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A Strategic Look at Friday Exceptions in Weekday Schedules for Urban Transit: Improving Service, Capturing Leisure Markets, and Achieving Cost Savings by Mining Automated Fare Collection Ridership Data

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Abstract

This paper describes a strategic business case for weekday exception scheduling in urban transit services, specifically, treating Fridays differently from other weekdays. As commuters trend towards more flexible work scheduling, telecommuting arrangements, and 4½-day weeks, gaps between midweek and Friday ridership have widened. Exception schedules neither were nor are unusual; transit operators ran full Saturday lunchtime rush-hours in the interwar era, while private bus companies, airlines, and freight railroads operate exceptions today. Systematic consideration of day-of-week scheduling confirmed that Friday modifications were best leveraged in better matching service supply to ridership demand. Longitudinal analysis of New York City Transit's (NYCT) Automated Fare Collection (AFC) data revealed more regular commuters skipped Friday's trip than other weekdays'. Analysis by route/time-period for 14 representative routes over ten months show 4.7% lower ridership on Fridays, potentially allowing 7.4% reductions in vehicle-hours operated. Available savings were route-specific, with 25% service reductions possible on some, whereas 25% service fortification was required on others with higher Friday ridership. Implementing separate Friday schedules systemwide could provide surplus of \$10~\$17 million (0.6%) for reinvestment elsewhere in the network. Additionally, reduced Friday crew requirements could lead to 1.2%~2.4% increases in desirable weekend-inclusive regular days-off (RDOs) and 2.4% reduction in non-preferred midweek RDOs. Two prerequisites for realizing savings are: a computerized run-cutting system and an infrastructure for ridership analysis across multiple days, routes, and time periods. Transit agencies should determine if its routes can benefit from weekday exceptions. If productivity improvements are indicated, contracts permitting weekday work program exceptions can be negotiated.

Introduction

This research begun as an anecdotal observation by one author that Friday's parking utilization at a suburban New Jersey express bus Park & Ride is noticeably lower compared to other weekdays. Informal counts also revealed lower Friday ridership. The authors posed the strategic question: can urban transit agencies improve both productivity and service by operating and publicizing different schedules on Fridays, or some other day(s) of the week? Using New York City as example—a more urban setting than Jersey—this paper explores if ridership differences were sufficient to warrant routine (picked) schedule adjustments, and if these adjustments will have meaningful impacts on performance and efficiency. Is there a business case for weekday exception scheduling?

The 2008 economic crisis had compelled the Metropolitan Transportation Authority (MTA) to take several unprecedented actions to restore fiscal health and eliminate budget deficit: aggressive cost reduction and value engineering through our "Making Every Dollar Count" concept (*1*); most extensive fare adjustments and fare policy revisions in recent memory (*2*,*3*); early retirement incentives and involuntary separation for certain employees (*4*); and for the first time in thirty years, systematic and wide-ranging service reductions (*5*,*6*). These unfortunate actions are taking place while high gasoline prices make transit an attractive alternative. Despite the recession, 2010 subway ridership was the second-highest since 1950 (*7*). Desire for cost-neutral service improvements drives this research—determining whether meaningful resource reductions are achievable; if new markets can be captured; and if projected savings can allow reinvestment, asset redeployment to new service, or reinstating lost service.

The current effort is divided into four parts: (a) academic literature review; (b) state-of-practice review, to determine extents of weekday exception schedule operation by transportation carriers; (c) ridership analyses, to explore scope and nature of weekday ridership pattern exceptions, understand why they occur, and determine if differences are exploitable through scheduling; (d) cost analysis, to determine available savings and/or reinvestment potential. The ridership data is derived almost entirely from the Automated Fare Collection (AFC) system. Agencies interested in leveraging recurrent travel patterns can conduct their own analysis using similar methods.

State-of-Practice and Literature Review

Operating different weekday schedules by day-of-week (DOW) might seem unconventional, although the general concept of matching service supply to resource availability or cyclic travel demand changes is not new. Alternatively, it could be viewed as a logical extension of operating different schedules on weekends.

Several prior research areas are relevant to weekday exception scheduling. Standard travel diary surveys have been conducted at the weekly level, whether self-reported (*8*), Global Positioning System (GPS) assisted (*9*), or even bus-driver and AFC assisted (*10*). These multiday surveys yield useful information about multimodal trip-making patterns, while multiweek surveys (*11*) capture peoples' daily rhythm. They're typically conducted for transportation demand model calibration rather than transit schedulemaking.

As AFC analysis became standard, single farecard multiday origin-destination enumeration and comparisons across days became ubiquitous (*2*,*12*). Much AFC research involves tracking farecards over longer periods (*14*), or aggregation to understand long-term averages (*15*). Papers often include discussions of transaction volume differences by DOW (*16–18*). Heuristics can exploit this property for data validation (*19*). Although extent research doesn't explicitly address using it for transit capacity management and scheduling, DOW-based highway congestion-pricing using electronic toll collection was studied (*20*).

Modern differential weekday schedule research appears to pre-date the flextime era, with staggered work hours and four-day, ten-hour work weeks implemented in some cities before 1975 (*21*), main motivation being energy conservation. This research continued into the 1990s (*22*). Indeed, current industry standard scheduling manuals briefly discuss exception scheduling:

> What type of service is operated on each day of the week? Monday through Friday schedules are common, but that was not always the case. Many systems use a different Friday schedule on some routes where traffic is particularly slow or where service operates later at night. […] On larger systems, is there a holiday or otherwise reduced schedule operated on designated holidays? Many systems operate Sunday schedules on "major" holidays. (*23*)

However, authors' research didn't find many North American transit agencies routinely *publishing* different Friday schedules. Some agencies schedule Friday and Monday crews differently for weekend transitioning purposes, but revenue trips generally remain unchanged.

Exception Schedules Today

Figure 1 provides published examples of weekday differential scheduling for different reasons, achieved in different ways. Its usage seems more common in the private sector.

On New York's subways, differential schedules mainly occur off-peak and overnight, to accommodate track work. Implementation of "supplemental" schedules involves calling regular crews with modified assignments, potentially extra-board and overtime crews, because construction differs every week, and is not known sufficiently in advance to be picked.

However, New York City buses operate a picked weekday exception schedule based on public and parochial school holidays; school calendars govern when reduced schedules are operated. Services are thinned out, and trips relieving school-related overcrowding aren't operated. However, specifically designed "school closed" schedules aren't appropriate for lighter regular days. Concurrently with our research, the idea of reducing Friday service to match class schedules at a local community college was independently suggested by a blogger (*24*).

Long Island Rail Road (LIRR) and Amtrak Friday afternoon extras accommodate peak travel demand and form a part of regular schedule. Even though they are considered normal operations repeating every Friday and planned prior to summer, extra-board crews are assigned. Both LIRR and Amtrak also adjusts consist lengths of regular departures to accommodate Friday ridership, necessitating different crewing arrangements on peak days. Recently, Amtrak's scheduled running times explicitly recognized seasonal and weekly factors, to improve reliability (*25*).

While intercity carriers and some transit agencies increase service to accommodate Friday leisure travel—like Massachusetts Bay Transportation Authority's (MBTA) Night Owl service (*26*), commuter carriers have deemed some employers' transition to 4½-day flexible work weeks important enough to adopt various Friday exceptions, including fewer morning trips (for lower loads), additional early afternoon trips (catering to those leaving early), and additional trips or modifications geared towards capturing leisure demand even on commuter routes.

Operators with Friday exceptions often recognize Friday travellers as a distinct market and support their needs specifically. San Diego's Breeze Bus and Taiwan's night trains (*27*) serves family needs of enlisted military, whereas Lucky Star and Sunshine Travel buses serve student and casino travel in immigrant communities (*28*).

Historical Examples

The most striking DOW modifications to weekday peak schedules actually came from NYCTA:

> Following World War II, New York City was still primarily on a 5½-day week workday schedule. Rush hour service generally included a Monday through Saturday morning rush, a Monday through Friday late afternoon/early evening rush, and a Saturday early afternoon (Noon-2:30 PM) return rush. A reduction in Saturday service gradually occurred from 1950 to 1953, as Saturday morning was eliminated from the typical workweek. (*29*)

NYCTA's practice was not uncommon in interwar years, when work weeks were considered Monday through Saturday. "Weekday" and Sunday schedules for Boston-Riverside suburban service shows adjustments accommodating 5½-day work weeks (Figure 2). Also in Boston, special Wednesday schedules were operated in the 1940s to accommodate heavy downtown evening shopping. Such practices weren't limited to the Northeast:

> [In Chicagoland,] Saturday schedules required adjustment in 1949 to tailor service to the 5-day week then rapidly becoming universal. The dropping of [Saturday morning workday] made rush hours practically indistinguishable on such days. (*30*)

Curiously, Metra Electric still publishes "Weekday" schedules with Saturday exceptions (*31*), even though many railroads have since moved to Monday-Friday formats.

