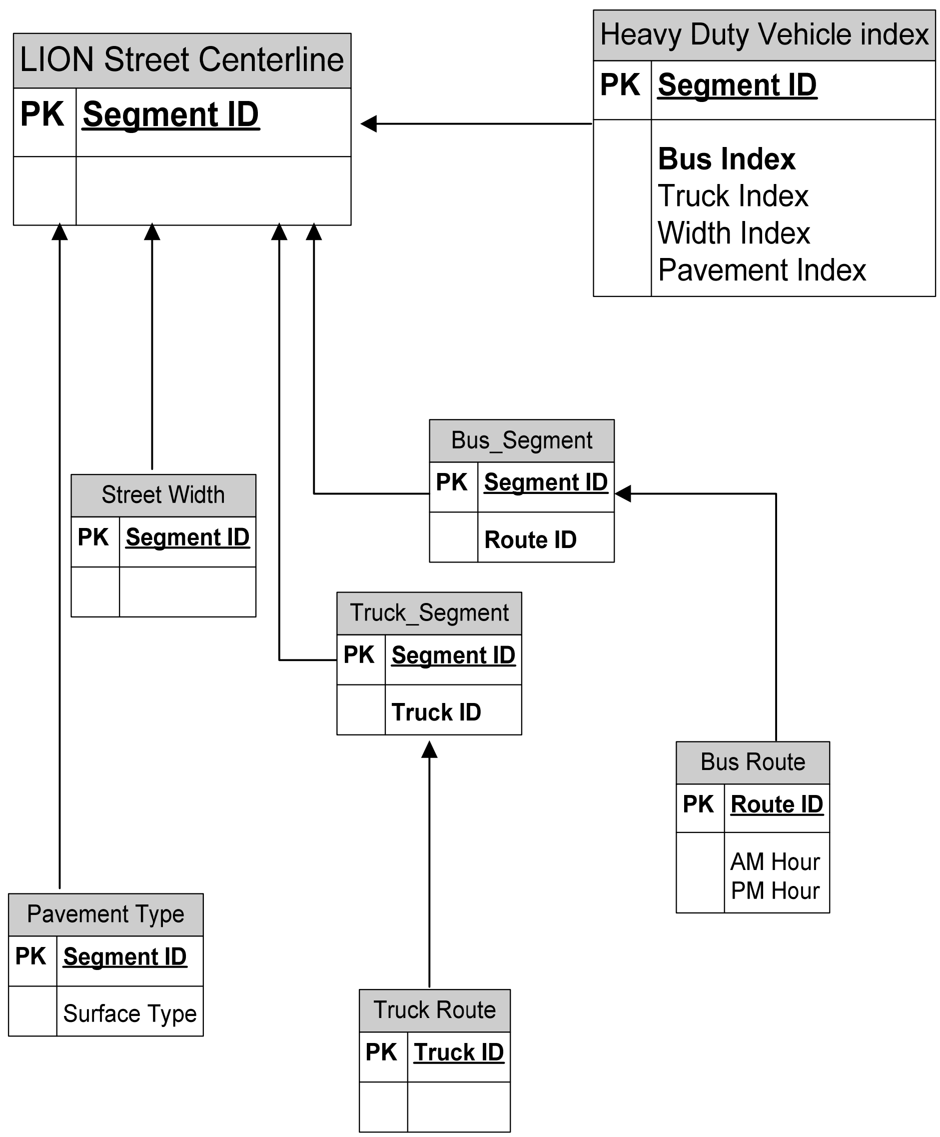


Table 7: Many-to-Many Cardinality

Street Centerline Origin Class	
Object ID	Segment ID (PK)
7	4532
67	7654
34	89064
3	5678

Relationship Class		
FID	Segment ID (FK)	Bus ID
1	4532, 7654	654,90
2	7654	890
3	89064,5678	890,90
4	5678	40

