Design, Development, and Implementation of the Manitoba Highway Traffic Information System

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A thesis submitted to the Faculty of Graduate Studies
in partial fulfilment of the requirements for the degree of Master of Science

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DESIGN, DEVELOPMENT, AND IMPLEMENTATION OF THE MANITOBA HIGHWAY TRAFFIC INFORMATION SYSTEM

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Abstract

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The Manitoba Department of Highways and Transportation requires a variety of traffic volume and other statistics on the usage of provincial highways. This paper describes a review of the Department's former traffic data collection system and the design, development, and implementation of a new traffic information system. The research includes: (1) characterization of traffic data systems generally and the former Manitoba traffic monitoring system in particular; (2) formulation of performance criteria for the system based on general principles of data collection, definition of particular data needs in Manitoba, and technical criteria related to efficiency and effectiveness; (3) an evaluation of the former data collection program against these performance criteria; and (4) the design and implementation of numerous improvements to the system to address the identified shortcomings. Key components of the new system are a new method of specifying traffic pattern groups and a "factorless expansion" process for expanding short-term traffic counts to estimates of average annual daily traffic.

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Chapter 1 Background

1.1 Context of this research

This research is the result of five years' work undertaken with the support and co-operation of Manitoba Highways and Transportation (MHT), the University of Manitoba Transport Institute, and the University of Manitoba Transportation Information Group (UMTIG). This work led to the design and implementation of a new system to provide information about the usage of Manitoba highways to support MHT's planning, design, maintenance, safety, traffic operations, and research functions.

This process included four basic steps:

1. ***Characterize the system.*** The former system was not well documented, so the first step was to define the system and its operation.
2. ***Establish criteria for evaluation.*** To determine the effectiveness of the former system, performance criteria were established. Three broad groups of criteria were used: (1) general principles of data collection, (2) data needs which the system must support, and (3) technical criteria related to system efficiency and accuracy.
3. ***Carry out the evaluation.*** System performance was evaluated against the three main groups of criteria, and any shortcomings of the system were noted.
4. ***Design and implement new system components to address failures.*** Where the former system failed to meet the performance criteria, modifications were suggested and eventually implemented.

This is an ongoing process. The new system continues to be evaluated against performance criteria, and modifications continue to be made. The author was responsible for leading the initial review of the former traffic information system and for leading the development and implementation process from project inception through the summer of 1995. This paper draws on working papers, reports, and other documents published during this period.

1.2 Historical Background

The MHT-UMTIG partnership is the result of a process that began in the fall of 1991, when MHT commissioned the University of Manitoba Transport Institute to "design a traffic monitoring system to service the needs [of] Manitoba Highways and Transportation." MHT was concerned about costly and inflexible mainframe-based data processing procedures, accuracy and reliability of data summaries, long lag times between data collection and the availability of reports, and isolation from MHT's traffic data needs. The resulting document, *Design, Development, and Implementation of a Traffic Monitoring System for Manitoba Highways and Transportation*, (called *Design* hereafter) was submitted in April 1993, making fifty-one recommendations. A parallel research project, *A Reliable System for Monitoring Truck Movements and*

Characteristics in Manitoba, led by A. Ostroman, developed recommendations related to the collection and analysis of trucking information.

Further discussions between MHT and the University led to the submission of a Concept Outline in February 1994 and Discussion Notes in March, in which a co-operative venture to operate a new traffic information system was proposed. The University was to take on responsibility for data analysis, preparation of annual reports, and needs assessment, while MHT would remain responsible for overall management, setting policy, and data collection. A series of meetings was held in the following months to discuss details.

In May 1994, a draft agreement between MHT and the University regarding the development of a new Traffic Information System (TIS) was developed and presented for approval by both parties. On June 1, the University was instructed to begin the first stage of the project: "to prepare a detailed proposal which addresses, identifies, and/or quantifies the steps necessary to place [the] proposed TIS project into operation." This detailed proposal, the draft *System Specifications*, was submitted in July and accepted in principle by MHT. After some revisions, an agreement between MHT and the University was signed in August 1994, and development of the TIS proceeded over the following months. The first annual report by the new team, *Traffic on Manitoba Highways 1994*, was produced in July 1995, followed by special reports on vehicle-kilometers of travel and truck traffic covering the year 1994. The second annual report, *Traffic on Manitoba Highways 1995*, was completed in June 1996.

1.3 Structure of this Paper

This report describes the process followed in reviewing the former Manitoba Highways Traffic Information System and designing an improved system. It is structured as follows:

Chapter 1 Background, Definitions, and Description of the Former Traffic Monitoring System
This chapter introduces the context of the research, defines terms related to traffic information systems, and provides a summary description of the former traffic monitoring system.