Ridership Analyses

NYCT's AFC data shows that Fridays, school holidays, religious holidays, days immediately before or after public holidays, and inclement weather days (*32*) have total ridership lower than "peak" weekdays—Tuesdays and Wednesdays. Called "bridging effects" in economic literature (*33*), lower Friday ridership is evident in many cities' published AFC data (*16–18*).

However, to achieve true productivity and utilization improvements, differences on lower ridership weekdays (i.e., "valley" days) or different travel patterns must be significant enough to require modified service frequencies, particularly during rush hours. Additionally, modified days must be periodic and predictable, allowing different services to be planned in advance of schedule picks and publicly communicated. Last-minute short-term changes potentially confuse customers—and decrease crew utilization or incur overtime rather than achieve improvements, because crews have already been scheduled.

Cluster Analysis by Day-of-Week

Cluster analysis ("clustering") is assigning observations into subsets ("clusters") such that observations in the same cluster are similar. It's a method of unsupervised learning, commonly used for datamining (*34*). "Bottom-up" clustering works by merging the two observations that are closest together (based on defined distance measure) into a single group, then repeating this process on all subgroups until everything is in one large group (*35*). The output is a tree diagram ("dendrogram") showing relative relationships between all subgroups, with most similar observations always adjacent and grouped together.

Here, typical systemwide hourly bus ridership by DOW is clustered using an agglomerative hierarchical clustering algorithm (with weighted absolute difference in ridership as distance measure), resulting in clusters that can be scheduled together. The algorithm sorts DOWs in increasing ridership order. Generally, adjacent days and bracketed groups can be scheduled together if their ridership differences aren't too large. The intent is to examine systemwide day-groupings analytically.

Figure 3 shows clustering results using bus AFC data from 4/1/2010 through 4/30/2011 (13 months), containing 55-57 observations days per DOW. Ridership is first summarized by hour and date, and then 85-percentile values within each hour and day-type are found. 85-percentiles are used to prevent very-high ridership outliers (e.g., day before Thanksgiving) from skewing results, and to determine reasonable maximums (rather than averages) for scheduling purposes. Peak travel periods, often a cost-of-service constraint, are shown in grey.

As expected, Saturday/Sunday riderships are close and could be scheduled together, evidenced by (7-6) pairings; some agencies already offer "Weekend" versus separate Saturday/Sunday schedules. Early Friday afternoon ridership is weak compared to Mondays through Thursdays, with large percentage differences (5% to 8%) amounting to thousands of passengers; late afternoon, Friday and Monday ridership is weaker than Tuesdays through Thursdays (midweek) as evidenced by (5-1) pairings. Although effects are not quite so marked, Friday mornings (sometimes with Mondays) also show weaker ridership. Interestingly, Friday middays (noon to 2:59pm) show strongest travel demand of all weekdays, surpassing even Wednesday, normally the highest ridership day, as shown by unusual (3-5) pairings. After 11:00pm, Friday-Saturday and Sunday-Monday pairings became prominent; Friday ridership is substantially stronger than midweek, whereas Monday is weaker.

While clustering doesn't explain why variations occur, 5½-day transitional schedules of the interwar years offer an anology. Back then, early-quit on pre-weekend days meant tour-of-duty dismissals Saturdays before lunch; workers headed home on the railroad between noon and 2:00pm. Increasingly, although not overwhelmingly, Friday early-quitters are riding transit between noon-3:00pm, causing a mini-surge. While most workers continued to work into Friday's evening rush, some already returned home whilst others stayed late to enjoy City nightlife, resulting in lower-than-weekday late Friday afternoon volumes.

Borough-Level Analysis

New York City consists of five boroughs (administrative equivalent of counties), with different land use, commerce, and travel characteristics. Breaking down bus ridership by borough may reveal exploitable information for service planning. NYCT buses are divided into seven major service groups: rabid bus service (branded +selectbusservice), NYCT's express commuter buses from Brooklyn and Staten Island (with route identifiers beginning 'X', excluding MTA Bus Company's services), and one for local and limited routes in each borough (with arbitrary single-borough assignments for interborough routes, like B15 serving Queens/Brooklyn, and Q44 serving Bronx/Queens).

Figure 4 shows time versus DOW ridership profiles for six service groups using 85-percentile total hourly boardings, both as (absolute hourly) differences and (relative) percentage differences between Monday and Friday counts versus midweek averages. This analysis used data from 7/1/2010 through 4/30/2011, containing 44-46 observations days per DOW, excluding earlier data from NYCT's major service restructurings (*5*) effective 6/27/2010 which significantly altered many routes' characteristics.

All Friday difference curves, whether absolute or relative, seem similar at first, assuming prototypical 'W' shapes. For discussion, we term the first valley 'AM dip,' first peak the 'midday surge,' second valley the 'PM dip,' and final peak the 'night rush.' Closer inspection reveals subtle differences between boroughs, leading to further hypotheses.

Deepest 'AM dip' in absolute difference for all outer boroughs (except Manhattan) coincides with heaviest one-hour ridership, from 0700-0759 ('07' hour). In Manhattan, deepest 'AM dip' is during 07 hour, but highest ridership is 08 hour. Since morning peak service is generally most expensive to staff (*36*), reducing service during Friday's 'AM dip' could improve productivity. However, deepest 'AM dip' in percentage difference for all boroughs precede heaviest one-hour ridership by an hour. Outer boroughs have maximum relative 'AM dip' at 06 hour although peak ridership occurs during 07 hour; again, Manhattan has 'AM dip' at 07 hour and peak ridership during 08 hour. This suggests early commuters are over-represented amongst those with different Friday travel patterns.

Highest 'midday surge' in percentage difference occurs during 14 hour, but the surge's magnitude and duration varies by borough. Queens has the smallest surge, during 14 hour only; Bronx and Staten Island from 13-14 hours; Manhattan from 12-14 hours; Brooklyn from 11-14 hours. If midday surge is associated with commercial activity, Brooklyn and Manhattan are boroughs with highest business densities—therefore longest surges. Bronx and Brooklyn have heaviest 'midday surge', because subways offer competitive trip alternatives in Manhattan. Queens and Staten Island have lowest 'midday surge' because they are mostly residential.

Alternatively, if 'midday surge' is associated with commuters leaving work early, peaking ridership patterns should correlate with employment; indeed, Queens and Staten Island have lowest employment densities and smallest surges. The answer is probably a combination; Express Bus (dominated by commuters and not midday errands) show tiny midday surges in absolute terms, but dramatic spikes at 13 hour—likely resulting from a few commuters leaving Manhattan after Friday half-days.

Although end of 'midday surge' coincides with end of school days (14 hour), it's likely not exclusive to school activity. Separate analyses (using a smaller one-month dataset) showed that Monday and Friday trends remained robust even without student swipes. While students' Friday early quits contribute to midday rally, the general population was primarily responsible.

Temporal Characteristics Analysis

While trip purposes can't be determined from AFC alone, information can be inferred from same cards' multiday behaviour (*37*). Figure 5(a) is obtained by finding all cards whose first bus swipe of the day (FBSOD) occurred during Tuesday's and Thursday's morning commuter hours (in the same week)—presumably commuters whose inbound trip involves buses—then determining when their FBSOD occurred on Wednesday, Friday, and Saturday, and plotting frequency distribution of timing differences. If commuters on Fridays arrived at work earlier, later, not at all, (or used other modes exclusively), the effect ought to be visible by comparing Wednesday and Friday distributions. Presumably many don't work Saturdays, thus Saturday distributions should look very different. NYCT's morning peak extends well past 9am; this analysis defines morning commuter hours as 6am to 9:59am.

We chose the five-day Spring study period from Tuesday 3/1/2011 through Saturday 3/5/2011. Comparisons show that amongst regular commuters, few discernable differences exist between FBSOD on Wednesdays versus Fridays, but many exist when compared to Saturday (Figure 5(a)). Thus, as many commuters change regular morning commute times on Fridays as they do Wednesdays, inferring that reductions in Friday morning ridership aren't due to regular commuters with flex-time arriving (and leaving) early.