Bus route Destination Class	
Object ID	Bus ID
5	890
8	654
6	90
15	40

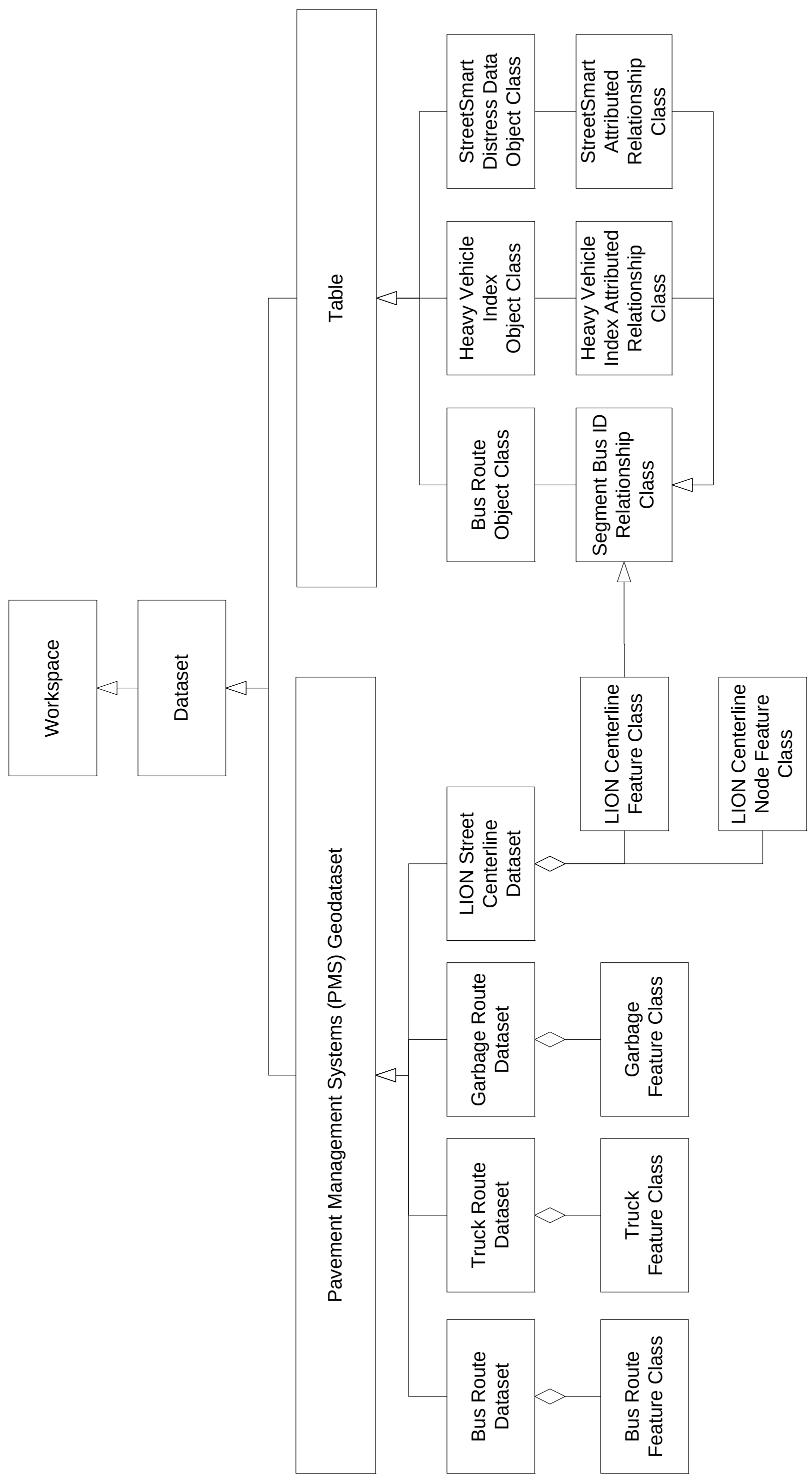
PK = Primary Key   FK = Foreign Key

4.3 LION Primary Keys

Another management task was to attribute the Heavy Duty Vehicle Index as a numeric data item keyed to a LION identifier. The LION file was composed of three structural entities: LIONKEY, Node ID, and Segment ID. The LIONKEY consisted of the Borough Code, Face Code, and Sequence Number, which constituted the LIONKEY for each record within the DCP LION file. Each LION file contained one record for each street segment. A segment is an uninterrupted portion of a street between two consecutive cross streets (nodes) or non-street features. Segment ID differed from the LIONKEY in that the former identified a segment—a geographic entity—whereas the latter identified a record in the LION file. The records played an important role in sequencing a feature's records to enable the Geosupport Function[6], and have no spatial components in themselves.

[6] Geosupport Systems is a data processing system designed to support geographic processing needs common to New York City agencies. Geosupport uses its geocoding functionality and spatial (x,y) coordinates system, in conjunction with an interactive computer mapping systems to enables graphic visualization of geographically related data.

Figure 8b: **Structure of the Geodatabase.**



4.4 Indexing Methodology

The heavy-duty vehicle index's composite indices were dependent on the simple accumulation of scores assigned to individual indicators such as pavement width, pavement type, bus frequency, and truck type. Each indicator is scaled and assigned a numeric score defined by frequency distribution. The distribution – internal response reflects a description of individual variability or intensity within each indicator. A ratio-equal weight factor was then – based on the assumption that all variables have equal influence on the roadway; implemented to determine the composite index.. The following sub-sections discuss the creation of each independent indicator and the composite pavement index.

4.4.1 Bus Frequency Indicator

A pavement's life expectancy relates to its present and projected traffic volumes. Of the total traffic volume, heavy vehicles with high axle load (trucks and buses) are considered primarily responsible for load-related road wear (Martin 2002). The bus frequency index measures the number of buses per hour per route on each street segment.

