How Smooth Are New York City's Streets?
Technical Appendix

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This Technical Appendix is divided into four sections. The first section describes some of the technical background of the study. The second defines relevant terminology. The third describes the measuring devices and other equipment used during the field measurements, data collection, data processing, data presentation and analysis. The final section discusses estimation and computation of standard errors of estimates from the sample.

The methodology for the two street smoothness surveys we have conducted was similar. The technical appendix to our first report (*How Smooth Are New York City's Streets?, 1998*) provided considerable detail about this methodology as well as an extensive list of relevant references. Only a summary of the technical details is provided in this report. For further information, please consult the earlier report.

Much of the material in this appendix was prepared by Galaxy Scientific Corporation.

I. BACKGROUND OF THIS STUDY

**History**

From October through November 1997, the first reported full-scale attempt to objectively quantify the smoothness of city streets took place on the basis of research needs identified by the Fund for the City of New York. Data were collected by a team of Fund and Galaxy personnel in all five boroughs of New York City and in every one of the city's 59 Community Districts. The collected data were analyzed by the Fund for the City of New York and presented in a report published in September 1998 entitled *How Smooth Are New York City's Streets?*. The data provided a baseline record of the pavement roughness condition for New York City. Incorporating some of lessons learned from the 1997 study, measurements of the same number of randomly selected street segments were conducted from September 7 through October 6, 1999 to provide data for comparison with the baseline record.

**About Galaxy Scientific Corporation**

Galaxy Scientific Corporation (Galaxy) conducted the survey of the smoothness of the city's streets on behalf of the Fund for the City of New York's Center on Municipal Government Performance. Galaxy is a high-technology firm providing systems integration, engineering and other technical services and product development to the Federal Aviation Administration, U.S. Departments of Transportation, Defense, Commerce, and commercial clients. Galaxy has offices in 14 cities in the United States, and one in Taiwan, Republic of China. The Fund contracted with Galaxy's Safety Technology Division, engaging them to apply their tested equipment and processing to New York City's streets. Galaxy engineers and scientists are experts in highway and runway profile design and measurement, and the design of airport pavements. Galaxy's staff of engineers and data processors has extensive experience in working with pavement measurement devices and analysis of profilometry data.
Preliminary Testing, 1997

Preliminary tests were conducted in 1997 for the Fund for the City of New York to demonstrate how reliable profilometry devices are in replicating road roughness measures when driving different roads of varying roughness at varying speeds. Galaxy conducted roughness measurements on two secondary road segments in their home office area to test/demonstrate repeatability and consistency of their roughness measures at the same and at different speeds. The tests resulted in similar measurement at varying speeds on the same streets as shown in Table 1.

Table 1. Pilot Test Results

<table>
<thead>
<tr>
<th>Road Segment</th>
<th>Pass</th>
<th>IRI</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough</td>
<td>1</td>
<td>12.538</td>
<td>23 mph</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12.441</td>
<td>20 mph</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>12.188</td>
<td>25 mph</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>12.524</td>
<td>30 mph</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>12.537</td>
<td>15 mph</td>
</tr>
</tbody>
</table>

The Fund then asked Galaxy to conduct another test of several road segments in New York City. At the same time, DYG, Inc., a social science research company convened a panel of New York City drivers to rate the same road segments being measured by Galaxy. These tests were conducted to determine if there was a high degree of correlation between the objective measurements and the perceptions of typical New York City drivers.

The Fund’s statistician performed a regression analysis of the Galaxy data and New York City driver ratings and, indeed, found a high degree of correlation ($R^2=0.8726$). After asking the drivers to rate the quality of the roads from their perspectives, Table 2 was developed correlating their judgments with the City Roughness Index (CRI) measurements recorded by Galaxy.