To confirm this null result and explore potential seasonality/religious observance impacts, more limited analyses using only morning commute data (Figure 5(b) and 5(c)) were carried out for two further study periods: Summer (Tuesday 6/15/2010 through Friday 6/18/2010) and Winter (Tuesday 12/14/2010 through Friday 12/17/2010). Summer captures potentially more flexible employer work-hour policies on Summer Fridays; Winter quantifies impacts of Jewish Sabbath observers, who must return home Friday before sundown, potentially resulting in earlier Friday morning rush hours close to Winter solstice. Following Cohen et al. (*32*), periods were carefully selected to avoid religious and secular holidays.

Figure 5(b)'s nearly symmetrical shape and extremely weak seasonality effect confirms that amongst regular MetroCard bus commuters, Friday morning temporal usage patterns are no different from other days. During Summer, slightly more variability exist in commuters' schedules, but no significant directionality in whether regular morning commuters travelled earlier or later. Figure 5(e) visualizes Spring data. If substantial biases (later or earlier) existed, the "flame" should arch upwards or downwards.

Lack of Friday commute time biases suggests other explanations for ridership decreases and temporal shifts. Regular commuters are neither arriving at work earlier nor making more trips later in the day (as on Saturdays), suggesting 'midday rally' is due either to: (a) regular commuters leaving work early, or (b) increased activity by non-regular commuters.

To explain decreased Friday peak ridership, Figure 5(d) shows an entire week's missing bus ridership patterns for all three study periods. Only about 30% of cards were seen all four mornings. For cards seen three days, passengers were twice as likely to skip morning commutes Fridays (11–12%) than Wednesday and Thursday (5–6%). For cards seen twice, passengers were doubly likely to skip Thursday and Friday (10–11%) than Wednesday/Friday or Wednesday/Thursday (4–5%)—attributed to part-timers working Mondays through Wednesdays. It appears employees not commuting Fridays simply stayed home—at least, until 10am. Larger but still quite weak seasonality is observed when cards not seen are considered. During summer, passengers are less likely to work full weeks (27% versus 32%), and more occasional passengers travel in the morning (30% versus 26%).

Multiday farecard number tracking efforts have one caveat: media attrition problems. Especially on New York's buses, farecards attrite at higher rates than in cities with hardier farecards like contactless or personal identification cards. Bus riders generally prefer lower sales-value media; many still use $4.50 pre-valued cards good for two rides. Recent fare policy changes (*2*) make it difficult to purchase exact rides—the 2003 MetroCard Bonus program required $10 purchase for exactly six $2 rides; 2008 revision required $7 purchase for four $2 rides plus five cents leftover; 2010 revision required $10 purchase for four $2.25 rides plus $1.70 that couldn't be spent without refilling. Larger residual values encouraged farecard reuse, consequently increasing average Pay-per-Ride farecard life from 7.7 to 8.6 fares. Some Thursday/Friday drop-offs can be attributed to attrition. Weekly pass customers may have corresponding paydays, and thus expiring passes on Thursdays/Fridays, which could also explain the data.

This analysis suggested reasons for peak 'dips,' and ruled out the late-arrival hypothesis for 'midday rally.' However, shopping traffic and early-quitters couldn't be differentiated (although, distinction may be difficult because early-quitters can also be shoppers.) Further AFC analysis examining second or third daily linked-trips, or by routes travelled, can further shed light on this area.

Route-Level Analysis

Boroughwide trends may not hold for individual routes. A representative set of 14 routes with different characteristics (feeder/grid; local/limited; large/small) covering all boroughs was selected for exploratory analysis.

Study period hourly ridership by route was averaged by DOW and grouped into Mondays, Fridays, and midweek. Figure 6(b) and 6(c) show differences between midweek and Mondays/Fridays. Most routes show lower Monday ridership than midweek, but several routes (above zero baseline) were higher, illustrating differences between routes. On Fridays, different patterns emerge. During commuter rush hours, most routes were below midweek average, but there were some exceptions. In middays and evenings, opposite was true—most routes were above midweek average, although some remained below. Significant variations exist between routes; some show dramatic reductions in ridership, up to –200 to –300 riders/hr. Conversely, on certain routes, additional capacity may be needed during Friday middays and late evenings with +100 to +150 extra passengers.

Figure 6(d) uses Friday's data, averages, maximums, and minimums to show each route (group) in single charts. Not all trends are immediately obvious or comprehensible. B1,B41, and B46 are three large routes in Brooklyn; B1 shows large negative deviations at all times, whereas B41 shows hardly any deviations (especially given its size), while B46 Limited shows large negative deviations in the mornings, large positive deviations middays, and not much deviations at all in afternoons and evenings.

Some interpretive context might shed light on routes requiring priority screening and rescheduling. Routes with heavy suburban-type feeder components, or heavily utilized by subway transfer riders show more marked 'AM dip' than others. As described in Figure 6(a), B1,M86,B46,BX12, and Q27 are Crosstown feeders in one sense or another. B1 is circumferential and feeds all major subway lines in Southern Brooklyn. M86 is Manhattan's 86 St Crosstown. BX12 is Fordham Road's Crosstown and connects major Bronx subway lines (*38*). Q27 is a circumferential feeder in Queens. Although B46 has a radial component with Williamsburg as its western hub, heaviest ridership section along Utica Av serves as a feeder.

Perhaps subway-reliant downtown commuters are more likely to have flexible work schedules compared with, say, retail or restaurant workforce whose timings are variable but inflexible, and whose travels are geographically diverse and not particularly concentrated on Crosstown feeders. Timing of 'AM dip' also suggests regular morning commute involvement—closer-in routes like M86 and M4 show maximum dip at 08 hour, whereas further-out routes (B46, BX12) show maximum dip at 07 hour.

B1 and Q27 have different shapes than other routes; most routes display 'midday surge' on Fridays, not present in B1 and Q27. The common factor in those two routes is colleges: Kingsborough Community College at B1's eastern terminus, and Queensborough Community College mid-route on Q27. Class scheduling may produce different Friday ridership patterns compared to Mondays through Thursdays (*45*). However, college presence doesn't preclude 'midday rally', as B41,M4,BX12, and BX19 serve Brooklyn College, Columbia University, Fordham University, and Hostos Community College respectively.

Midday surge's extents and durations seem to reflect size of business districts served, consistent with the theory that retail and commercial travel drives midday surge. B1 and Q27 don't provide circulator-type service to major business districts, whereas M86 connects Manhattan's East and West sides, B46 provides service along East New York's Broadway corridor, and BX12 covers Fordham Road. Fridays attract more shoppers due to New York's cultural tradition of "shopping for the weekend," and perhaps reflects payroll timing for weekly or bi-weekly employees.

Economic activity's cyclic nature was long established; empirically-measured daily weights represent DOW demand variations in trading day adjustment methods (*39*), with Friday stronger for retail. Q44/20 seems to be an exception, a crosstown feeder without the characteristic 'AM dip'; despite serving Jamaica Center and Flushing, no Friday lunchtime rally was indicated.

Consistent with midday retail hypothesis, X17 Express Bus shows 'AM dip' at 07 hour and no midday surge, because express ridership is dominated by downtown commuters and tends not to carry midday business traffic. However, effect is much less marked on X1, perhaps because data didn't include other X1-X9 variants.

Routes with more sedate suburban demographics (B1,Q20,X1,X17,S78, and S79) have less marked 'night rush' compared to other routes (B41,B46,M86,Q27,Q44, and BX19).

While this analysis demonstrates that routes have different DOW characteristics, overall trends were somewhat inconclusive. Some routes have barely discernable Friday effects whereas others have large and quite actionable effects. The research thus far cannot identify or quantify underlying factors affecting Friday ridership changes. Further work might develop some indices for route properties ("radialness" or "feederness", number and size of business districts served, and whether colleges were present). Figure 6(a) shows total boardings to peak load ratio, a crude feederness measure for routes feeding single locations only; ideal feeders have ratios of 1.00, since no passengers disembark prior to maximum load point, the transfer location. For multiple-point feeders, better metrics are needed. Future researchers can develop rigourous methods for quantifying and describing sizes, timings, and shapes of 'AM dip' and 'midday surge'. Standard correlation methods might then ascertain trends. Alternatively, another group of routes with similar properties could be selected qualitatively using analysts' judgment, and compared to study routes to see if these hypotheses held true.

Cost Analysis

This section analyzes likely magnitudes of service changes from Friday exception scheduling, and assesses reinvestment potential using rough cost estimation methods.

