The Effect of Source Data Automation Technology on Paratransit Efficiency

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A UNIVERSITY TRANSPORTATION CENTER FUNDED THROUGH TEA-21

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Prepared for:
U.S. Department of Transportation
Research and Special Programs Administration
Washington, DC 20590

January 2003
Final Report

DISCLAIMER

Abstract

This research describes the role of statistical process control methodologies in a systems approach to assessing transit performance. Control charting techniques are used to evaluate the effect of the implementation of automated passenger data collection technology on the performance of a small urban transit system. Results indicate that while transit performance was fairly consistent at the beginning of the implementation, operating data later exhibited unnatural variation, indicating an upward shift or improvement in the mean. Comparison of the control charting results with traditional analysis of variance results revealed that the control charting methodology detected performance changes more rapidly. This finding illustrates the value of control charting methodologies in monitoring the effects of technology implementation on transit performance.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
DTRS93-G-0018

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
THE EFFECT OF SOURCE DATA AUTOMATION ON PARATRANSIT EFFICIENCY

5. Report Date January 2003

6. Performing Organization Code

7. Author(s JOANNE M. SULEK AND MARK R. LIND

8. Performing Organization Report No.

9. Performing Organization Name and Address
Urban Transit Institute/Transportation Institute
NC A&T State University, Greensboro, NC 27411

10. Work Unit No.

11. Contract or Grant No. DTRS93-G-0018

12. Sponsoring Agency Name and Address
US Department of Transportation
Research and Special Programs Administration, Washington, DC 20590

13. Type of Report and Period Covered
Final January 2002-December 2002

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The purpose of this research was to investigate the use of statistical process control methods to monitor the effect of an automated passenger data collection technology on transit performance. Control charts were constructed to evaluate process consistency in a small urban transit system. While performance was consistent prior to the technology implementation, operating data exhibited an upward trend after the technology was introduced, indicating improved performance. Comparison of control charting results with traditional analysis of variance results revealed that the control charting methodology detected performance changes more rapidly. This finding illustrates that control-charting techniques are well suited to monitoring the effects of new technologies and other improvement initiatives on transit operations.

17. Key Words
Statistical Process Control
Source Data Automation Technology
Control Charts

18. Distribution Statement

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
19

22. Price
N/A

Acknowledgments

The co-principal investigators wish to thank the Department of Transportation and the Urban Transit Institute for their generous research support. In addition, the co-principal investigators wish to express their sincere appreciation to Mr. Heyward Johnson, Director of Augusta Public Transit; Ms. Barbara Richburgh-Cado, Administrative Manager of Augusta Public Transit; Mr. Juriah Lewis, Transit Planner for Augusta Public Transit; Mr. Scott Murphy, Executive Director of Aiken Public Transit; Mr. Mike Bradshaw, Transit Manager for Piedmont Wagon, Hickory, N.C.; and Mr. Tom Crider, Executive Director of Cleveland County Public Transit.

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Introduction

As the principles of the Total Quality Management approach to public transit management become more widely accepted, transit managers are paying greater attention to the role of performance measurement in the continuous improvement process. Traditionally, performance measurement of transit operations involved the construction of a variety of productivity ratios that provided a “snapshot” of transit performance for a particular month or year. (Fielding, 1987) More recently, a number of studies have argued that riders’ perceptions and experiences should constitute a key component in a TQM approach to transit performance evaluation and improvement (Cunningham and Lee, 1997).

While both of these approaches can provide useful information to the transit manager, they do not comprise a sufficient set of tools for supporting continuous improvement. This is especially true when a transit system implements a large-scale performance improvement initiative such as the adoption of a new technology. In such cases, management requires performance measurement tools suitable for continuously monitoring the effect of the innovation on the service process and, even more importantly, capable of signaling a significant change in performance in a timely manner.