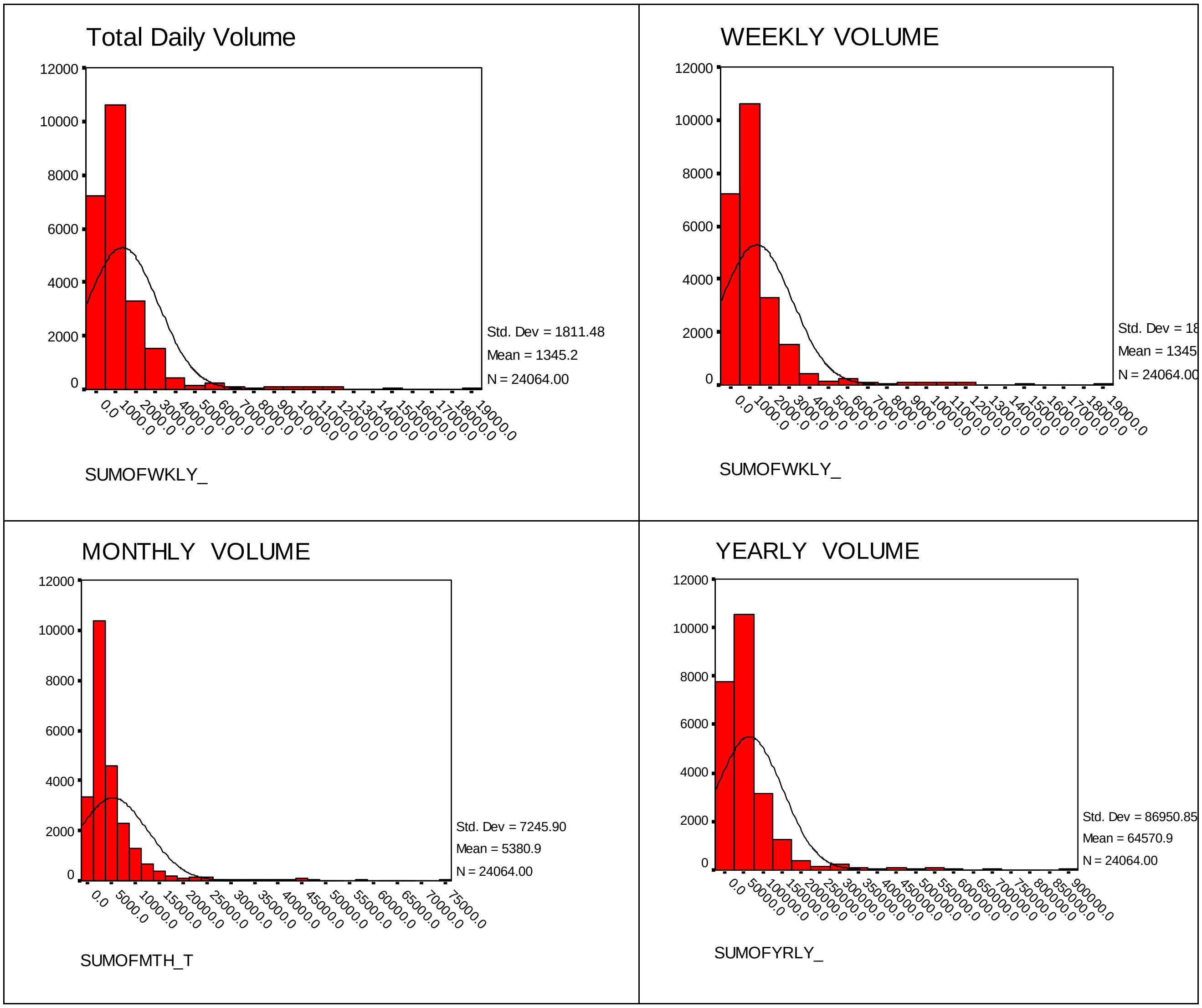
The computation of a bus frequency index required certain assumptions about each bus route schedule, especially where information was absent or missing. The assumption centers on bus AM and PM schedules. Because AM and PM schedules of certain buses were absent, it was necessary to replace them with placeholders values until accurate information becomes available. The first assumption attributed AM bus schedules to PM schedules where no PM schedule was obtainable. The second assumption also attributed PM bus schedules to AM schedules where no AM schedule was available. The third assumption populated buses without AM and PM schedules with schedule information from buses traveling in the opposite direction. For instance, bus

B103_E would have the schedule information of B103_W. The fourth assumption considered AM and PM hours as a 4-hour period between the hours of 6-10 and 4–8, respectively. Schedule information for other time periods were non-existent so they were not included in the analysis.

Once each bus was populated with schedule information, a count of all traversing buses and the total volume per hour per segment was estimated. Each bus' AM and PM hourly schedule represented the number of buses per hour. While daily volume per bus segment was obtained by summing AM and PM hourly, the daily volume per street segment of all traversing buses was obtained by summing the combined AM and PM hourly volumes of each bus. For instance, if street segment 9190 was traversed by 3 bus lines, its daily volume would be the sum of each bus' AM and PM schedule. Weekly, monthly, and yearly volumes were obtained in a similar manner. These calculations excluded weekend schedules.

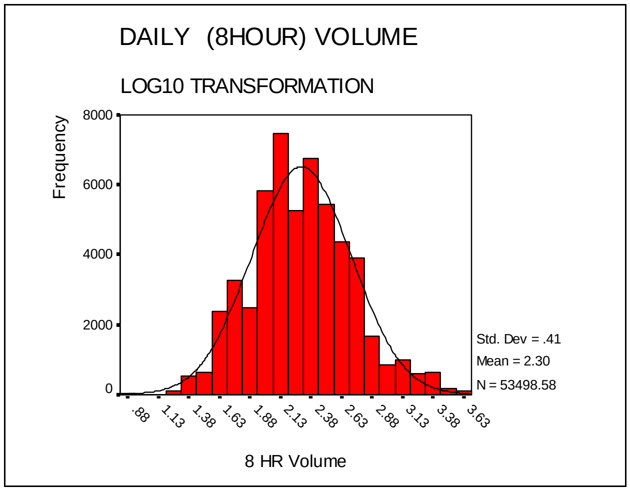
The results are imported into statistical software (SPSS) and ArcGIS software for exploratory analysis. The analysis revealed an uneven distribution of streets traversed by buses. A histogram plot of the daily, weekly, monthly, and yearly bus volumes per segment overlaid with a normal distribution curve shows that the distribution was not normal (see Figure 9). The analysis further revealed the presence of outliers. Outliers are data observations that lie outside the overall pattern of the distribution. The distribution also revealed a positively skewed dispersion (approximately 4.4) for daily, monthly, and yearly volumes. Because the mean and standard deviation value obtained from the daily, weekly, monthly, and yearly volumes do not represent robust values, a log 10 transformation was necessary. Accurate interpretation of the mean and standard deviation was only valid when the underlying data conformed to a normal theory with a bell-shaped symmetry. In a situation such as this, robust statistics such as the median, quartiles, and percentiles are appropriate.

Figure 9: Histogram of Daily, Weekly, Monthly and Year Volume



Normalizing the daily volume per segment by a log 10 transformation produced a normal distribution. Transformations are generally used to attempt to model non-linear and non-normal distribution data into linear and normally distributed data. The histogram below (figure 10) shows a normally distributed daily volume.