Transit industry has notoriously complex cost functions and is beset with complicated labour agreements. NYCT recently deployed run-cutting optimization packages enabling incremental service changes. Computerized crew scheduling systems can quickly evaluate large permutations of run-cuts, split-depot, and interlined operations. Small schedule changes, like adding a single peak trip, may have previously been accommodated manually by altering a few operators' work programs or even generated extra workpieces picked separately from regular work. With computerized systems, additional workpieces can be integrated globally into whole depot's work programs in just over an hour, producing near-optimum overall schedules for all services. In essence, small changes previously considered "not worth doing" because of high costs of re-making feasible run-cuts, or potentially counterproductive because piecemeal work program amendments over multiple picks might actually increase overall costs, are now more likely to yield cost reductions or productivity improvements.

Service Change Assessment

Classic transit scheduling paradigm calls for frequency determination using acceptable peak loading guidelines at maximum load points, with frequencies thinning out as ridership fall either side of peak load points or time periods (*23*). To assess scope for service changes at a high level, the operating day was split into three periods (morning: 6am-10:59am, midday: 11am-2:59pm, afternoon: 3pm-7:59pm), selected to capture "shoulder" transitions around morning and afternoon peaks. Highest ridership hour within each period was found using midweek AFC data (Figure 7(a), Columns 2-5).

Current scheduled operating frequencies were used to “back out” capacity utilization ratios, i.e., how many times seats are turned over during one hour (Columns 6-13). Schedule frequencies were then adjusted using Friday average ridership deviations. Standard running time and vehicle cycle calculations (Figure 7(b)) were used to estimate expected changes in revenue vehicle-hours operated (Columns 14-16), accounting only for trip additions/subtractions, not dwell & running time changes from reduced loads. In New York, traffic congestion drives bus running time, with only 22%–27% of running time attributed to dwell (*38*,*40*); when loads are lighter on Fridays, traffic congestion in New York is about 8% worse (*41*) as weekenders seeking refuge from city life drive out-of-town (*42*). Results provide an estimate of expected surplus from implementing Fridays-only schedule changes.

The nature of transit service provision with high demand peaking around rush hours tends to escalate unit costs in sometimes hard-to-predict ways (*36*). With Friday exceptions, much vehicle-hour decreases occurs in both peaks, when system resources are stretched thin and incremental service reductions are most helpful, especially on systems without part-time operators. However, during middays, additional service should be provided to better serve increased customer demands, and prevent overcrowding. Overall, percentage change in vehicle-hours corresponds well with ridership changes, despite concerns regarding policy headways and integer nature of bus service frequencies. However, the data showed large differences between routes and between time periods, with nearly –25% saving available on some routes, but also up to +25% service increases required in other cases. Large variability underscores the importance of responding to different travel patterns on Fridays.

Systemwide Reinvestment Potential Estimation

To provide order-of-magnitude approximations of available savings if Friday exception schedules were extended systemwide, four methods were used. In Method #1, “before” and “after” costs (Figure 8(a)) and vehicle-hours (Figure 8(b),(c)) data from NYCT’s 2010 Service Reductions (*5*) plan was used to derive marginal cost reductions per vehicle-hour eliminated ($38.8 million ÷ 0.63 million veh-hr = $61.27/veh-hr, Figure 8(d)). Based on 14 representative routes (15.4% of overall vehicle-hours, Figure 8(e)-(f)), estimated 463 vehicle-hours saved were factored up to annual systemwide levels (463 veh-hrs/Friday ÷ 15.4% × 52 Fridays/year = 156,338 annual veh-hrs eliminated), then multiplied by cost reductions per vehicle-hour. Friday schedule modifications potentially reduce vehicle-hours by 7.4% on Fridays, resulting in 1.2% annual budget reductions—or alternatively a 1.5% reinvestment potential for Monday-Thursdays.

Method #2 applies the same marginal cost ($61.27), but uses scheduled vehicle-hours and computed Friday percentage change to estimate expected vehicle-hour decreases (46,563 × 7.4% = 3,437 Friday veh-hrs saved)—accounting for overhead movements like deadheading, and route identification/grouping differences between AFC and operators’ work programs. Method #3 is the simplest; it assumes directly proportional relationships between vehicle-hour reductions and variable portion (64.7%) of annual operating budget ($2,211 million), and applies annual vehicle-hour percentage-change to the budget ($2,211 million × 64.7% × 1.2% = $16.9 million).

Method #4 is similar to #1, except that NYCT's National Transit Database operating cost per bus hour ($99.31) is used.

These reductions potentially generate between $9.6 and $16.9 million in benefits, which is equivalent to total annual operating budget of some small town transit agencies—like the Merrimack Valley Regional Transportation Authority in Haverhill, Mass. Whereas actual surplus cannot be known without a proposed schedule and run-cut, this analysis provides a planning estimate.

While New York's public is unlikely to tolerate more service cuts, the small yet tangible savings achieved can leverage reinvestments in service addbacks (after 2010 Service Reductions), new market development where assets could be deployed productively (e.g. midday express buses to Kingston and Albany), or critical supervision functions improving overall system reliability, productivity, and performance (e.g. dispatcher positions). This would represent responsible stewardship of scarce transit operating dollars.

Crewing Issues

Crewing is particularly difficult and complex. This section explores impacts on regular day-offs (RDOs) if: (a) Fridays runs (crew assignments) were proportionately reduced by 7.4%, as cost analysis suggest; (b) excess Fridays runs were proportionately re-allocated for system expansion, resulting in 5.9% Friday work reduction but 1.5% increase in Monday-Thursday runs.

Making the basic assumption that average daily operator utilization is eight hours, vehicle-hours were converted into daily operator requirements by DOW (Figure 9(a)). Using standard integer program modelling software, three scenarios were solved: Base Case (current coverage with full weekday schedules on Fridays), and Alternatives (a) and (b) above, subject to constraint that each operator must work five consecutive days then receive two consecutive RDOs. Rather than using "Day-Off Relief" crews, this model covers whole week's requirements by assigning different RDOs while minimizing total headcount (equivalent to minimizing total excess coverage, i.e. daily available crews exceeding requirements.) To underscore this model's simplicity and high-level nature, it ignores all depot and shift constraints. Actual run impacts will be different, depending on systemwide peak-to-base ratios on Fridays. However, similar principles will likely apply at lower levels once these various constraints are applied.

Many operators prefer RDOs that include at least one weekend day, i.e. Fri/Sat, Sat/Sun, or Sun/Mon. Other configurations are usually not preferred and often enforced on newer operators by seniority-based pick processes. Under Figure 9(b)'s Alternative (a), although Sat/Sun RDOs are reduced by 255 jobs, Fri/Sat & Sun/Mon RDOs are increased by 340 jobs, giving net gains of 85 jobs with desirable RDOs (Figure 9(c), 1.2%, bright shades).

Conversely, undesirable midweek RDOs would also change, but in a positive direction—net reductions of 170 jobs (2.4%, darker shades). Although run-reductions occur only on Fridays, the assignment covered more Sat/Sun work with Thu-Mon/Sat-Wed crews (2,439 jobs), resulting in larger decreases in other non-preferred work (119 jobs). The change produces overall reductions of 85 jobs (7,100 operators versus 7,185, or 1.2%) over the seven-day week. In effect, reduced Friday crewing requirements allowed the assignment program to give more crews

Fri/Sat off, in turn causing substitution of some Sat/Sun off crews with Sun/Mon off crews, which consequently reduces requirements for midweek RDOs. Under Alternative (b), where the removed Friday crews are evenly reinvested in weekday service resulting in no job losses, almost all reinvested crews have Sat/Sun off.

This is potentially an important point in required negotiations creating weekday exception schedules because it creates incentives for the workforce to push for jobs with desirable RDOs, and may make proposals more generally acceptable.

Rostered Day Off—Generalization

Figure 9(d) shows prototypical results of Friday service levels adjustments for a transit agency with 400 weekday runs (equivalent to single garage/depots at large agencies) using assumptions similar to New York's, under various scenarios of Saturday and Sunday crew requirements. These results may not generalize to agencies using part-time operators.

In Scenarios #1,#2, and #4, up to 10% Friday service reduction resulted in substantial decreases in crews with midweek RDOs, large increases in Fri/Sat & Sun/Mon RDOs, and smaller decreases in pure Sat/Sun RDOs. Within this range, cancellation of Friday runs tends to result in overall crew savings. New York's case falls within this range.