The research effort described in this report investigated the use of statistical process control methodologies for monitoring and evaluating the effect of an automated passenger data collection technology on transit performance in a small urban transit system. The material presented in this technical report is organized as follows. First, the role of statistical process control methodologies using a systems view of transit performance will be examined. This will be followed by a discussion of the research context and the data collection technology that was implemented. The control chart methodology will then be illustrated and results of the longitudinal analysis will be presented. Next, implications of the study’s findings will be delineated. Finally, dissemination of the methodology and findings contained in this study will be reported.

A Systems Approach to Transit Management

A public transit system, like any other service operation, consists of a set of processes that transform a variety of resources into service products. Thus, as in other service contexts, superior performance by a transit system depends on a system-wide effort. Building on the work of Fielding (1987), the co-principal investigators proposed a systems model for evaluating transit performance in an earlier phase of their research (Sulek and Lind, 2000). In this systems model, high performance depended on the efficient use of multiple inputs (e.g. labor, capital, fuel, and materials) in producing service output.

The research effort described in this report extends the systems approach used in the authors’ earlier study in two ways. First, it broadens the systems perspective used in the earlier study by applying a diagnostic framework of service delivery, as proposed by Chase and Bowen (1991), to transit performance evaluation. Second, it illustrates how statistical process control (SPC) techniques can be used to enact this broader systems perspective of transit performance.

In the Chase and Bowen (1991) framework for service delivery, service quality is determined by three major system components: technology, people, and systems. In a transit context, the technology component includes vehicles, facilities, equipment, and software. The second component, people, consists of transit employees, riders, and other stakeholders in the transit system. The systems component encompasses control systems as well as scheduling and routing systems. Transit performance may benefit when aspects of these components are redesigned in some manner. For instance, the introduction of an automated passenger data collection technology may simplify vehicle boarding and unloading, scheduling and billing, and may encourage increased ridership and revenue through new payment options (Hess, Yoh, Iseki and Taylor, 2002).

In proposing their systems framework, Chase and Bowen (1991) call for the development of an “integrated systems management tool” to monitor the effect of changes in technology, systems and worker/customer attributes on system performance. While their service effectiveness questionnaire (Chase and Bowen, 1991), as well as similar survey instruments, qualifies as a diagnostic tool with a systems focus, it incorporates only perceptual data – not operating data generated by the process itself (Sulek, 2003). When a new technology or other system change is implemented, it is not advisable to rely only on perceptional data to gauge its effect on transit operations. Since on-board surveys can be both time consuming and labor intensive, they are not typically undertaken on a continuing basis. Thus, perceptual data may be collected only intermittently and results from the survey-data analysis may lag actual data collection by a considerable length of time. Moreover, while customer comments may provide useful feedback, they cannot deliver a complete systems view of transit performance. Operating data are also required.

When operating data are used to assess the effect of a new technology or other system design change, data analysis should involve more than just the computation of annual performance ratios. Because such measures are summary statistics, they reflect overall performance averages, which smooth both high and low values that may have occurred during the year. In addition, averages mask upward and downward trends in performance data. While some transit managers may choose to augment their analysis of annual ratios with monthly or weekly time-series data, an accurate picture of system performance will not emerge unless the data are analyzed from a systems perspective.

When guided by a systems perspective, data analysis not only utilizes a process focus but also addresses the critical issue of performance consistency. A process focus entails more than evaluating the quality of the final service product; it also includes analysis and control of the service process itself (*Western Electric Handbook*, 1956; Sulek, 2003). Since any service process will change to some extent over time, it is important to establish reliable monitoring and control systems to determine when fluctuation or variation in a process variable exceeds what is normally expected (Wheeler and Chambers, 1991). In other words, the ability to monitor process consistency constitutes a key element in a systems perspective of service performance (Chase and Bowen, 1991).

If a process is inconsistent prior to the introduction of a new technology or other initiative, then it will be difficult, if not impossible, to assess the effect of the innovation on the process. Apparent shifts in the levels of key process variables may result from the presence of special, intermittent causes of variation, which have entered the process. These sources of unnatural fluctuation may be completely unrelated to the implementation effort. Clearly, it is critical to identify and remove these special causes prior to the introduction of a new technology or other system changes. Fortunately, a statistically rigorous methodology already exists for accomplishing these objectives.