Figure 10: Daily Bus Volume



The proposed bus frequency index was based on comparison of the raw score and the transformed daily volumes. To aid comparison, a frequency distribution was used to group the raw scores into three and five classes. These represented cutoff points that acted as natural breaks within the data. Each category had its equivalent index score base in their deviation from the mean value of the Log 10 daily volume. To allow for greater variation within the data, a class grouping of five was selected. Finally, each index was assigned a descriptive term indicative of its condition value. Table 8a, b, c shows the statistical results.

Table 8a: Bus Frequency Statistics

N	Valid	24064
	Missing	0
Mean		2.2232
Std. Error of Mean		2.616E-03
Median		2.2041
Mode		2.11
Std. Deviation		.4058
Variance		.1647
Skewness		.262
Std. Error of Skewness		.016
Range		2.67
Minimum		.90
Maximum		3.57
Sum		53498.56

Table 8b: Frequency index with 5 Classes

Daily Volume	Index value	**Category**
8 – 68	0 - 1.85	Very Lower Volume
69 – 124	1.86 - 2.10	Lower Volume
124 – 204	2.11 - 2.31	Medium Volume
205 – 356	2.32 - 2.55	High Volume
357 – 3736	2.56 – 4.00	Very High Volume

Table 8c : Frequency index with 3 Classes

Daily Volume	Index value	**Category**
0 - 116	0 – 2.06	Lower Volume
117 - 252	2.07 – 2.40	Medium Volume
253 - 3736	2.40 – 4.00	High Volume

4.4.2 Truck Index

As mentioned earlier, trucks and buses contribute largely to roadway wear and tear. Because truck transportation plays a large role in the haulage of goods and service in New York City, their detrimental effects on roadways need to be measured. Currently, there are two modes of truck haulage, one being local, the other regional. The latter consists of routes that represent the movement of goods and services between their points of origin and destinations while the former represent neighborhood deliveries.

The truck index was developed based on the assumption that local routes are more likely to cause damage to streets than through routes. This assumption was premised on the fact that local truck routes with static loads have a persistent presence over certain sections (delivery points), over a prolonged period of time, and lasting through the delivery contract. This assumption would be valid only if all roads were smooth, thus voiding the effects of dynamic loading on through routes Potter et al (1996).

The truck route index had a numeric rating based on a tenth of a point, with a maximum score of 1, meaning the absence of damaging effects from trucks. Values of

0.75 and 0.5 were assigned to streets with through and local routes, respectively. Trucks with through routes were less likely to cause pavement deterioration as quickly. Table 9 shows an example of the truck index.

Table 9: Truck Index

Truck route type	Index value	Category
Local	0.50	Sever Damage
Through	0.75	Medium Damage
No truck	1	No damage

4.4.3 Width Index

The width of any roadway is an important factor in determining the total road right-of-way and pavement width. The right-of-way width must be sufficient among other things to contain the pavement and curbing, street utilities, sidewalks, and shoulder areas for drainage. Right-of-way widths vary based on the widths of their component parts. The most common recommended right-of-way width is 60 feet but considerable variation does exist. The width index is determined by the pavement width. A minimum pavement width must allow safe passage of moving traffic in each direction. Usually the designed pavement width is governed by the land use type and density, type of parking (i.e., off-street versus on-street), traffic volume, traffic speed, type of vehicle (i.e., cars, trucks, buses) and distance between pavement edge and any roadside obstacles. Roadways where pavement width does not consider these factors would experience a high degree of degradation.

Currently not all streets data are attributed with their width data. The index was computed with 91,274 street segments that may or may not have included those segments with bus and truck route information. Exploratory analysis of the raw scores revealed outliers that severely biased reading of the mean value. The width distribution did not conform to the normal distribution theory, thus making the use of standard deviation and mean value invalid. A log 10 transformation produced a normal distribution with relatively robust mean and standard deviation values. Extreme values (width of 900 feet) were also eliminated because they skewed the distribution.

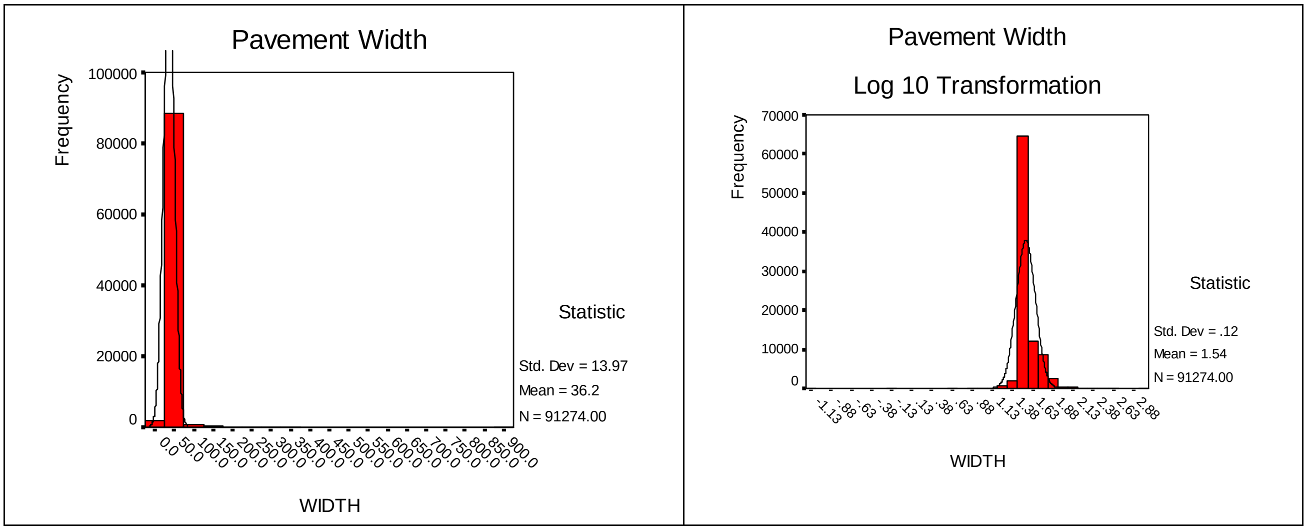
The raw score was than compared to the transformed width value. This provided the basis for grouping the raw data into different categories. This was accomplished by creating a frequency distribution of three classes to represent the entire width distribution. The width index for each category was then assigned based on the standard deviation from the mean value (with extreme values excluded). The transformed width value formed the basis for creating the index. Table 10 and Figure 11 show the mean and the dispersion characteristics.