However, as cancelled Friday runs (together with already-reduced Saturday and Sunday runs) consume available rostering freedoms, cost impacts can plateau—when further reductions in Friday service results in no change to overall crew requirements, nor decreases in midweek RDOs, instead increasing excess crews. Scenario #3 plateaued at 5%; Scenario #1, at 10%. At this point, further productivity gains requires negotiating non-traditional rest-day assignments like four-on/three-off (ten-hour days); any-two-in-seven; voluntary work-your-RDO, etc. A premium might be expected for those arrangements. MBTA investigated ten-hour day work rule options (*43*) in 1989, but found disagreements even amongst union officers.

This strategic study doesn't attempt to reproduce all constraints and considerations in crewing a consolidated bus system (New York City Transit Authority, Manhattan and Bronx Surface Operating Authority) with more than 4,500 buses, in excess of 6,000 weekday runs, 21 depots, several different labour agreements, plus a separate 2,000 bus system with another 8 depots (MTA Bus Company) that shares the same route network, management, and some administrative services. While crew assignment processes and work program optimization (from both management and crew perspectives) is much more complex than RDO assignment modelling, this model's basic finding is likely to remain true: service readjustment to reduce Fridays coverage requirements usually yields more weekend-inclusive RDOs.

Conclusions and Recommendations

This strategic analysis provides a business case for NYCT's weekday exception scheduling. Case study indicates about $13 million (0.6%) in annual service reinvestments could be available based on improved productivity from better matching Friday service to travel demand on buses alone. The main findings are:

1. **Labour Agreements are Necessary Prerequisites.** Regardless of whether surpluses are reinvested in service improvements, a necessary precondition to realizing this productivity is labour agreements explicitly providing for weekday exception picked schedules. This paper doesn't propose exact implementation mechanisms; rather it sets out benefits of having Fridays/Mondays (possibly other days) operated on work programs different from generic weekday schedules.

2. **Computerized Run-Cutting is Critical.** Although not attempted in this study, implementation of improvements depends on computerized crew scheduling able to generate run-cuts without labourious manual processes. Besides typical utilization improvements, the ability to quickly assess savings and implement different schedules in response to holidays, events, weekday exceptions, or seasonal ridership changes is integral to justification for these software packages.

3. **Weekday Exceptions are Normal.** Exception scheduling is actually fairly common and transcends all transportation industry sectors, from chartered to scheduled carriers, from railroads and oceangoing freighters to public transit and airlines. Rather than presenting them as 'exceptions', they should be part of all schedulemakers' regular toolkit.

4. **Friday Exceptions Should be Published.** Friday ridership has distinct patterns; some Friday travellers have different trip-purposes, and could include a substantially different market segment not easily reached otherwise. Publicizing and properly delivering special or improved services on Fridays could expand the transit market, reach a larger population, and garner additional support for public transit.

5. **Exception Schedules Match Demand to Supply.** Slightly reducing service throughout Mondays and moving capacity from Friday peak periods to middays and evenings may regularly produce better service by relieving off-peak overcrowding while improving peak capacity utilization. Exception scheduling also allows picked schedules to better handle once-a-week activities, like sports or school events timed on weekly cycles.

6. **Multiple Factors Cause Friday Ridership Changes.** Data indicates some regular commuters may be staying home Fridays, reducing both morning and evening peak ridership; others may be travelling normally in the morning, but leaving early for shopping or to return home, increasing midday ridership.

7. **Productivity Improvements Vary by Route.** Available improvements vary by route and perhaps over the course of long routes due to different ridership patterns specific to local demographics. At this point, demographic variables are explanatory rather than predictive; even then, several hypothesized trends were not observed. Further research is required, and may yield fruitful results.

8. **Minor Frequency Adjustments Results in Benefits.** This method required service levels to be adjustable in infinitesimal increments, allowing response to ridership perturbations through frequency changes. Marginal changes by route may result in no

actionable savings because adjustments must be made in whole buses. On New York's buses, percentage-decrease in vehicle-hours corresponded well with ridership reductions, despite concerns regarding policy headways and integer service frequencies.

9. **Reducing Friday Coverage Results in Cost Decreases and Potential Crew Benefits.** In New York, cancellation of Friday runs result in reduced crew requirement but also more weekend-inclusive RDOs. The RDO assignment model also shows this is usually true in typical transit operating environments.

10. **Analytical Infrastructure Needed.** Although the present study is conducted with AFC data utilizing high-level assumptions, AFC alone does not necessarily capture rider distributions at peak load points. Detailed ridership determination requires an analytical infrastructure allowing merging of AFC and Automated Vehicle Locator (AVL) data. Since such equipment have been available for some time, industry needs appears to be in datamining, particularly longitudinally over longer time horizons rather than simply looking at average-day data.

Discussion of Implementation Issues

For broader applicability outside of dense cities with strong transit cultures, or even in New York, some potential implementation issues may remain to be resolved:

1. **Network Impacts.** Systems with infrequent service or network features like timed-transfers may be negatively impacted by small Fridays-only reductions. Further research is needed to find ways to adjust service on these systems. Friday adjustment practices on timed-departure suburban commuter carriers (Academy, Suburban, Trans-Bridge, Martz—Figure 1) and hub-and-spoke airlines offers potential solutions for low-density systems.

2. **Mitigating Customer Schedule Confusion.** Carriers in Figure 1 have developed strategies and marketing machinery for overcoming common confusion associated with exception schedules:

    a. NYCT uses "The Weekender," an interactive map, to make supplemental schedules easier to understand (*44*);
    b. Amtrak, British Rail, and airlines use date-sensitive trip planning tools or reservation sites to custom-tailor an itinerary for each rider;
    c. NCTD's Breeze Bus and Boston University's Shuttle publish schedules with Monday-Thursday, Friday, Saturday, and Sunday shown on separate pages; customers already understand that different schedules apply on Saturdays & Sundays—they will understand the extra "Friday" page;
    d. MBTA gave their Friday-exception service the distinctive name "Night Owl";
    e. Lucky Star Bus simply operate Fridays-only trips as unadvertised extras, a technique that railroads have also used;
    f. For minor adjustments, railroad and commuter bus schedules have departures endorsed "Fridays Only" or "Fridays Excepted".

While there is no shortage of potential solutions, marketing must find one approach that works for target customers. New York's local press explained this concept to the public (*45*) as "casual Friday schedules." As transit industry trends towards a fully-connected customer base reliant on real-time information and computer-assisted trip-planning tools, paper schedules and their associated confusions will become quaint relics of yesteryear, much like Edmondson tickets and their punches.

3. **Validating Productivity Gains.** This study estimated crew reallocations at a planning level without actually generating proposed operating plans and run-cuts. Implementation requires detailed scenario testing through computerized run-cutting.

4. **Scheduling Workload Will Increase.** Adding additional daytypes (Fridays, Mondays, School Closed Days, Holidays/Adjusted Weekdays, etc.) may require additional resourcing in schedule production. Spreading out run-cutting over a longer time period or cross-training other managers for scheduling work are two possible strategies.

5. **Support Infrastructure Needed.** Operations support functions are not currently setup for arbitrary day-types. Software for timekeeping, payroll, trip planning, for generating driver instructions, paddles, and internal reports all require modification prior to deployment.

Future Directions

- Transit agencies should conduct specific, route-by-route research to determine if their specific services or segments can benefit from weekday exception scheduling.
- If specific analyses show potential for productivity improvements, transit agencies should negotiate the ability to include weekday exceptions in work programs.
- For transit agencies without computerized run-cutting facilities or applications for datamining AFC/AVL logs across multiple days, if benefits are indicated in higher level analyses, software packages and analytical expertise should be procured to maximize service improvements or cost reductions.
- Further research is needed to determine other types of regular ridership patterns, to explore ways to predict ridership fluctuations using demographics, to better explain commuter work-schedule trends and weekday ridership fluctuations, and to understand reinvestment potential from implementing weekday schedule exceptions operationally.