Table 2. 4-Point City Roughness Index (CRI) Scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>People’s Description</th>
<th>CRI Boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good</td>
<td>3.81 or less</td>
</tr>
<tr>
<td>2</td>
<td>Fair</td>
<td>3.82-7.12</td>
</tr>
<tr>
<td>3</td>
<td>Poor</td>
<td>7.13-13.28</td>
</tr>
<tr>
<td>4</td>
<td>Terrible</td>
<td>13.29 or higher</td>
</tr>
</tbody>
</table>

1 See the Definitions section for explanation of IRI and CRI.
II. DEFINITIONS

This section provides brief definitions for some terms that were operative over the course of planning and execution of the two surveys. Some are common terms that have a specific meaning in the context of this work and some may be wholly unfamiliar. A detailed treatment of the more technical terms can be found in our earlier report.

**Block** – One physical street length (within a cluster) starting at the beginning of an intersection and ending prior to the start of a second intersection.

**Bump** - A deviation from a straightedge at either of two locations: entry and exit. An upward bump has a rise at the entry point and a fall at the exit, as shown below.

![Upward Bump](image)

A downward bump, such as a pothole, would have a drop at the entry point and a rise at the exit.

![Downward Bump](image)

Additionally, in order for the vehicle to “feel” the bump, the entry and exit points could be no less than a tire print and no more than the distance between the front and rear wheels of the vehicle. For these reasons, a minimum length of ½ foot and a maximum 6-foot straightedge was selected. As a result, only the entry or exit (peak) of a bump with a surface length of less than six feet would be counted and, only the largest of a set of bumps within six feet of each other (in the same wheelpath) would be counted.

**Bump Index** – The ratio of the bump height to the bump length. This bump index was developed by the Boeing Company for examining acceptability of runway roughness to their aircraft.

Boeing considers bump index measurement of 1.0 and above to be potential causes of aircraft injury. Therefore, Galaxy Scientific produced information to the Fund about all bumps with an index of 1.0 and above. The Fund for the City of New York chose to report the more severe bumps and therefore in this report includes only those bumps that have an index of 1.5 and above. This decision was made to account for the differences between airplane and automobile stress, and to reflect the fact that people in the focus...
groups said they expect some bumpiness in the city's streets but find severe bumps intolerable.

**Cluster** – A selected length of road surface measured during one recording interval (comprised of one to several blocks). In the sample design used for the two surveys, 40 clusters are measured in every community district. Generally, the clusters in the sample consisted of 4-6 blocks in dense areas and 6-10 blocks in less dense areas.

![Block and Cluster Diagram](image)

**Community District** – As authorized in the New York City Charter, New York City has 59 community districts. They were originally designed to have similar populations when practicable. They vary in geographic size. Forty groups (clusters) of randomly selected contiguous blocks within each district were selected by the Fund’s sampling consultant to be measured in these street smoothness surveys.

**CRI** – A direct computation of the International Roughness Index (IRI) without using the standard (and constant) measurement speed of 50 mph. *See also IRI.*

**IRI** – The International Roughness Index (IRI) is a mathematical model developed through research sponsored by the World Bank in the 1970's for measuring road roughness.² A computer program calculating the IRI takes the measured profile of a street as its input and gives a measure of the street's roughness as an output. The output is given in terms of slope (e.g. vertical inches/horizontal mile) and indicates the total accumulated deflection of the suspension of a theoretical car per distance traveled. The standard measurement speed of the IRI is 50 mph. Because this speed could not be obtained in the City due to lower legal speed limits and traffic conditions, the Fund has designated the measure a *City Roughness Index* (CRI). The IRI index is very useful for relating a roughness measure to overall ride quality. It satisfies the criteria of being time-stable, transportable, and relevant, while also being readily measurable by all practitioners. The IRI is also strongly related to the subjective opinions about road roughness that can be obtained from the public. A perfectly smooth road would have an IRI of 0 m/km whereas a very rough road could have an IRI of 20 or higher.