Chapter 2 Principles of Data Collection
This chapter defines fundamental principles that should govern a traffic data collection system, evaluates the former system's performance with respect to these principles, and describes system improvements resulting from this research.

Chapter 3 Traffic Data Needs in Manitoba
As part of the review of the former system, each Branch's need for traffic data was examined. This chapter summarizes the result of this needs study, evaluates the former system's performance with respect to meeting the needs, and shows how system performance was improved as a result of this research.

Chapter 4 Technical Evaluation

This chapter describes a series of technical criteria dealing with issues such as accuracy and efficiency, evaluates the former traffic monitoring system with respect to these criteria, and shows how measures to improve system performance were implemented.

Chapter 5 Traffic Information System Current Status

This chapter briefly outlines the operation of the new traffic information system, shows the evolution from the former traffic monitoring system to the current system, and suggests directions for further research.

1.4 Additional Research of Interest

This paper summarizes the work performed by the author in connection with the development of the MHTIS. Additional research at the University of Manitoba including contributions from other researchers, which may be of interest to readers seeking more information about the MHTIS or about traffic information systems generally, includes:

A. Clayton, B. Lucas, M. Alam, and P. Cordeiro, *Design, Development, and Implementation of a Traffic Monitoring System for Manitoba Highways and Transportation.* University of Manitoba Transport Institute, April 1993.

A. Clayton, B. Lucas, M. Alam. *Manitoba Highway Traffic Information System: System Specifications.* University of Manitoba Transportation Information Group, July 1994.

B. Lucas, A. Clayton, D. Hurl. *Design, Development, and Implementation of a Traffic Monitoring System for Manitoba Highways and Transportation: A Case Study.* Presented at the Canadian Society for Civil Engineering Annual Conference, 1994.

Ostroman, A. *A Reliable System for Monitoring Truck Movements and Characteristics in Manitoba.* M. Sc. Thesis, University of Manitoba, 1993.

Penner, A. *Truck Data Collection for the Engineering Needs of the Manitoba Department of Highways and Transportation.* Departmental report, 1991.

The annual *Traffic on Manitoba Highways* reports as well as vehicle-kilometers of travel and truck traffic reports are also available from the University of Manitoba Transport Information Group.

1.5 Historical Overview of North American Traffic Monitoring Practices[1]

The first traffic counting programs began in the 1930s in an effort to quantify highway capacity analysis and speed-volume relationships, and to identify the stochastic properties of traffic. Early surveys were short-duration manual counts but by 1940 mechanical counters came into wide use.

By the mid-1950s, the modern system of using a permanent mechanical counter as a control station to expand nearby short-term counts had been developed. Since the 1950s, as computers became available, more people turned to the analysis of the data, searching for ways to quantify and reduce the errors known to be involved in short-term sampling.

Boris Petroff, one of the pioneers of traffic data analysis, began considering the problem of estimating the errors of short-term counts in 1954. At the time, short-term counts were expanded by selecting the nearest permanent counter as a control station. By 1958, this practice was recognized as inappropriate and agencies began to switch to using highway functional classification as the main criterion for assigning control stations. The current edition of the FHWA *Traffic Monitoring Guide* traces its recommendations in this area back to Petroff's work in the mid-1950s.

Petroff's work was based on the assumption that machine breakdown was the primary source of errors in AADT estimates. Because of this, methods for "patching" data were developed throughout the 1960s to account for missing data and correct data believed to be in error.

Throughout the development of traffic data analysis in the 1950s and 1960s, the inherent variability of traffic was neglected. In 1956, Petroff wrote that AADT estimates with 10-12% error for roads with an AADT of 500 vehicles per day or more were satisfactory. The inherent variability in his best samples, however, was around 8%. The suggested error range of 10% was accepted by later writers as a level which would normally be satisfactory -- and attainable -- in any traffic survey. The Bureau of Public Roads, the Institute of Traffic Engineers, and others echoed the 10% error range into the 1970s and 1980s, but all ignored the effect of the inherent variability of traffic. Statistical methods were proposed in the 1980s for handling errors arising from many sources except the inherent variability of traffic, which can have an effect far greater than the errors introduced at any other stage.

The 1960s was the "golden age" of highways in North America, and traffic monitoring grew in importance accordingly. Changes and innovations were occurring rapidly, enthusiasm was high, and many people were working on the problems of traffic monitoring. After the 1960s, however, the "golden age" of highway construction ended and highway departments began to lose some of their power. Traffic monitoring programs were cut, since they were viewed as not essential to department operations.