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List of Tables and Figures

FIGURE 1 Examples of Differential Scheduling Practices in the Transportation Industry

Company Name	Description of Differential Scheduling Practice
New York City Transit Authority (NYCTA)	Since NYCTA operates 24/7 subway service, smaller scale capital construction work often takes place on Tuesday, Wednesday, and Thursday nights, allowing Friday nights to be reserved for larger scale work requiring track out of service for an entire weekend. In effect, a different schedule is often operated on Fridays, implemented via "supplemental" schedules that varies from one week to the next, and are overlaid on top of picked "base" schedules.
New York City Bus and MTA Bus Company	On the weekdays when New York City public and parochial schools are closed, NYCT and MTA Bus operates a "school closed" picked schedule omitting certain trips designed to relieve school crowding, and reducing service frequencies on some routes during morning peak and 2pm-4pm school rush hour. The dates operated are based on published school calendars.
The Long Island Rail Road (LIRR)	Owing to summer travel demand between New York City and the Hamptons by seasonal beachgoers, LIRR has long operated extra express trains (and extended locals) on summer Fridays and Sundays. Known as the "Cannonball", these trains feature reserved seating, beverage service, and operate at close to 100% load factor. On the Montauk Line, weekend ridership is higher than weekday ridership, a unique situation for a commuter rail authority.
Metro-North Commuter Railroad (MNCR)	Metro-North operates numerous weekday exception schedules for special events on a non-recurring basis. Baseball specials are operated during the season. Earlier Friday peak hour services are operated as necessary to support religious observances. Extra midday shopping trips are added during the December holiday season.
Massachusetts Bay Transportation Authority (MBTA)	MBTA operated the Night Owl bus service from 2001-2005 on Friday and Saturday nights only along four subway lines and five key bus routes between 1:00am and 2:30am at an annual cost of $1.4 million using regular operators hired on overtime. The ridership consisted mainly of college students and young adults.
Chicago Transit Authority (CTA)	Although CTA doesn't have Friday schedules different from weekdays, certain trips operate Tuesdays through Saturdays (technically, a Monday exception). These routes (X98—Avon Express; 169—UPS Express) serve workers on Mon-Fri graveyard shifts in industrial facilities. Early morning work-bound trips omit Saturdays while return trips skip Mondays.
Transit Authority of Northern Kentucky (TANK)	The Southbank Shuttle, a trolley designed to serve the downtown areas and connect entertainment venues, operates a longer span of service on Fridays late into the evening, much like the MBTA's Night Owl and is designed to cater to partygoers.
San Diego North County Transit District (NCTD) Breeze Bus	Breeze Bus Route 395 serves multiple armed services locations near Camp Pendleton and operates a Friday through Sunday peak schedule of 14-18 trips per day, whereas the midweek Monday through Thursday off-peak schedule has 5 trips per day. These scheduling decisions appear to mirror the leave schedule of military personnel.
San Diego North County Transit District (NCTD) Sprinter Light Rail	The Sprinter light rail shares track with a freight railroad, but is operated under a "temporal separation" regime. Freight service requires track access after 9:30pm, thus services wind down at that time. On Friday and Saturday nights, when freight doesn't work the line, extra services are operated until 12:30am, catering to students who stay out later on weekends.
Amtrak (National Railroad Passenger Corporation)	Amtrak's low-density long-distance routes, e.g. Cardinal (Washington D.C.–Chicago via West Virginia, have long operated every-other-day trips. Even in high-density areas, variations of regular trains operate to cater for the increased leisure travel demand on Fridays only: #83/#93 extended from Richmond, Va. to Newport News; #136/#196 from New York to Springfield, Mass.

Company Name	Description of Differential Scheduling Practice
Suburban Transit (Coach USA)	Several morning peak buses are marked "Mon-Thu" on Line 300 (Exit 8A-Port Authority) and Line 600 (Princeton-Wall St). Additionally, "adjusted weekday" schedules apply on holidays or religious days that are not universally observed, reflecting lower ridership on those dates.
Academy Bus (Jersey Shore/N.Y.)	Primarily a suburban New Jersey commuter express carrier, certain capacity-relieving morning trips are marked Mon-Thu only, and some trips are combined on Fridays.
Trans-Bridge (Allentown/Bethlehem)	One early afternoon departure from New York (2:30pm) operates on Fridays only. Several other trips work Mon-Thu to a casino, but do not operate to the casino on Fridays.
Martz Trailways (Wilkes-Barre/N.Y.)	One late morning peak trip for New York (arr. 9:00am) does not operate on Fridays. One late afternoon reverse peak trip for New York (arr. 7:40pm) operates Fridays only.
Lucky Star Bus (Boston-N.Y. Chinatown)	Lucky Star serves the weekly commuter and budget leisure travel markets, both of which have lower demand on Tuesday through Thursday. Schedule variations include early morning Boston departure which operates at 6:45am Tue-Thu but operates in two sections at 6:30am and 7:00am on Fri-Mon. Regular seven-day schedule is hourly, but unadvertised extra buses are operated on the half-hour on Friday and Sunday afternoons between 2:00pm and 5:00pm.
Hampton Jitney (N.Y.-Montauk)	Like the LIRR, the Hampton Jitney serves the weekend vacation traffic to the Hamptons. Various trips operate with exceptions on Thursdays, Fridays, Mondays, and Tuesdays. Other trips operate Thu-Sat; some trips operate every-other-day (e.g. Sun, Mon, and Wed).
Boston University Shuttle (the BUS)	The BUS, operated by Peter Pan/Academy, publishes a late night schedule that has Mon-Wed "weekday" variant, and separate special schedules for Thu, Fri, Sat, and Sun.
United Airlines	United, and predecessor Continental, like all other major airlines, schedules flights on a day-of-week basis. Flights in timetables are endorsed with "Frequency" indicators, showing "X16" for except Mon & Sat, "2345" for Tue-Fri, "1457" for Mon, Thu, Fri, Sun only. Reasons for such scheduling practices include travel demand variations and aircraft maintenance requirements.
New York Waterways	NY Waterway's East River Ferry operates between Manhattan and Brooklyn/Queens mainly to serve commuters, but makes an extra stop at Atlantic Av Pier on Friday nights for bar patrons.
Union Pacific Railroad	Union Pacific, like others in the freight transportation industry, schedules special "super-express" departures from the West Coast on Monday nights designed to hit an East Coast delivery window on Friday mornings for a particularly short permutation of three-business-days transit requirement on behalf of certain large shippers. (All other combination of three-business-days provides a weekend cushion of available extra transit time.)
British Railways (and successors)	British Railways in the 1980s purchased seat reservation, revenue management, and train scheduling software from several firms that have experience in the U.S. airline industry, and have adopted certain deregulated airline industry practices, including trains in weekday schedules endorsed "ThFO", "FO", "FSX", meaning Thursdays and Fridays Only, Fridays Only, and Fridays and Saturdays Excepted (i.e. does not operate on Fri/Sat) respectively.
Taiwan Railways Administration (TRA)	Historically Friday/Monday exceptions involving extra night local trains and additional cars on late-evening express trains were operated to accommodate military personnel travelling to/from bases and to accommodate weekly commuters. Many night trains were discontinued following Taiwan High Speed Rail's inauguration, but some Friday/Monday exceptions remain.

Figure 2
Boston to Riverside Suburban Service Schedule (Outbound) of the Boston & Albany Railroad, Effective October 17, 1932, Showing a Six-Day Work Week with Saturday Operating Exceptions

EFFECTIVE OCTOBER 17, 1932

BOSTON AND ALBANY RAILROAD
N.Y.C.R.R.CO. Lessee

BOSTON AND RIVERSIDE

AND INTERMEDIATE STATIONS VIA MAIN LINE AND HIGHLAND BRANCH

NEW YORK CENTRAL LINES

E. W. GOODWIN, ASST. GENL. PASS'R AGENT — E. E. PIERCE, ASST. GENL. PASS'R AGENT
W. A. BARROWS, GENERAL PASSENGER AGENT
BOSTON, MASS.