**Jolt** – A bump having an index of 1.5 or above. The term "jolt" is used by the Fund for the City of New York at times instead of the term "bump" because bump is commonly understood to mean a rise in the surface. In fact, all significant upward rises as well as significant downward depressions were measured, both of which create the sensation of a jolt and are the cause of rider's discomfort and dismay. The technical term to describe both upward and downward deviation is "bump."

**Profilometer** – an instrument for measuring road roughness that can be attached to a vehicle. The profilometers used in these surveys consist of three parts: laser, accelerometer and speed sensor. The profilometer produces a profile of every variation in the street surface as the car to which it is attached travels down the street.
III. METHODOLOGY

The methodology used in this study replicated and built on the previous study completed in 1998. In order to provide comparisons between the two studies the same testing and analysis procedures were employed. A brief description of the measuring devices used, sampling, data collection, data processing, data analysis, issues that emerged during the quality control checks, and weighting procedures are given here. For a full description of the testing process, see the previous report.

Measuring Devices Used

Profilometer

Galaxy Scientific Corporation uses a Class II inertial profiling device to conduct pavement roughness measurements (Figure 2). Short of manually using a rod and level (Class I), this is the best available method for measuring long distances. Specifications for Galaxy’s profilometers exceed the requirements of American Standard Testing and Materials (ASTM) Test Method E-950, "Measuring the Longitudinal Profile of Vehicular Traveled Surfaces with an Inertial Profilometer." The profilometer has three major components: the laser, the accelerometer, and the non-contact speed sensor.

Figure 2. Galaxy Inertial Profiling Device Equipment Configuration

The laser measures the deviation of the vehicle from the pavement surface. The model used illuminates an area (spot size) of 1 square millimeter. The sampling rate is 32 kHz, which gives a sampling distance of 0.011 inch at a test speed of 20 mph. The accelerometer measures the car’s vertical movement; it is measured so that it can be filtered out later to produce a profile of the street uncontaminated by the vehicle's response. This filtering creates the effect of the laser remaining stationary as the contour of the road passes under it. The accelerometer signal is also sampled at 32 kHz. The non-contact speed sensor provides information on the speed of the vehicle. The distance is derived from the speed. For this configuration, the measurement speed is limited to a maximum of 38 mph and approximately five minutes
of data recording per measure (16,600 ft).

The laser's data, tempered by the accelerometer, produce a representation of surface deviations in the form of a profile. (See Figure 3 for a sample profile.) The ends of the profiles are forced to have the same elevation to provide a better representation of the surface deviations, ignoring the difference in elevation between the start and stop points. The 32 kHz profile is filtered and decimated to give a final sample spacing of approximately 1 inch.

A typical inertial profiler operates optimally at speeds between 9 mph to 63 mph while maintaining a constant speed. Galaxy profiling equipment works optimally at speeds between 2 mph and 38 mph, while operating at variable speeds. These are ideal characteristics for city profiling. In these surveys, two profilometers were used to measure the left and right wheel tracks.

Other Equipment

Laptop computers in the test vehicle capture the data from the measuring devices. The data are then processed at Galaxy's offices to produce IRIIs, bump indices and supporting data.

For the most part, the profiling equipment used during the 1999 survey was identical to that used in the 1997 effort. As in 1997, the 1999 data collection effort was conducted for approximately twelve hours (2 shifts) per day, six days per week. The equipment was serviced weekly (on the seventh day). A video camera mounted on the dashboard of the vehicle was also used to provide a pictorial record of the road surface conditions for future analysis by the Fund. Both left and right wheel paths were measured. Because of the data collection schedule and volume of data collected, on site examination of the collected data was not possible. At the end of each day, the collected data were sent to the Galaxy offices for examination and processing.

Changes in 1999

Some minor changes were made to the measuring procedures and equipment since the first survey. One of the accelerometers was replaced with another one of the same type. Based on lessons learned from the previous effort, the cabling was redesigned for more rugged operations. Spare parts and tools were readily available and the operators had significantly more experience with the equipment and procedures. Although the profilometer is designed to produce results independent of the vehicle used, it is worth noting that a 1999 model of Mercury Sable was used for the 1999 survey instead of a 1997 model used for the 1997 survey.