For over sixty years, the manufacturing sector has used statistical process control charts to assess process consistency. In recent years some researchers have begun to examine the use of control charts in service contexts; however, the advantages of control charts have generally been overlooked by service managers – including transit managers. The relative simplicity of control-chart construction and interpretation makes control charting an attractive alternative to more complex techniques. Furthermore, control charts can be used when process data do not meet the assumptions of statistical models or when data aggregation obscures the true effect of a process improvement initiative. Unlike traditional statistical techniques, control charts can convert limited operating data into a graphical representation of the state of the service system. Thus, control charts can quickly identify a decline or improvement in performance.

On a traditional control chart, as originally devised by Dr. Shewhart, statistical limits called control limits represent the boundaries on variation that would be expected from a stable process. If a process is consistent, values plotted on the chart should fall between the two limits nearly 100% of the time. An observation that is plotted beyond either limit indicates that the process is inconsistent or unpredictable and special causes of variation should be sought. Even if all observations remain within the limits, unnatural data patterns may still be appear on the control chart. These unnatural patterns also indicate that some special cause of variation has entered the process. The *Western Electric Handbook* (1956) discusses these unnatural control chart patterns in detail and describes specific problems that may cause these patterns.

Once special causes of variation have been removed from a process, remaining variation in process output will be due to common causes, which are inherent in the process and thus impossible to remove without redesigning some aspect of the process. When only common cause variation is present in a process, the process is said to be in a state of statistical control, and it is considered a consistent (or predictable) process.

In practice, there are two basic types of Shewhart control charts: (1) those that use variable data and (2) those that use attribute data. Variable data are measured on a continuous scale. For instance, the number of gallons of fuel used by a fleet of buses in a particular week is a continuous variable. The monthly repair costs for a fleet of vans is another example of variable data. In contrast, attribute data are measured on a binary scale since an item either has a desired characteristic or it does not. For example, a rider is either satisfied with transit service provided or is not satisfied, a van either passes vehicle safety inspection or it does not, a bus driver is either on time at a particular stop or is not on time, and so on.

This report will illustrate the application of control charting to operating data that were measured on a continuous scale. As the following section will discuss, the application occurred during the implementation of an automated passenger data collection technology by a small urban transit system.

Research Context

Small transit systems, like their large urban counterparts, must confront spiraling productivity problems and higher costs, particularly in such areas as paratransit services (Levine, 1997). Simultaneously, transit systems must effectively monitor and maintain an acceptable level of system performance (Briddell and Arden, 1998). To deal with these concerns, a number of larger systems have implemented automated technologies, which enable managers to collect passenger and system data with a degree of accuracy and in volumes that were heretofore impossible (Baltes and Rey, 1999). Currently, a number of small urban and rural systems are considering the adoption of this same type of technology.

Four such small transit systems formed the context of this research effort. These systems were: (1) Augusta Public Transit, Augusta, Georgia; (2) Piedmont Wagon, Hickory, North Carolina; (3) Cleveland County Transit, Shelby, North Carolina; and (4) Aiken Public Transit, Aiken, South Carolina. All of these systems considered automated data collection technology a promising tool in improving the performance of their transit operations, including paratransit services; however, some of these systems have experienced problems in implementation.

Consequently, the statistical analysis presented in this report is based on operating data from Augusta Transit only. In Year II of this research effort, the principal investigators will report their findings on the implementation efforts of the remaining three systems.

Augusta Public Transit (APT) serves the Augusta-Richmond County area in northern Georgia. The system operates twelve fixed routes with a peak-load fleet of seventeen buses. Bus service typically operates from 6:00 AM to 6:30 PM Monday through Friday. Ten routes operate on Saturday and there is no Sunday service. Augusta Public Transit increased its regular fare from $.75 to $1.00 in April 2001. At the same time, APT purchased automated fare box technology that would allow the system to offer its passengers new payment options such as monthly swipe-card passes. The technology was implemented during the following winter with weekly and monthly passes becoming available to riders in March 2002. In addition to providing riders more convenient payment options, the new technology was also viewed as a tool for improved systems monitoring and evaluation. As the following section will illustrate, control charting further enhanced the systems monitoring capability provided by the new technology.