Form 3

BOSTON TO RIVERSIDE VIA MAIN LINE

WEEK-DAYS

LEAVE	3 AM	151 ★B AM	61 AM	153 ★B AM	65 B AM	155 ★ AM	157 ★B AM	7 AM	73 AM	407 AM	171 B PM	81 PM	331 ★B PM	173 ★B PM	409 ★ PM	335 ★B PM
Boston	4.15	6.35	6.50	7.05	7.35	7.55	8.15	8.30	9.45	11.05	12.20	12.35	12k55	1.05	1k20	1k22
Trinity Place	4.19	6.39	6.54	7.09	7.39	7.59	8.19	8.34	9.49	11.09	12.24	12.39	12k59	1.09	1k24	1k26
Cottage Farm														1.14		
Allston	4.25	6.45		7.16	7.46	8.05	8.29		9.55	11.15	12.30		Runs Saturdays only	1.17		Runs Sat. only
Brighton		6.48		7.19	7.49				9.58	11.17	12.32			1.19		
Faneuil		6.51		7.22	7.52	8.08	8.32		10.01	11.20	12.35			1.22	Runs Saturdays only	1k36
Newton		6.54		7.26	7.56	8.11	8.35		10.04	11.24	12.38		1k10	1.25		1k39
Newtonville		6.57	7.05	7.30	7.59	8.15	8.38	8.45	10.07	11.27	12.41		1k14	1.28		1k42
West Newton	4.35	7.00		7.34	8.03	8.19	8.41		10.10	11.30	12.44		1k17	1.31		1k45
Auburndale		7.03		7.38	8.08	8.22	8.44		10.13	11.33	12.47		1k20	1.34		1k48
Riverside... Ar.	4.39	7.05	7.11	7.45	8.11	8.29	8.47	8.53	10.16	11.36	12.50	12.55	1k23	1.37	1k42	1k51
Ar. N. L. Falls		7h20	7h20	7.53												
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	PM	PM	PM	PM	PM	PM

WEEK-DAYS

LEAVE	175 B PM	89 ★ PM	23 PM	179 ★B PM	97 ★ PM	91 PM	181 ★B PM	95 PM	183 PM	187 ★B PM	415 ★ PM
Boston	1.45	k2.00	2.10	2.50	k3.05	3.30	3.45	4.20	4.25	4.45	4.50
Trinity Place	1.49	k2.04	2.14	2.54	k3.09	3.34	3.49	4.24	4.29	4.49	4.54
Cottage Farm									4.34		
Allston	1.55	Runs Saturdays only		3.01	Runs Saturdays only	3u40	3.55		4.37	4.55	
Brighton	1.58						3.58		4.39	4.57	
Faneuil	2.01			3.04			4.01		4.42	5.00	
Newton	2.04		2.25	3.07		3.45	4.04		4.46	5.03	
Newtonville	2.07		2.28	3.10		3.48	4.07		4.50	5.06	
West Newton	2.10		2.31	3.13		3.51	4.10		4.54	5.09	
Auburndale	2.14		2.34	3.16		3.54	4.13		4.58	5.13	
Riverside.... Ar	2.17	k2.20	2.37	3.18	k3.25	3.57	4.15	4.41	5.02	5.15	5.10
Ar. N. L. Falls											
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

BOSTON TO RIVERSIDE VIA MAIN LINE

WEEK-DAYS

LEAVE	1189 ★B PM	2189 B PM	105 B PM	1191 ★B PM	2191 ★B PM (Does not run Saturdays)	193 ★B PM	1195 ★B PM	2195 B PM	109 B PM	197 ★B PM	113 PM	201 ★ PM	115 PM	119 B PM	207 B PM	121 B PM	125 B PM	127 B PM
Boston	5.02	5.07	5.15	5.22	5.25	5.26	5.40	5.50	6.00	6.05	6.25	6.55	7.30	8.30	9.35	9.45	10.30	11.25
Trinity Place	5.06	5.11	5.19			5.31	5.44	5.54	6.04	6.09	6.29	6.59	7.34	8.34	9.39	9.49	10.34	11.29
Cottage Farm						5.37		5.59										
Allston	Does not run Saturdays	5.17		Does not run Saturdays		5.40	Does not run Saturdays	6.03		6.15	6.35	7.05	7.40	8.41	9.45		10.40	11.35
Brighton						5.43		6.06		6.17	6.38							
Faneuil		5.21			5.38	5.46		6.09		6.20	6.41	7.08	7.43	8.44	9.48		10.43	11.38
Newton		5.25			5.42	5.49	5.54	6.12		6.23	6.44	7.11	7.47	8.48	9.51		10.46	11.41
Newtonville	5.18	5.28		5.39	5.45	5.52	5.58	6.16		6.26	6.47	7.14	7.51	8.51	9.54		10.49	11.44
West Newton	5.22		5.35	5.43	5.48	5.56	6.02	6.19		6.29	6.50	7.17	7.55	8.54	9.57		10.52	11.47
Auburndale		5.33	5.39	5.47	5.52	5.59	6.05	6.22		6.32	6.53	7.20	7.58	8.57	10.00		10.55	11.50
Riverside... Ar.	5.27	5.36	5.41	5 49	5.58	6.02	6.08	6.25	6.19	6.35	6.56	7.22	8.01	9.00	10.02	10.05	10.57	11.54
Ar. N. L. Falls		h6.00	6.00	6.00			6.25		h6.25									
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

SUNDAYS

LEAVE	71 AM	79 PM	85 PM	91 PM	185 B PM	33 PM	111 PM	119 B PM	121 B PM	209 B PM	127 B PM
Boston	9.05	12.35	2.05	3.30	4.45	5.00	6.35	8.30	9.45	10.00	11.25
Trinity Place	9.09	12.39	2.09	3.34	4.49	5.04	6.39	8.34	9.49	10.04	11.29
Cottage Farm											
Allston	9.15	12.45	2.15	3.40	4.55		6.46	8.41		10.10	11.35
Brighton	9.17										
Faneuil	9.20	12.48	2.18		4.58			8.44		10.13	11.38
Newton	9.25	12.51	2.21	3.45	5.01		6.51	8.48		10.16	11.41
Newtonville	9.29	12.54	2.24	3.48	5.04		6.55	8.51		10.19	11.44
West Newton	9.32	12.57	2.27	3.51	5.07		6.58	8.54		10.22	11.47
Auburndale	9.35	1.00	2.30	3.54	5.10		7.01	8.57		10.25	11.50
Riverside... Ar.	9.38	1.03	2.33	3.57	5.12	5.19	7.04	9.00	10.05	10.27	11.54
Ar. N. L. Falls											
	AM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

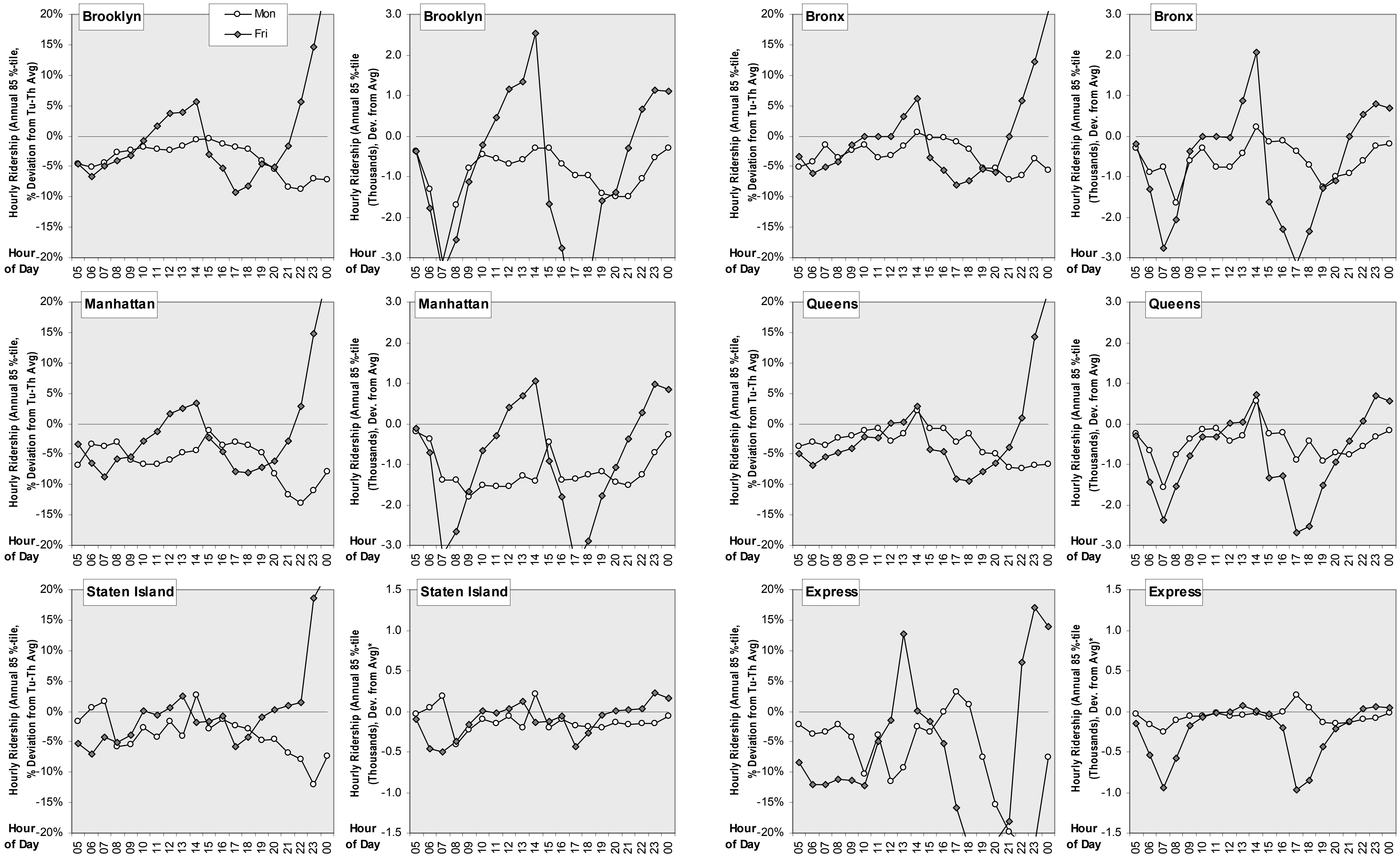
B No baggage carried on this train.
h No service to N. L. Falls on Sundays or holidays.
k Runs Saturdays only.
u Stops holidays only.
★ Does not run on holidays. Feb. 22 and April 19, 1933.