The laptop computers used in the 1999 survey had faster processors and more hard drive space than the ones in the 1997 survey. This upgrade expedited data collection. Additionally, a scaled down version of the data analysis software was loaded into each of the laptops. This allowed the Galaxy engineers to more thoroughly check the operation of the equipment during their calibration (bounce) tests to ensure that all parts of the profilometer were working. It also allowed them to conduct periodic data checks and to provide more significant information to the troubleshooting team standing by at Galaxy's home office. Periodic bounce tests were conducted by the field team during the survey as well.

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The video camera and the filming techniques used in 1997 did not capture all the road segments adequately. Therefore, a new digital video camera was used and it provided more satisfactory results. Nighttime recordings were even possible.

In the previous effort, data had been shipped back to the Galaxy headquarters for analysis on disk. Because that method was time consuming, the new effort set up a personal computer offsite, connected to the Galaxy network via a high speed Internet connection. Unfortunately, because of transmission delays, the data could not be processed as quickly as expected. The procedure did save some time in comparison with the 1997 effort and allowed Galaxy Office personnel to analyze the previous day's calibration data and suggest preventative maintenance procedures.

**Sampling**

A sample representation of streets within each community district of New York City was selected for testing. The New York City Department of Transportation (DOT) streets database (StreetSmart) was the base from which the sample was drawn. In order to assure that the sample would be both valid and objective, the sample selection was based on the principles of "Probability Sampling," which uses randomly generated numbers to determine the selection.

Systematic random sampling was used to obtain a sample of 40 clusters of streets within each community district. Systematic random sampling was used because it assures that each cluster of streets and each individual block, as well, is given an equal probability of selection and it assures implicit geographic stratification of the resulting sample.³

Once the clusters to be surveyed were identified and the routes and driving directions were established, the lane assignments were chosen by means of a coin toss. Although driving direction and lane assignments were predetermined, specific road conditions (double-parked cars, traffic jams, and other impediments) dictated the precise path followed by the test vehicle.

**Data Collection**

The data collection team consisted of a professional driver and a navigator, both provided by the Fund, and a Galaxy Scientific engineer. The driver handled the vehicle to best accommodate the data collection equipment while maintaining a safe environment for the data collection team, the equipment and surrounding traffic. Using driving routes that were preplanned, the navigator was essential in guiding the driver and in providing advance notice of the next street cluster to be measured. The navigator also kept records of events (such as closed roads, construction detours, heavy traffic, etc) that hindered the data collection process, periodically checked the aiming/framing/quality of the video recordings, and made observations of events that should be considered in future survey plans. The Galaxy engineer monitored, operated and maintained the profiling and video equipment and noted instances that might have an impact on the data analysis. Also, whenever the vehicle crossed an intersection, the engineer injected block markers in the data and profile by pushing a button that produces a designated signal.

In both surveys, data collection was scheduled for two eight-hour periods per day, six days per week maximizing the availability of sunlight. In general, the morning shift started from their hotel area between 5:30 and 6:00 AM, where the driver and navigator met the Galaxy engineer and data collection vehicle. The vehicle was driven to the community district to be measured and then the electronic equipment was mounted and calibrated. The driver, navigator and Galaxy engineer of the second shift met the first shift at a predetermined location at approximate 2:00 PM in order to maximize the use of the vehicle for data collection rather than travel time. The second shift collected data until approximately 10:00 PM. The equipment was re-calibrated during the change of each shift, when/if the equipment was removed from the vehicle (during lunch breaks or traveling long distances between community districts), and/or when deemed necessary by the Galaxy engineer.

The data collection schedule reflected the expected traffic density of the individual districts. For example, lightly trafficked districts were scheduled during "rush hour" periods and the more congested districts were scheduled during very early morning or evening hours. Data from three midtown Manhattan districts were collected from 10:00 PM to 6:00 AM.