Methodology

The principal investigators utilized a longitudinal approach in evaluating system performance at Augusta Public Transit. The initial data collection stage occurred in January 2002 when time-series data for revenue, vehicle mileage, passenger counts, and fuel usage were collected. Additional data collection occurred in the fall of 2002, after the swipe card system was introduced. Since APT regarded revenue and ridership as key indicators in their service monitoring and evaluation process (*Augusta Public Transit: Transit System Analysis, Final Report*, 2001), control charts for the ratio revenue per passenger will be used to illustrate the control charting methodology presented in this report. In constructing these charts, the principal investigators selected a type of Shewhart chart known as the x chart or control chart for individuals. This type of chart is appropriate when only one observation per time period is available. The *Western Electric Handbook* (1956, p.21) notes that x charts are particularly useful for monitoring efficiencies, quality costs, shipments, productivity ratios, maintenance costs, revenues, absences, and the like.

The steps for constructing the x chart are described in the *Western Electric Handbook* (1956) and will be illustrated in detail for the time series data collected in January 2002. This time series consisted of 20 ratios, which are shown below in Table 1.

Table 1

January Bus Day	**Revenue/Passenger**
1	0.508
2	0.599
3	0.690
4	0.538
5	0.657
6	0.547
7	0.544
8	0.524
9	0.664
10	0.562
11	0.523
12	0.514
13	0.506
14	0.481
15	0.667
16	0.503
17	0.624
18	0.465
19	0.452
20	0.612

The following steps were used to construct the x chart:

1. The centerline value for the x chart was found by taking the arithmetic mean ($\bar{x}$) of the 20 individual observations: $\bar{x}$ = (.508 + .599 + .690 ... + .612)/ 20 = .588

2. The 2 period moving ranges for the set of individual ratios were computed by subtracting each weekly ratio from the preceding week's ratio and recording the absolute value of this difference. For example, the first moving range = .508 (week #1's ratio) - 599 (week #2's ratio) = .091. Similarly, the second moving range = .599 – .690 = .091. There were 19 moving ranges in all.

3. The arithmetic mean $\overline{MR}$ of the moving ranges found in step #2 was calculated:

$\overline{MR}$ = (.091+ .091 + .152 + .119 ... + .160)/ 19 = .089

4. The upper control limit (UCL) and the lower control limit (LCL) for the control chart were found by applying the formulas:

UCL = $\bar{x} + 2.66\overline{MR}$ = 0.83

LCL = $\bar{x} - 2.66\overline{MR}$ = 0.35

5. The individual observations were plotted on the chart to determine if the process was in control. As the control chart in Figure 1 shows, this process was consistent since none of the ratios were plotted beyond the upper control limit or the lower control limit.

Results

Since the x chart for the variable revenue per passenger was in control during January, the principal investigators concluded that there were no significant special causes of variation in this time-series data. This indicated a stable cause system prior to the implementation of the swipe card technology. However, x charts for time series data collected during October and November 2002 – after the swipe card use had become well established – exhibited a lack of statistical control. Figure 2 shows a general upward shift in the October data with two observations on or above the upper control limits. In Figure 3 two points from the November time series exceed the upper control limit and an even more pronounced shift appeared.

In addition to control charting, the principal investigators used analysis of variance (ANOVA) to test the time-series data for significant changes in the mean. Single factor ANOVA results revealed no significant difference between the January mean and the mean for October (see Table 2) and no significant difference between the January mean and the mean for November (see Table 3). Thus, unlike the x chart, the ANOVA did not signal a significant improvement in the value of the ratio.

Managerial Implications

The preceding results demonstrate the value of control charting in evaluating process improvement following the implementation of a new technology or other system change. Because control charting allows continuous monitoring of a process variable, a transit manager can use control charts to quickly detect shifts in the level of a performance ratio. In contrast, if a manager uses ANOVA to examine the impact of a process redesign effort, he or she must wait until the analysis of variance reveals too much overall variation among sample means (Craig, 1947). This requirement is especially problematic when a downward trend is developing in a performance ratio since the ANOVA might not detect a lack of control in the process until special causes have greatly eroded some aspect of system performance.