Table 10: Width Index Summary Statistic

N	Valid	91274
	Missing	0
Mean		36.2
Median		
Mode		1.48
Std. Deviation		13.97
Skewness		11.40
Std. Error of Skewness		.008
Range		899.92
Minimum		0.08
Maximum		900
Pavement Width		

N	Valid	91274
	Missing	0
Mean		1.5396
Std. Error of Mean		3.965E-04
Median		1.4798
Mode		1.48
Std. Deviation		.1198
Variance		1.435E-02
Skewness		.987
Std. Error of Skewness		.008
Range		4.05
Minimum		-1.10
Maximum		2.95
Pavement Width Log 10Transformation		

Figure 11: Pavement Width Histogram



The width index rates street segments based on their width size. A minimum width for streets with vehicular traffic and two-sided curbside parking was 30 feet. This distance is ideal because it is effective in limiting bunching and allowing the free flow of traffic. The minimum width for vehicular traffic was set at 16 feet while 14 feet was reserved for two-sided curbside parking.

$W_s - (2W_c) = \Delta W \quad 30 - (2 * 7) = 16$

ΔW = Change in Width

W_s = Total Width

$2W_c$ = Two curb-side Parking

The rating is designed to discriminate against streets with width values below this minimum. Widths below 30 feet tend to increase the chances of occasional congestion and decrease traffic speed. This has the effect of increasing road-related weight stress caused by stagnant vehicles (buses and trucks), especially when bunching of vehicles occurs in the presence of two-sided curb parking. Table 11 shows the computed width index.

Table 11 : Width Index *

Width	Index	Category
0 - 29	0 – 1.48	Poor
30 - 42	1.49 – 1.64	Good
43 – 400	1.65 – 3.00	Excellent

* Values exceeding 400 were deemed outliers and therefore excluded from the index formulation

4.4.4 Pavement Index

The surface layer on which vehicles traverse is an important factor in planning for preventive maintenance. The pavement surface is designed such that it is capable of sustaining the vehicle load evenly along its structure. Pavement surfaces are generally of two kinds: flexible and rigid. Flexible (bituminous) pavements are constructed from asphalt concrete while rigid pavements are constructed from Portland Cement Concrete.

The New York City Department of Transportation does not have data on the type of pavement surface on their street network. A dummy variable was selected to represent the pavement surface types. A select number of street segments was populated with surface type of asphalt concrete and Portland Cement Concrete (PCC). Two subtypes of PCC (Joint Reinforced PCC and Continuous Reinforced PCC) were also included. Asphalt concrete has a numeric rating of three while Joint Reinforced PCC and Continuous Reinforced PCC have a rating of one and two, respectively. A value of three reflected the best pavement type whereas one represented the worst. Table 12 shows the pavement index.

Table 12: Pavement Index

Pavement Type	Index value	Category
Asphalt Concrete	3	Good
CRPCC	2	Medium
JRPCC	1	Fair

4.4.5 Composite Index

The Heavy Duty Vehicle Index was a composite index that summarized and rank-ordered several observations. The summary was obtained by accumulating scores assigned to individual indicators (pavement width, bus route frequency, truck type, and pavement structure type) to form the composite measure. The composite index was based on a numeric score from zero to 100. The scale was chosen to allow for a wide range of cases. A score of 100 reflected the highest rating a street segment could receive; i.e., a wide street with asphalt concrete and no bus or truck traffic.

Each measure received a weighting factor of 25, totaling 100 for the composite index. Equal weighting is ideal where each measure under observation has no correlation and has a slightly different influence on the outcome. The weight within each attribute was determined by obtaining a ratio between an assigned index value and the maximum index value and multiplying by the maximum weight.

$$\text{Index}_{(p)} = \text{Assigned Score}_{(p)} / \text{Maximum Score}_{(p)} * \text{Maximum Applied Weight}$$

Where Index $_{(p)}$ there reflects the index pavement account for the Pavement type

The composite score per segment was obtained by adding all individual index scores.

$$\text{Index}_{(p)} + \text{Index}_{(f)} + \text{Index}_{(t)} + \text{Index}_{(w)} = \text{Index}_{(HVDI)}$$

Where Index $_{(f)}$, Index $_{(t)}$, Index $_{(w)}$ and Index $_{(HVDI)}$ represents the index scores for bus frequency, truck type, pavement width and the overall heavy-duty vehicle index respectively.

Table 13 shows a sample index computation for two different sample segments under different conditions. Calculation described below.