During the 1997 effort, the routing for the data collection was confined to one community district at a time, and many cluster measurements started from a right or left turn. The 1999 effort bridged different districts to take advantage of a more efficient routing and, for the most part, the 1999 routing initiated a cluster from a straight on direction.

One of the most significant changes to the 1999 survey was the improved routing. In 1997, the field crew spent an enormous amount of time locating "non-geocoded" street clusters -- those streets that could not be found automatically on the routing company's navigational database and thus did not have predetermined routing. In 1997, approximately 10 percent of the sample were non-geocoded clusters. Before the start of the 1999 survey, the Fund staff located these non-geocoded streets manually and worked with the routing company to insert them into the routes. This eliminated the time needed to locate these non-geocoded streets in the field.

After the completion of each second shift, the data collected for the entire day were transferred to a desktop computer at the hotel and subsequently transferred to the Galaxy home office.

As the data arrived, bounce test data were retrieved and analyzed immediately to assess the working condition of the equipment and suggest any preventative maintenance, if needed. During the entire data collection period, the bounce tests indicated that the equipment was operating within specified parameters.

To preclude the possibility of any catastrophic loss of data, cluster data were written to compact disks as they arrived at the Galaxy offices and file transfer counts were confirmed with the on-site personnel. As the file transfers were confirmed, the data were deleted from the hotel computer.

Only three reportable incidents occurred during road operations:

1. A car tire had to be replaced.
2. A connection in the control box needed to be resoldered.
3. A laser cable required minor repair.
In addition, data were not collected on four days of inclement weather. Instead, equipment and computer preventative maintenance was performed on those days.

**Data Processing and Presentation by Galaxy**

The data were processed by district and an automated document file was generated for each cluster/segment within the district that contained a:

1. Plot of the cluster profile;
2. Plot of the vehicle speed;
3. Plot of the block marker;
4. Plot of IRI;
5. Plot the Bump index.

Profile sheets, as illustrated in Figure 3, were compiled by borough and forwarded to the Fund. Further computer processing of the outputs listed above generated an Excel workbook, for each district, containing spreadsheets for:

1. Average cluster and block lengths (combined left and right wheelpaths);
2. Average IRI for each block and cluster (combined left and right wheelpaths)
3. Bumps with indexes greater than or equal to 1.0 within the cluster (and the first bump index <1.0)
Figure 3. Profile Sheet

Cluster R01016R

Table Indexes of cluster R01016R

<table>
<thead>
<tr>
<th>Block</th>
<th>Length (ft)</th>
<th>IRI (m/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>346.1</td>
<td>6.3214</td>
</tr>
<tr>
<td>2</td>
<td>803.2</td>
<td>3.6616</td>
</tr>
<tr>
<td>3</td>
<td>231.4</td>
<td>4.1146</td>
</tr>
<tr>
<td>Total</td>
<td>1380.7</td>
<td>4.4043</td>
</tr>
</tbody>
</table>

Table Bump Index R01016R

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Distance from Start (ft)</th>
<th>Bump Index</th>
<th>Reference Height (in)</th>
<th>Bump Height (in)</th>
<th>Bump Length (in)</th>
<th>Edge Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59.2</td>
<td>1.135</td>
<td>0.87</td>
<td>0.988</td>
<td>16.724</td>
<td>5.807</td>
</tr>
<tr>
<td>2</td>
<td>65.5</td>
<td>0.987</td>
<td>0.87</td>
<td>0.859</td>
<td>16.724</td>
<td>5.807</td>
</tr>
</tbody>
</table>
**Issues Emerging from the Quality Control Checks**

As part of Galaxy's extensive analysis of data, Galaxy performed a "signal analysis" of all raw data. During this phase, Galaxy checked the voltages applied to the system to make the instruments work properly. If the proper (excitation) voltages are applied, the instruments will produce output voltages that represent distance (laser), speed (speed sensor) or force (accelerometer) values during the data processing. There are corresponding voltage limits to what the instruments can measure. During the signal analysis, Galaxy checked all the voltage readings to see if any were out of range. For 59 out of 2,321 clusters, it was discovered that the signals for the laser were unreliable (perhaps not wrong, but unreliable) for one side.