Despite the erosion of support for traffic monitoring, information continued to be provided but with less accuracy, and little effort could be spared to improve techniques. The accuracy and reliability of the data were seldom questioned by data users, and the people providing the information had few resources to spare for research and self-analysis. For many years, traffic monitoring programs were allowed to drift, and each highway department developed its own techniques to handle cutbacks. In the United States, the only force holding programs together was the requirement for states to report certain statistics to the federal government in order to qualify for federal highway funds. These requirements described the information that was required but did not define how to collect it, so states developed techniques independently. In Canada, there was no such federal requirement and provinces developed completely independent traffic monitoring systems.

In 1987, traffic monitoring suddenly became important again with the launch of the Strategic Highway Research Program (SHRP). One portion of the program, the Long Term Pavement Performance (LTPP) program, was a twenty-year data collection and analysis program intended to track pavement deterioration and relate it to various construction, environmental, and traffic factors. The inconsistencies, errors, and biases in available traffic data, however, were so great as to make it impossible to carry out its mission without first creating a new set of traffic monitoring standards.

Supported by the requirements of SHRP, the analysis of traffic data has been completely re-evaluated and re-designed. Many of the assumptions previously made about traffic flows have been proven incorrect, and many of the methods used to analyze traffic data have been cast into doubt. For example, traffic flows vary from day to day, and this variation has always been assumed to be normally distributed. In fact, a 1989 review of New Mexico traffic data demonstrated that two-thirds of that state's permanent traffic counters showed significant skewness; not one of the 14 urban arterial locations monitored showed a normal distribution. The inherent variation of traffic was also shown to be far higher than the 10% error margin that had been considered acceptable; only two of New Mexico's 62 monitoring sites showed variations under this 10% margin. ASTM, AASHTO, FHWA, and ITE have all recently released new standards for traffic monitoring.

Traffic monitoring programs in the past have always concentrated on volumetric measures. Vehicle classification, truck weights, and other programs were typically treated as adjuncts to the volume monitoring program and were sampled by short-term manual surveys on a subset of the volume counting network. As such, many of the problems with volume counting, such as the inherent variation of traffic and non-normal distribution, also apply to other traffic monitoring programs.

Non-volumetric programs have relied in the past on short-term manual surveys, with little or no year-round continuous data. Recently, automatic vehicle classification (AVC) technology has become widely available, with the result that it is now possible to obtain the year-round continuous coverage required to develop a reliable program. Work is also proceeding on weigh-in-motion (WIM) equipment, but so far WIM is not yet advanced enough to be a reliable design or enforcement tool.

1.6 Overview of Traffic Statistics -- What is Traffic?

"Traffic" may be defined as the movement of vehicles, people, and goods on the highway system. "Traffic information" includes all measurable characteristics of traffic, some of which are listed in Table 1. This report, like most transportation studies, concentrates on vehicle movements and in particular, volumetric measurements of vehicle movements. Some key definitions related to particular traffic volume measurements which will be of interest for this study are described below.

Table 1: Types of traffic information

Vehicle Movements	People Movements	Goods Movements
Volumes	Numbers	Quantities and commodities
Types	Demographics	Spatial properties
Weights	Trip purpose	Temporal properties
Dimensions	Spatial properties	
Speeds	Temporal properties	
Performance		

1.6.1 Vehicle Movements

1.6.1.1 Volumes

Volume and flow: The quantity of vehicular traffic on a road, or flow, is denoted q, and has units of vehicles per unit of time. The flow q is calculated as Q/t, where Q is the number of vehicles observed and t is the time period over which the observations are made. When the number of vehicles is observed over standard intervals t such as one year, one month, one day, or one hour, q is given standard names. Some common intervals and their uses are described below.

Average Annual Daily Traffic (AADT): The number of vehicles passing a point on an average day of a given year. This is the flow Q/t when the time interval t is equal to one full year -- in most jurisdictions, this is taken as the calendar year. AADT is a gross average representation of the usage of a road, and is probably the most frequently referenced statistic. It is used for such applications as[2]:

- establishing traffic growth trends
- calculating accident rates
- evaluating system improvements
- identifying capacity deficiencies
- programming maintenance activities
- environmental impact studies
- geometric design
- pavement design

Average Summer Daily Traffic (ASDT): The number of vehicles passing a point on an average day of the summer. Summer traffic on most roads in Manitoba is higher than the winter traffic and the annual average. In Manitoba, the summer period is defined as May 1 through September 30, but in other jurisdictions, other definitions of the summer period may be appropriate.