Table 13: Composite Index

Condition	Segment ID	Index $_{(p)}$	Index $_{(f)}$	Index $_{(t)}$	Index $_{(w)}$	HVDI
1	75	25	9.375	25	10.83	70.205
2	75	8.33	14.5	18.75	13.75	55.33
3	75	16.66	16	12.5	12.416	57.5765

<u>Condition 1:</u>

Under Good Pavement Type

$Index_{(p)} =$ Assigned Score $_{(p)}$ / Maximum Score $_{(p)}$ * Maximum Applied Weight

$Index_{(p)} = 3/3 * 25$

$= 25$

Very Lower Volume

$Index_{(f)} =$ Assigned Score $_{(f)}$ / Maximum Score $_{(f)}$ * Maximum Applied Weight

$Index_{(f)} = 1.5/4 * 25$

$= 9.375$

Under no truck Damage

$Index_{(t)} =$ Assigned Score $_{(t)}$ / Maximum Score $_{(t)}$ * Maximum Applied Weight

$Index_{(t)} = 1/1 * 25$

$= 25$

Under Poor Width Size (23 feet)

$Index_{(w)} =$ Assigned Score $_{(w)}$ / Maximum Score $_{(w)}$ * Maximum Applied Weight

$Index_{(t)} = 1.3/3 * 25$

$= 10.83$

$Index_{(HVDI)} = Index_{(p)} + Index_{(f)} + Index_{(t)} + Index_{(w)}$

$Index_{(HVDI)} = 25 + 9.375 + 25 + 10.83$

$Index_{(HVDI)} = 70.205$

<u>Condition 2:</u>

Under Fair Pavement Type (JRPCC)

$Index_{(p)} =$ Assigned Score $_{(p)}$ / Maximum Score $_{(p)}$ * Maximum Applied Weight

$Index_{(p)} = 1/3 * 25$

$= 8.33$

Very high Volume (206 daily volume)

$Index_{(f)} =$ Assigned Score $_{(f)}$ / Maximum Score $_{(f)}$ * Maximum Applied Weight

$Index_{(f)} = 2.32 /4 * 25$

$= 14.5$

Under Medium damage (Through truck type)

$Index_{(t)} = \quad Assigned\ Score_{(t)} / Maximum\ Score_{(t)} * Maximum\ Applied\ Weight$

$$Index_{(t)} = 0.75 /1 * 25$$
$$= 18.75$$

Under Excellent Width Size (43 feet)

$Index_{(w)} = \quad Assigned\ Score_{(w)} / Maximum\ Score_{(w)} * Maximum\ Applied\ Weight$

$$Index_{(t)} = 1.65/ 3 * 25$$
$$= 13.75$$

$Index_{(HVDI)} = Index_{(p)} + Index_{(f)} + Index_{(t)} + Index_{(w)}$

$Index_{(HVDI)} = 8.33 + 14.5 + 18.75 + 13.75$

$Index_{(HVDI)} = 45.33$

<u>Condition 3:</u>

Under Medium Pavement Type (CRPCC)

$Index_{(p)} = \quad Assigned\ Score_{(p)} / Maximum\ Score_{(p)} * Maximum\ Applied\ Weight$

$$Index_{(p)} = 2/3 * 25$$
$$= 16.66$$

Very High Volume 357

$Index_{(f)} = \quad Assigned\ Score_{(f)} / Maximum\ Score_{(f)} * Maximum\ Applied\ Weight$

$$Index_{(f)} = 2.56/4.00 * 25$$
$$= 16$$

Under Sever Damage (local Truck)

$Index_{(t)} = \quad Assigned\ Score_{(t)} / Maximum\ Score_{(t)} * Maximum\ Applied\ Weight$

$$Index_{(t)} = 0.50/1 * 25$$
$$= 12.5$$

Under Good Width Size (30 feet)

$Index_{(w)} = \quad Assigned\ Score_{(w)} / Maximum\ Score_{(w)} * Maximum\ Applied\ Weight$

$$Index_{(t)} = 1.49/3 * 25$$
$$= 12.416$$

$Index_{(HVDI)} = Index_{(p)} + Index_{(f)} + Index_{(t)} + Index_{(w)}$

$Index_{(HVDI)} = 16.66 + 16 + 12.5 + 12.416$

$Index_{(HVDI)} = 57.5765$

A scheduled and planned program of surface treatments is dependent on certain established conditions. An HDVI of 70 is subjectively chosen to represent the medium level (see table 14). This represented a satisfactory roadway performance and ride quality. The HDVI of 100 represent the highest level a roadway can have, which is usually common on newly constructed roadways. Condition above a rating of 70 are consider good while those below were less desirable and thus requiring rehabilitative and reconstruction activities. The next chapter, Discussion, augment the accomplishment of this thesis. It attempts to summarize the pros and con of the general techniques and justifies the specific methods used. It also discusses the problems and for some suggestion for further research.

Table 14: Heavy Duty Vehicle Index

Condition Category	International Roughness Index (IRI)
Excellent	91 - 100
Good	71 - 90
Satisfactory	70
Poor	50 - 69
Unacceptable	> 49

Chapter 5: Discussion

The following section contrasts the method used in this research with other possible methods discussed in Chapter 3. It discusses technical issues and problem relating to the data and methodology. Furthermore, it directs and suggests ways to expand this research in response to the problems encountered. Lastly, it highlights the significance and implications of the outcome described in Chapter 4.

5.1 Evaluation of Methods

In general, integration (both spatial and non-spatial) requires criteria that take into account the scale, business processes, organizational characteristics, user requirements, data and data management characteristics, and the information system structure. Once these criteria have been defined, integration and data management can begin. Most DOT integration methods occur on an enterprise scale. The integration process begins with a needs analysis to understand the requirements of the organization. The next phase involves the selection and evaluation of alternatives for database architecture and various risk and cost assessments. Lastly, the database design, data specifications, development, testing, and implementation of the system ensure that it works to specification. Database integration occurs in two phases. The first phase determines the general database architecture while the second phase establishes detailed plans and methods of implementing the architecture.

The Maine Department of Transportation (DOT) uses a geographically linked warehouse database called the Transportation Information for Decision Enhanced (TIDE). The fused or warehouse approach has the advantage of simplicity, low cost, and data security. Its major disadvantage is that fusion requires conversion of databases and deployment within a new environment, rendering its data static and viewable only in readable formats.