At the request of the Fund, Galaxy re-surveyed these clusters plus additional clusters that had reliable laser data for both sides. A re-testing procedure was developed by the Fund's statistical consultant, Dr. Martin Frankel. On March 8 and 9, 2000, 94 street clusters were re-measured. The data were processed independent of the preceding survey data. The Fund delayed production of this report until retesting and subsequent analysis was completed.

Dr. Frankel and the Fund conducted several comparative analyses of the data from the March 2000, September 1999 and 1997 surveys. Data from the 1997 survey were reviewed to determine the differences in profilometer readings between the two sides of the car in the affected district(s); the readings were very similar. Sampling error ranges for the 1999 and 2000 retest were examined in light of the cut-offs that the people in focus groups set; again, the results were similar. Therefore, it was determined that by using the reliable 1999 data that was gathered on one side of the test vehicle and attributing it to the other side, we would have results that reflect the condition of the streets at the time of the survey in categories that reflect the people's assessments. In this report, then, we use data from the September 1999 survey, which has the added advantage of all data come from the same time period and season.

**Weighting**

Because of variation in the length of New York City blocks, statistics describing the percent of blocks were computed on a weighted basis. This means that, for example, longer block segments have relatively greater impact on the overall percentage of acceptable blocks while shorter blocks have relatively less impact.

The figures for Jolts Encountered Per Mile are simply the total number of bumps divided by the miles of street sampled. This ratio requires no weighting procedure.
IV. ESTIMATION AND COMPUTATION OF STANDARD ERRORS

Typical statistical procedures were employed to generate standard error measures and confidence intervals for the collected data. The standard error represents an estimate of the difference between the average values for the streets sampled and the true average for all the streets that could have been sampled. Usually, if the sample size is large, as in this study, the standard error will be small. Using the standard error a 90% confidence interval can be calculated. A 90% confidence interval is a range of values that has a 90% probability of covering the true value given the sample data available. For example, in our report, the measured average of significant jolts per mile for Community District Brooklyn 18 is 2.91. Using the confidence interval, it can be said that based on the available data it is 90% certain that the true value of jolts per mile in that district is between 2.12 and 3.70. The following formulae were used to estimate the standard errors. The confidence limits shown for the city, five boroughs and two districts in Table 3 are equal to the estimate $R$, plus or minus 1.64 times the estimated standard error of $R$. It should be noted that the sampling errors in community districts are higher than the sampling errors in the borough and citywide levels because the sample is smaller at the community district level.

Computation of Basic Estimates

The Basic Estimates (Percent of blocks acceptable and Number of Jolts Encountered Per Mile) are statistically described as "Ratio" estimates of the form

$$R = \frac{\sum_{h=1}^{H} \sum_{i=1}^{n_h} Y_{hi}}{\sum_{h=1}^{H} \sum_{i=1}^{n_h} X_{hi}}$$

In this formula, $H$ denotes the number of Community Districts included in the particular estimates. For various estimates, $H$ may range from 1, for a single community district, to 59, for the entire city. The lower case letter $h$ is used as the corresponding index for $H$.

The subscripted letter $n_h$ denotes the sample size (in terms of selected clusters) within the $h^{th}$ district. In general $n_h$ was 40, but in some instances the number was less than 40, because streets were either closed, non-existent or otherwise not measured.

The probability of selection applied to all clusters within the $h^{th}$ community district (with appropriate non-observation compensation) is denoted as $f_h$. The values of $Y_{hi}$ and $X_{hi}$ are defined as follows:

For both the percent of blocks acceptable and the number of jolts per mile, the value $X_{hi}$ is defined as the number of measured feet in the $i^{th}$ selected cluster of the $h^{th}$ community district. Then, the probability weighted value $X_{hi}$, is defined as $X_{hi} = X_{hi} / f_h$.