Monthly Average Daily Traffic (MADT): The number of vehicles passing a point on an average day of a given month. This is the flow Q/t when t is equal to one month.

Other measures of Average Daily Traffic (ADT): The average daily flow Q/t can be calculated for any combination of days over any period, in which case the generic term "average daily traffic" is used. For example, on a road serving a recreational area, one might be interested in the average daily traffic, Friday through Sunday, for the two-month peak season.

Hourly Variation: The flow Q/t can be reported in units of vehicles per hour, and is sometimes even reported as vehicles per quarter-hour. Different types of traffic show very different patterns at the hourly time scale. For example, commuter traffic tends to peak on weekday mornings and afternoons, while recreational traffic peaks on Friday and Sunday evenings, and some rural roads show significant peaks during the weekday lunch hour. Hourly variation is used for:

- geometric design
- determining capacity deficiencies
- justifying, planning, and locating traffic control devices
- justifying and planning regulatory measures such as parking restrictions and speed limits
- highway classification for geometric design and traffic engineering purposes
- justifying and planning enforcement measures

30th Highest Hour: For design purposes, many jurisdictions follow a practice of ranking all of the hourly traffic volumes at a site for the entire year and selecting the 30th highest hourly volume as the design input. This means that the design volume would be expected to be exceeded for 30 hours out of the year. The 50th highest or any other rank may also be used.

Peak Hour: Many analysis and design techniques use the concept of the *peak hour*, the number of vehicles passing a point during the peak 60-minute period of an average day of the year. The *peak hour factor* is the percentage of the AADT that occurs in this period.

Directional Distribution of Traffic: The directional distribution is the difference between traffic flows in opposite directions on the same road over some time period. On a long-term basis, it would be unusual for this split to be unbalanced; one expects that traffic proceeding in one direction on a road will normally return via the same route. On a daily or hourly basis, however, directional distribution is often unbalanced. Recreational roads often show heavy traffic towards a recreational area on Fridays and away on Sundays. Areas with a concentration of jobs show heavy traffic to work in the morning and away in the evening. Peak hour directional distribution is required for the design of roads with more than two lanes[3].

Lane Distribution: This is the proportion of vehicles using each lane in the same direction on a multi-lane highway. The lane distribution factor on rural highways is primarily influenced by the number of slow vehicles, which occupy the outer lane and force other traffic into the inner lane, increasing its volume.

Turning Movements: Monitoring intersection turning movements requires either a human observer counting manually or a large number of automatic counters able to isolate movements on each leg of the intersection. Turning movement counts are important because intersections are usually capacity bottlenecks and have high accident rates compared to the rest of the system. Turning movement counts are used in the following procedures[4]:

- planning new facilities
- analyzing system capacity
- geometric design of intersections
- planning maintenance activities
- planning and justifying traffic control devices and signalization
- safety studies

1.6.1.2 Vehicle Classification

Vehicle classification means determining the types of vehicles on the road, as distinct from the total number of vehicles. After the total traffic is measured, the proportion of vehicles in each of a number of classes is determined. Some applications require traffic to be separated into only two classes - passenger cars and trucks - in which case vehicle classification is usually reported as *Percent Trucks (%trucks)*. Other applications may need more detailed information, especially about the truck population, and may classify vehicles by axle configuration, weight, dimensions, or other characteristics. Various agencies use classification schemes ranging from only a few classes to as many as the 44 classes once used in Manitoba.

Since the traffic mix on a road changes from season to season and by hour of the day, the monthly, daily, and hourly variation of traffic can be determined by calculating the proportion of vehicles in each class over any time period, as discussed for total traffic. Vehicle classification can also be found by direction and lane.

Potential applications[5]:

- maintenance planning
- capacity analysis
- safety analysis
- environmental impact assessment

- project identification and selection
- geometric design
- pavement design
- highway system investment analysis
- public policy and legislation
- taxation

1.6.1.3 Vehicle Weights

Information about *gross vehicle weights (GVW)* and *axle loads* for different vehicle classes by axle configuration is important for pavement design and management, bridge design and maintenance, and various system policy decisions. Truck weights are recorded for each class of truck by weighing trucks at permanent and portable scales, or using weigh-in-motion sensors. The directional and lane distribution of truck loads can be very important in some circumstances. For example, a gravel pit haul road will carry fully-loaded trucks in one direction and empty trucks in the other, resulting in differential damage to the pavement. As well, because trucks tend to use the outer lanes of multi-lane roads, AASHTO standards recommend that the outer lanes be designed to sustain 25% more loading than the inner lanes.[6] Monthly distributions of truck weights are also of interest because pavement damage is related to the seasons.