In addition to promptly signaling sudden changes in process stability, control charts possess other advantages compared to more complicated techniques like analysis of variance. First, unlike ANOVA, the control chart is a visual device that is easy to understand; furthermore, the control charting procedure is easy to learn. Second, control charts can give the manager a picture of process performance on a daily or weekly basis, in contrast with analysis of variance, which is a summary method that is based on averages (Craig, 1947). Finally, a control chart can be used as long as the manager wishes, provided control limits are updated to reflect permanent changes in the dispersion or the mean of the process variable that is being monitored. As noted in the *Western Electric Handbook*, (1956), the manager may chart any process variable as long as it remains important. While it is fairly simple to track and analyze many variables simultaneously with control charting, it is more difficult to do so with more complex methods like ANOVA.

Despite the relative simplicity of control charting, certain implementation problems can limit its usefulness in practice. These problems include lack of management commitment, inadequate measurement systems, monitoring the wrong process variables and ratios, failure to understand the potential benefits of control charting, and inappropriate application and interpretation of control charts. Fortunately, many of these problems can be avoided if adequate training and education occur (Mason and Antony, 2000). However, training should encompass all levels of transit operations; in particular, the transit manager must understand why statistical control is vital to continuous improvement and how to assess process stability.

Dissemination of Research

Since education and training in statistical process control support the effective implementation of the charting techniques described in this research, the principal investigators made a special effort to properly transfer their research findings to transit managers. Initial technology transfer occurred during site visits when the principal investigators met with the transit managers participating in this research effort. Technology transfer will continue during the spring of 2003 with: (1) a training session on x charts to be conducted at Augusta Public Transit; (2) an executive research summary appearing in the NCPTA newsletter; and (3) dissemination of research findings at the NCPTA conference in Wilmington, NC, in May 2003. In addition, the principal investigators have prepared a tutorial on control charting for electronic dissemination to NCPTA members. Finally, the authors are preparing an article based on this research for submission to a refereed transit journal.

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Appendix

Table 2

**Single Factor Analysis of Variance:
January 2002 vs. October 2002**

SUMMARY

Groups	Count	Sum	Average	Variance
January	20	11.17917	0.589958	0.00517
October	20	11.82763	0.591382	0.01099

ANOVA

Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	.010513	1	0.0105	1.3003	.2613	4.0981
Within Groups	.307218	38	0.0081			
Total	.31773	39				

Table 3

Single Factor Analysis of Variance
January 2002 vs. November 2002

Summary

Groups	Count	Sum	Average	Variance
January	20	11.179	.558958	0.00517
November	20	12.07947	.603973	0.01200

ANOVA

Source of Variation	SS	df	MS	F	P-value	F Critical
Between Groups	0.020263	1	0.02026	2.3599	0.13277	4.098169
Within Groups	0.326288	38	0.008587			
Total	0.346552					