4 This section was prepared by Dr. Martin Frankel.
For the estimate of the percent of blocks acceptable we define $Y_{hi}$ as total number of measured feet in the "acceptable" blocks within the ith selected cluster of the hth community. This value was multiplied by 100, to convert a proportion to a percentage. For the number of jolts per mile, we define $Y_{hi}$ as the total number of jolts recorded in the ith selected cluster of the hth community divided by the constant 5,280. This constant is included so that the estimate is re-scaled from jolts per feet to jolts per mile.

Then, the probability weighted value $Y_{h'}$, is defined as $Y_{h'} = Y_{hi} / f_h$.

The standard error of $R$, $se(R)$ is estimated by $se(R)$.

$$se(R) = \left[ \frac{1}{X^2} \left( \sum_{h=1}^{H} \sum_{i=1}^{n_h} var(y_h) + R^2 \cdot var(x_h) - 2R \cdot cov(y_h, x_h) \right) \right]^{1/2},$$

where

$$X = \sum_{h=1}^{H} \sum_{i=1}^{n_h} X_{hi},$$

$$X_h = \sum_{i=1}^{n_h} X_{hi},$$

$$Y_h = \sum_{i=1}^{n_h} Y_{hi},$$

$$var(y_h) = \frac{1-f_h}{n_h-1} \left( n_h \sum_{i=1}^{n_h} y_{hi}^2 - y_h^2 \right)$$

$$var(x_h) = \frac{1-f_h}{n_h-1} \left( n_h \sum_{i=1}^{n_h} x_{hi}^2 - x_h^2 \right)$$

$$cov(x_h, y_h) = \frac{1-f_h}{n_h-1} \left( n_h \sum_{i=1}^{n_h} XY_{hi} - X_h Y_h \right)$$
Table 3. Selected Survey Findings and Confidence Interval Ranges (at a 90% Confidence Level)

<table>
<thead>
<tr>
<th></th>
<th>Findings</th>
<th>90% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>New York City</td>
<td>% of Blocks Rated Acceptable</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>8.7</td>
</tr>
<tr>
<td>Bronx</td>
<td>% of Blocks Rated Acceptable</td>
<td>59%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>8.5</td>
</tr>
<tr>
<td>Brooklyn</td>
<td>% of Blocks Rated Acceptable</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>8.1</td>
</tr>
<tr>
<td>Manhattan</td>
<td>% of Blocks Rated Acceptable</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>14.4</td>
</tr>
<tr>
<td>Queens</td>
<td>% of Blocks Rated Acceptable</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>6.7</td>
</tr>
<tr>
<td>Staten Island</td>
<td>% of Blocks Rated Acceptable</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>6.8</td>
</tr>
<tr>
<td>Brooklyn 18</td>
<td>% of Blocks Rated Acceptable</td>
<td>86.83%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>2.91</td>
</tr>
<tr>
<td>Manhattan 1</td>
<td>% of Blocks Rated Acceptable</td>
<td>20.56%</td>
</tr>
<tr>
<td></td>
<td>Number of Significant Jolts Per Mile</td>
<td>31.70</td>
</tr>
</tbody>
</table>

Statistical Significance of Difference Between Estimates From Two Survey Years

The standard error for the difference in score between the 1999 estimate and the 1997 estimate is determined as follows.

In formula terms, let A be the estimate from 1997, let B be the estimate from 1999, let C be the standard error from 1997, and let D be the standard error from 1999.

The standard error of the difference is

\[ SEDIFF = \sqrt{(C^2 + D^2)} \]

If the difference between the two years divided by the standard error is either more than 1.96 or less than -1.96, then the difference is statistically significant at the .05 level. This standard error of difference is conservative because it excludes the covariance term.

The formula for calculating the difference between the estimates of the two years is

\[ \frac{(A - B)}{SEDIFF} \]