Other DOT agencies use more compartmentalized environments known as the federated approach for running agency-wide maintenance programs for pavements and bridges (Data Integration Primer 2001). The federated approach consists of multiple distributed databases connected via a computer network. Although the cost can be prohibitive and data updates and access protocols rigorous, its long-term benefits are local control, preservation of legacy data, and access to a networked resource.

The scope and scale of the heavy vehicle index project required a less complex approach. A detailed database design – a relational database model, reference system and software (ESRI ArcGIS 8.3/9 and Microsoft Access) – was used to execute certain management tasks. Microsoft Access was used to perform the database query functions while the ArcGIS Suites 8.3/9 geo-relational database took care of the spatial integration and created the requisite relationship that keys in the index to the LION identifier.

The selection of a geo-relational database model and establishment of congruency and associations between the various data fulfilled the primary objective of the data management task. Relationship models are particularly useful in relating, linking, and managing attribute information from a variety of sources. Relationships can exist between spatial objects, non-spatial objects, or between spatial and non-spatial objects because they have a common field unique to all participants of the relationship. The segment ID field established congruency between the pavement type, LION, pavement width, truck route type, and bus route data.

The method of spatial integration used in this research was spatial join. Chapter Three discussed some other spatial integration methods: dynamic segmentation, spatial adjustment, and conflation. None of these techniques were used, however, because they were unsuitable for the data type being used.

Where dynamic segmentation requires that three measured coordinates (x, y, and z) be selected, the LION layer has only two defined coordinates. The addition of an *m* coordinate requires a slight adjustment to the LION reference system. The lack of a common field identifier between the LION and bus route layers limited the use of spatial adjustment and conflation techniques. Both techniques provide ways to transfer attributes from one feature to another by relying on some common matching fields between two layers.

5.2 Problems Encountered

As in most cases, the goal of spatial integration is to enhance data quality and accuracy. A spatial join mitigates the lack of a common identifier because the joining operation appends the attributes of the bus route onto the LION, based on the relative locations of the features. The appended attributes go through a series of quality controls – manual editing, visual inspection, and geoprocessing – to ensure that only valid street segments are selected. The final product, in this case attributing the LION layer with elements of the bus route information (NYCT), fulfilled the objective of linking disparate data sources and integrating them by some common parameter.

The majority of pavement maintenance indicators (ride quality, roughness, distress index, dynamic loading index) are designed based on engineering, economic and behavioral principles with the intent of measuring the smoothness parameter and its effects on ride quality. Road smoothness is important in determining rehabilitation activities and vehicle and pavement performance. While other factors like the distress index, visually inspecting and recording pavement deformities, and dynamic loading index measure the repetitive traffic loading or continuous bounce of vehicle suspensions over a section of pavement surface, the heavy vehicle index rates pavement performance based on a combination of factors.

The aggregate of these factors – bus frequency, pavement width, surface structure, and truck route type, forms the Heavy Duty Vehicle Index. The Heavy Duty Vehicle Index is a composite index dependent upon the internal response and intensity within each index. The index is the backbone of a preventive maintenance program. A scheduled and planned program of surface treatments is dependent on certain established conditions. Conditions above a rating of 70, where 70 represents a satisfactory condition, is considered good while those below are less desirable and thus require rehabilitative and reconstruction activities. The Heavy Duty Vehicle Index fulfilled the research goal of developing an asset management tool consistent with preventive maintenance methods that will enable the NYCDOT to set up a proactive street maintenance schedule.

The primary goal of this project was to develop an index or indicator that would aid in scheduling maintenance on roadways. The accuracy of the final output is solely dependent on the data inputs (variables). Where requisite information was either incomplete or entirely absent, assumptions have been made and dummy input created to represent real world examples, as in the case of pavement surface structure and bus route data. The precision of these estimates and assumptions greatly influence the outcome.

The absence of a common field in some data groups (LION and bus route) is also a prime concern. This situation arises because the data source originates from parallel agencies with different requirements. Although a spatial technique was able to solve this problem, the process of dissociating each bus route entity and joining each layer (902 times), and editing (weeding out bus route features that do not share line segments with the LION features) was quite laborious and repetitive. Although the procedure was laborious and would be unsuitable for large-scale projects, it ensured data integrity and accuracy.

A related concern was the need to create a mechanism for future updates and upgrades from a variety of ever changing data sources. NYCDOT currently utilizes a series of scripts to institute change management procedures. Each written script is comprised of a series of subroutines, codes that determine certain promotion rules in each reference table. Promoting data requires that a newer version of a database schema and data undergo propagation and deployment to reflect the changing conditions. It suggested that such subroutine be adapted to achieve this management goal. The reference tables that have promotion rules include the bus route layer, truck route tables, pavement width, and the LION. This fulfills the second part of the management task objective, which was to create a mechanism for future updates and upgrades from ever changing disparate sources.

During the spatial process, a small number of "non-street" segments were flagged as bus routes. The probable explanation is that the closest feature to the route may have been a non-street feature (where the field FType is not equal to 'S'). It is probable that there were some places where LION streets are either not 100% accurate or do not exist at all. It is therefore necessary to cross-reference these cases with the Department of City Planning for clarification. See Appendix A for a list of all non-street segments and their traversing bus routes.

Although the process of editing, joining, and dissociation were part of the quality control process to ensure data integrity, a better and less time-consuming technique is called for. An approach to this would be to develop codes to automate the spatial process. Automation eventually will quicken the integration process and limit human error. Automation is also requisite to efficiently and cost-effectively implementing change management techniques for propagating and deploying newer versions of the data.