Figure 1

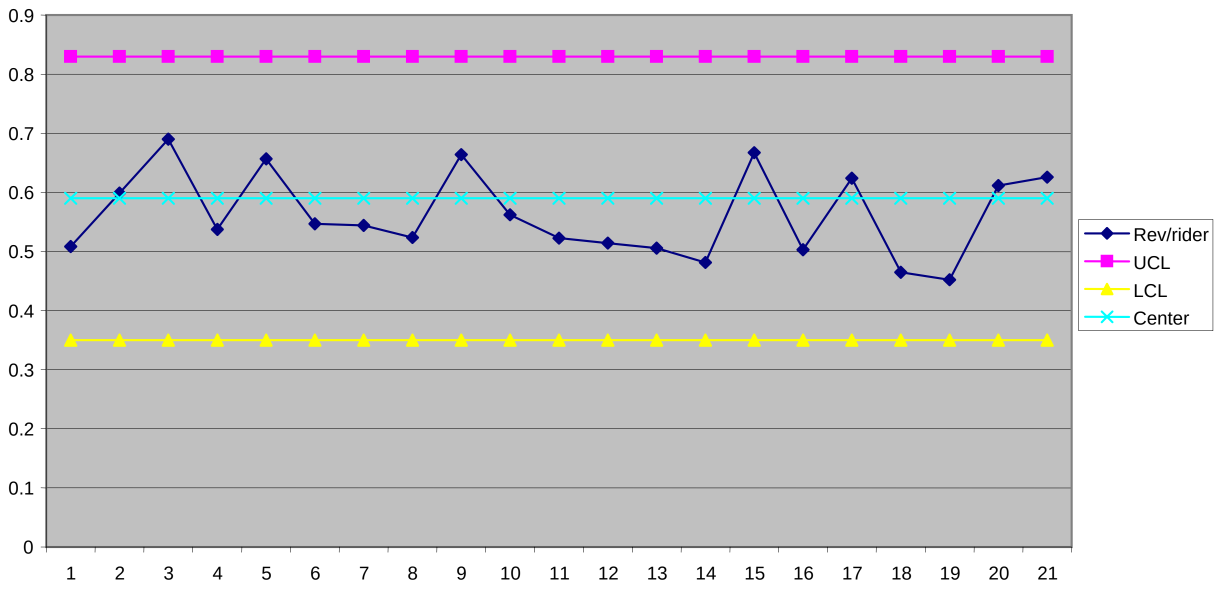
Revenue Per Passenger in January
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Rev/rider
UCL
LCL
Center

Figure 2

Revenue Per Passenger in October

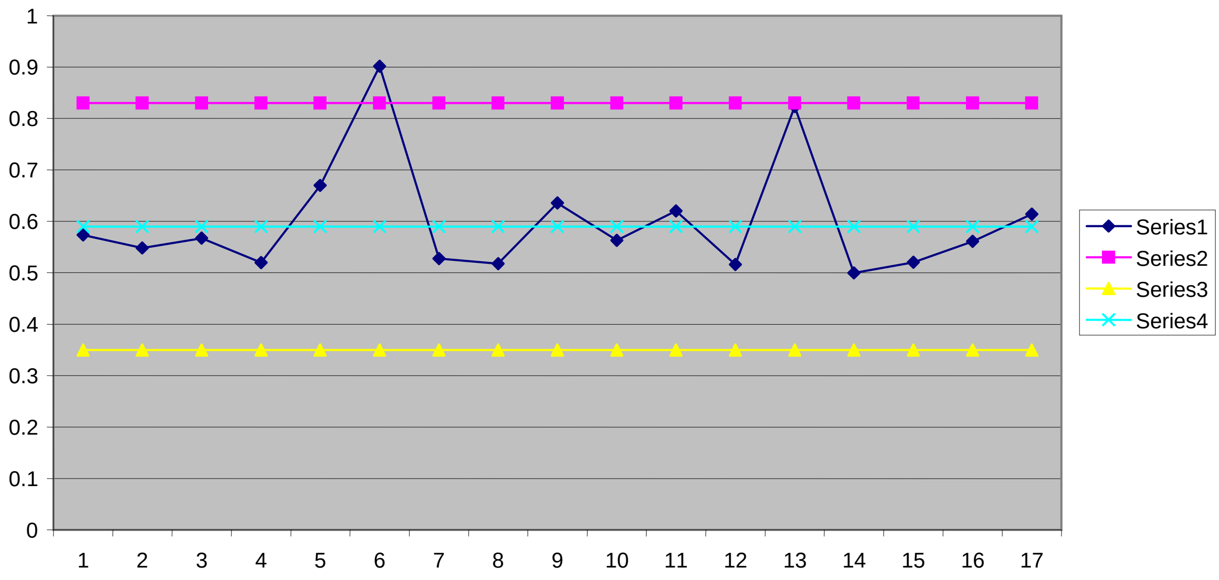

Figure 3

Revenue Per Passenger in November