1.6.1.4 Vehicle Dimensions

Roadway horizontal alignment and vehicle dimensions are inter-related. On the average, passenger cars have been getting smaller over the years while trucks are getting larger. Highways must be designed to accommodate the turning radii and wheel-tracking of large articulated trucks. Information about vehicle dimensions provides input to geometric design and the establishment of weight and dimension regulations.

1.6.1.5 Speeds

Information about vehicle speed is usually collected either by paired vehicle sensors that calculate the time it takes the vehicle to move from one sensor to the next, or by a roadside observer with a radar gun. Traffic speed information is used for[7]:

- evaluation of traffic control devices
- accident analysis
- geometric design
- evaluating or identifying the need for enforcement programs

1.6.1.6 Performance Characteristics

Horizontal and vertical alignment considerations such as curve radii, grade selection, provision of passing lanes, and many others influence and are influenced by the performance characteristics of vehicles. These characteristics include articulation, ability to maintain speed on grades, maximum speed, acceleration and deceleration rates, stability, and control.

1.6.1.7 Vehicle-Kilometers of Travel

Estimates of the total distance travelled by road users -- *vehicle-kilometers of travel, VKT* -- are made by multiplying the total number of vehicles using a road segment (the AADT is typically used) by the length of the road. VKT information is not relevant on a site-specific basis, but is used to track changes in regional traffic patterns for the following purposes[8]:

- project planning
- policy assessment
- environmental impact assessment
- energy consumption estimates
- safety studies
- taxation studies
- funds allocation

1.6.2 People Movements

1.6.2.1 Vehicle Occupancy

One of the most important factors in highway decision-making is the quantity of traffic using a road. This is usually expressed in vehicles, but the number of people using the road is also of interest. This is normally calculated as the average number of people per vehicle, or *vehicle occupancy*. If resources are to be allocated so as to benefit the greatest number of people, it should be noted that two roads carrying the same number of vehicles are not equivalent if the vehicle occupancies are different. A similar argument can be made in risk assessment when evaluating and priorizing safety improvements: a road carrying more people might have a higher priority than another carrying the same number of vehicles but fewer people.

1.6.2.2 Traveller Demographics

The demographic characteristics of travellers can be significant in analysing their trip-making behaviour, as linked to age, sex, income, occupation, and education[9]. They can also be used to identify the need for highway improvements. Driver age, for example, affects physical abilities such as reflexes and visual acuity, so a road with a high proportion of elderly drivers might warrant special treatment to accommodate them. Age, sex, and marital status are all used by insurance companies to identify high-risk drivers; highway agencies might use these factors as well to indicate roads which are at a priority for various safety improvements.

1.6.2.3 Trip Purpose

Trips are generally classified as one of five types[10]: work, school, shopping, social/recreational, or business. All but the last are considered to be home-based. The purpose of the trip affects its other characteristics, such as destination, route, time, and number of people travelling together.

1.6.2.4 Trip Spatial Properties

The spatial properties of a trip are its origin, destination, and the route travelled. Planning departments are the major users of this information, normally collected in some form of origin-destination (O-D) study. An O-D study identifies major trip origins, destinations, and routes in the study area, and can be used in network planning functions like evaluating highway relocation or town bypasses. The principal methods of conducting an O-D study include license-plate surveys and interviews conducted at roadside, in the home (in person or by telephone), or at work.

1.6.2.5 Trip Temporal Properties

The time of day and day of the week that a trip is made is important for planning and design functions. Work trips, for example, are mostly made on weekdays during short periods in the morning and afternoon, requiring commuter facilities to be designed to handle these peak flows. Shopping and business trips, on the other hand, are made throughout the week and often start later in the day but return home at the same time as work trips, making the afternoon peak higher than the morning one. Finally, recreational trips tend to peak on weekends, especially to resort destinations.

The duration of trips is also an important statistic of interest to planners. Travel time studies are used to identify problem locations in the network, to measure the overall network level of service, to evaluate the economic impacts of the system, and as an input to planning models. Travel time can be measured by test-car runs, license-plate observations, or roadside observations.

1.6.3 Goods Movements

1.6.3.1 Commodities

It is important to consider the commodities carried by trucks, just as it is important to consider the people inside their cars. If resources are to be allocated where they will provide the greatest overall benefit, a commodity-flow survey might allow planners to identify roads carrying large quantities of goods or high-priority goods. Identifying commodities carried on particular routes will also help in understanding the truck fleet mix and performance characteristics, since commodities are linked to the truck types that carry them and many trucks are specially designed to carry certain types of commodities.