5.3 Suggestions for Further Research

A simple approach to spatial integration is to introduce a measured value, along with the two-dimensional x, y coordinate system. The insertion of a measured value enables the Department of City Planning LION to function as a point and linear route network. While point locations are useful as part of general asset management goals for recording discrete locations along a route (sign point, traffic lights, and accident occurrences), linear route locations are useful for describing a portion of a route using a from- and to-measure value. Pavement surface type is one example. The benefit of instituting this change would be to first develop a linear referencing method for data collection and storage, especially with regard to developing a pavement type database. Secondly, it would prompt the use of either of two techniques – dynamic segmentation or conflation – to quicken the spatial integration process.

City agencies should follow the guidelines set forth in the Spatial Data Standards for Facilities, Infrastructure and Environment (SDSFIE) (Carpenter 2002) American National Standards Institute (ANSI) (http://www.ansi.org/), and Federal Geographic Data Committee (FGDC) (http://www.fgdc.gov/). The guidelines stipulate policies, procedures, and standards for the production, sharing, and distribution of geospatial information. Standardization ensures compatibility, is time and cost saving, provides greater accuracy and consistency, and increases the ability to share information between agencies.

5.4 Significance of Study and Conclusion

This research is significant in that a preventive maintenance schedule will aid the NYCDOT in managing roadway pavement, a transportation asset. This approach will greatly increase the Department's efficiency by applying cost-effective and proactive measures to their resurfacing programs. This advances the DOT's overall goals as public stewards: increasing rider comfort, maintaining an established use of service, and meeting financial obligations as well as requirements for new accounting practices.

In summary, this thesis achieved the goal of linking and integrating disparate data sources by establishing a segment ID as the primary means of associating and keying the Heavy Duty Vehicle Index to the LION. It developed a relational database model capable of managing and preserving database referential integrity, both referential and entity. Lastly, it computed a frequency-based composite index for scheduling street maintenance. In conclusion, this thesis serves as a tool for proactive measurement of resurfacing programs as well as a comprehensive document on tasset management and pavement management.

APPENDIX

<u>Appendix A</u> Here is a list of all non-street segments that were flagged as bus route.

Bronx

BX17_N	-	70489/70487

Brooklyn

B15_W1	-	52067/52069/52073/54829/54843/54850
B11_W	-	17896/17898
B11_E	-	17915/17913
B35_W1	-	20864/20860
B35_E	-	20864/20860
B51_E	-	23794
B9_W	-	17788/17786
B9_E2	-	17771
B9_E1	-	17771
B8_W2	-	17121/17205/17207/17314
B8_E2	-	17205/17207/17314
B8_E1	-	17121/17205/17207/17314
B77_W	-	22112/22121
B77_E	-	22132/22134
B70_N	-	17121/20891/20893
B70_S	-	17121/20877/20879
BM4_w1	-	106134/106135/34750
BM2_w1	-	106134/106135/34750
BM2_E1	-	34826
BM3_E1	-	34826
BM3_w1	-	106134/106135/34750
BM1_W1	-	106134/106135/34750
BM1_E1	-	34826

Manhattan

M103_N	-	23784/115084/115085
M16_E	-	106134/106135/34750
M15L_N2	-	23784/115084
M15_N2	-	23784/115084
M35_W	-	65811/65812/65813/65815/65878
M35_E	-	65811/65812/65813/65815/65878
M9_N	-	23784/115084/104364
M60_W	-	83336/83340/83341/84444/108171

Staten Island

S51_S1	-	14916/14921/14947/14952/14959/14960/14984/14986/14995/16100/111729 Type = 6
S51_N2	-	14916/14921/14947/14952/14959/14960/14984/14986/14995/16100/111729 Type = 6
S51_N1	-	14916/14921/14947/14952/14959/14960/14984/14986/14995/16100/111729 Type = 6
S44_E	-	4841
S44_W	-	4841
S54_S	-	114505/114506/114507/114508/114510/114556/114557/114558/114549/114551
S54_N	-	114505/114506/114507/114508/114510/114556/114557/114558/114549/114551
S62_W	-	8399/105461/195462/108282/108283/108284
S57_N	-	114505/114506/114507/114508/114510/114556/114557/114558/114549/114551
S57_S	-	114505/114506/114507/114508/114510/114556/114557/114558/114549/114551
S94_E	-	4839
S81_S	-	14916/14921/14947/14952/14959/14960/14984/14986/14995/16100/111729 Type = 6

Xbus (Express)

X14_N	-	34750
X90_N	-	106134/106135/34750
X38_N2	-	106134/106135/34750
X38_N1	-	106134/106135/34750
X37_N	-	106134/106135/34750
X42_N	-	106134/106135/34750
X25_S	-	36049
X25_N	-	105047/34736

Queens

Q48_W	-	83336/83340/84444
QM11_E	-	23784/115084/115085
M24_E3	-	23784/115084/115085

Appendix B: Query Sample

```
ELECT B1_N.SEGMENTID, B1_N.AVG_ID
FROM B1_N;
UNION

  SELECT B100_W.SEGMENTID, B100_W.AVG_ID
FROM B100_W;
UNION
   SELECT B11_E2.SEGMENTID, B11_E2.AVG_ID
FROM B11_E2;
UNION
   SELECT B12_W1.SEGMENTID, B12_W1.AVG_ID
FROM B12_W1;
UNION
   SELECT B14_E.SEGMENTID, B14_E.AVG_ID
FROM B14_E;
UNION
   SELECT B15_W1.SEGMENTID, B15_W1.AVG_ID
FROM B15_W1;
UNION
   SELECT B16_S2.SEGMENTID, B16_S2.AVG_ID
FROM B16_S2;
UNION
   SELECT B17_S2.SEGMENTID, B17_S2.AVG_ID
FROM B17_S2;
UNION
   SELECT B20_N1.SEGMENTID, B20_N1.AVG_ID
FROM B20_N1;
   SELECT B23_E.SEGMENTID, B23_E.AVG_ID
```

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