FIGURE 3
Cluster Analysis of Hourly Total Bus Ridership, 85-Percentile of Annual Data by Day-of-Week

Hour Period	85-Percentile of Hourly Total Bus Ridership by Day-of-Week (Thousands of Swipes per Hour)							Diff.* from Tue-Thu Avg		Pcnt Diff. Tue-Thu Avg		Compressed Dendrogram (Low to High)
	Mon (1)	Tue (2)	Wed (3)	Thu (4)	Fri (5)	Sat (6)	Sun (7)	Avg–Mon	Avg–Fri	Avg–Mon	Avg–Fri	
03:00~03:59	2.0	2.1	2.2	2.2	2.3	2.6	2.5	-0.2	0.1	-8%	6%	(1-((2-(3-4))-5))-(7-6)
04:00~04:59	5.9	6.1	6.1	6.1	6.1	3.7	3.1	-0.3	0.0	-5%	-1%	(7-6)-**(1-(5-**(4-(2-3))**))**
05:00~05:59	26.0	27.2	27.4	27.0	26.1	9.9	6.8	-1.2	-1.1	-4%	-4%	(7-6)-**((1-5)**-(4-(2-3))**)**
06:00~06:59	88.7	93.2	92.2	91.1	86.1	25.4	16.5	-3.5	**-6.1**	-4%	**-7%**	(7-6)-**((5-1)**-(4-(3-2))**)**
07:00~07:59	220.9	232.1	229.2	224.3	214.9	47.8	30.9	-7.7	**-13.6**	-3%	**-6%**	(7-6)-**((5-(1-4))**-(3-2)**)**
08:00~08:59	202.1	205.7	207.0	205.9	197.3	66.3	40.5	-4.2	**-8.9**	-2%	-4%	(7-6)-**(5-(1-**((2-4)-3)**))**
09:00~09:59	114.8	117.1	118.1	117.2	113.7	66.6	45.7	-2.7	-3.8	-2%	-3%	(7-6)-**((5-1)**-((2-4)-3)**)**
10:00~10:59	87.4	89.4	89.9	89.3	88.7	68.8	53.4	-2.2	-0.9	-2%	-1%	(7-6)-**(1-(5-**((4-2)-3)**))**
11:00~11:59	87.4	90.1	90.5	89.0	90.3	78.0	58.5	-2.5	0.4	-3%	0%	7-(6-(1-(4-((2-5)-3))))
12:00~12:59	97.7	100.3	101.9	100.0	103.1	89.6	65.4	-3.0	2.4	-3%	2%	7-(6-(1-((4-2)-(3-5))))
13:00~13:59	110.4	111.6	115.1	111.9	116.0	95.6	73.1	-2.5	3.2	-2%	3%	7-(6-((1-(2-4))-(3-5)))
14:00~14:59	145.3	144.1	149.0	144.4	152.0	96.4	77.1	-0.6	6.2	0%	4%	(7-6)-(((2-4)-1)-(3-5))
15:00~15:59	184.2	185.1	182.1	183.1	178.8	98.6	78.2	0.8	-4.7	0%	-3%	(7-6)-**(5-**((3-4)-(1-2))**)**
16:00~16:59	171.7	175.8	174.1	171.3	164.2	97.8	76.0	-2.0	**-9.5**	-1%	**-5%**	(7-6)-**(5-((4-1)**-(3-2))**)**
17:00~17:59	179.5	184.6	183.5	179.9	167.5	93.3	73.1	-3.2	**-15.1**	-2%	**-8%**	(7-6)-**(5-((1-4)**-(3-2))**)**
18:00~18:59	149.4	152.0	152.1	149.6	139.9	84.5	67.0	-1.8	**-11.4**	-1%	**-8%**	(7-6)-**(5-((1-4)**-(2-3))**)**
19:00~19:59	105.4	108.7	110.7	110.9	104.4	74.4	58.6	-4.7	**-5.7**	-4%	**-5%**	(7-6)-**((5-1)**-(2-(3-4))**)**
20:00~20:59	78.8	81.1	81.7	83.4	77.8	65.0	50.6	-3.3	-4.3	-4%	**-5%**	(7-6)-**((5-1)**-((2-3)-4)**)**
21:00~21:59	53.1	56.3	58.0	58.6	56.9	50.8	38.3	-4.6	-0.7	-8%	-1%	7-((6-1)-((2-5)-(3-4)))
22:00~22:59	37.1	39.4	40.8	41.3	42.8	39.6	29.9	-3.4	2.2	-9%	6%	7-(1-(((2-6)-(3-4))-5))
23:00~23:59	25.0	26.4	27.1	27.4	30.9	29.4	20.7	-2.0	3.9	-7%	14%	7-((1-(2-(3-4)))-(6-5))
00:00~00:59	13.4	14.2	14.4	15.0	17.7	16.7	11.0	-1.1	3.1	-8%	21%	7-((1-((2-3)-4))-(6-5))
01:00~01:59	4.9	5.1	5.3	5.7	7.6	7.2	4.0	-0.4	2.2	-8%	41%	(7-(((1-2)-3)-4))-(6-5)
02:00~02:59	2.1	2.2	2.3	2.5	3.4	3.6	2.1	-0.2	1.1	-10%	45%	(((1-7)-(2-3))-4)-(5-6)

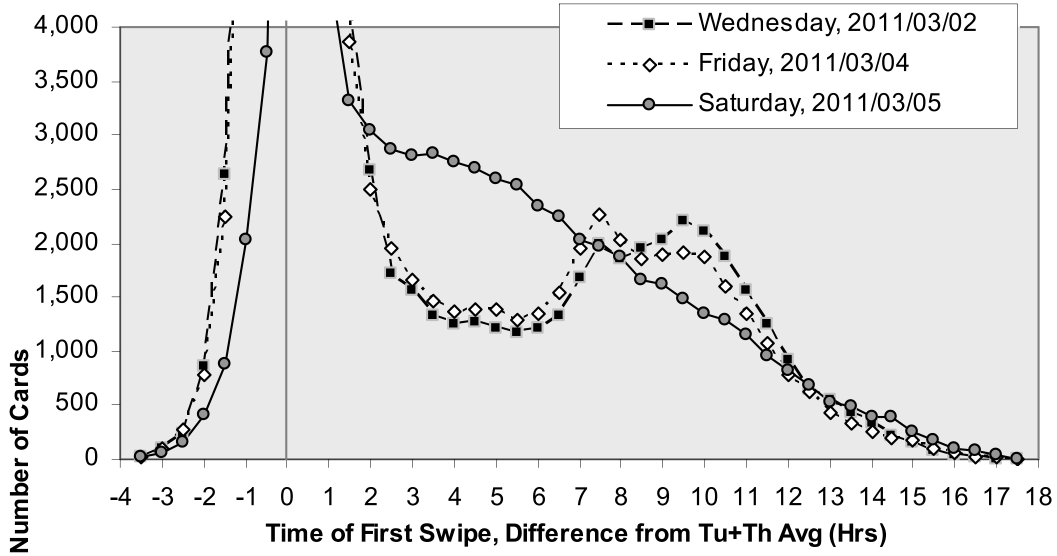
Notes: Shaded area represents highest ridership time periods. * Annual 85-Percentile Hourly Total Bus Ridership for Mondays or Fridays subtracted from Average of the same for Tuesdays, Wednesdays, and Thursdays.

FIGURE 4 Time-of-Day/Day-of-Week Ridership Profiles (85-Percentile of Total Boardings per Hour) by Borough Service Group

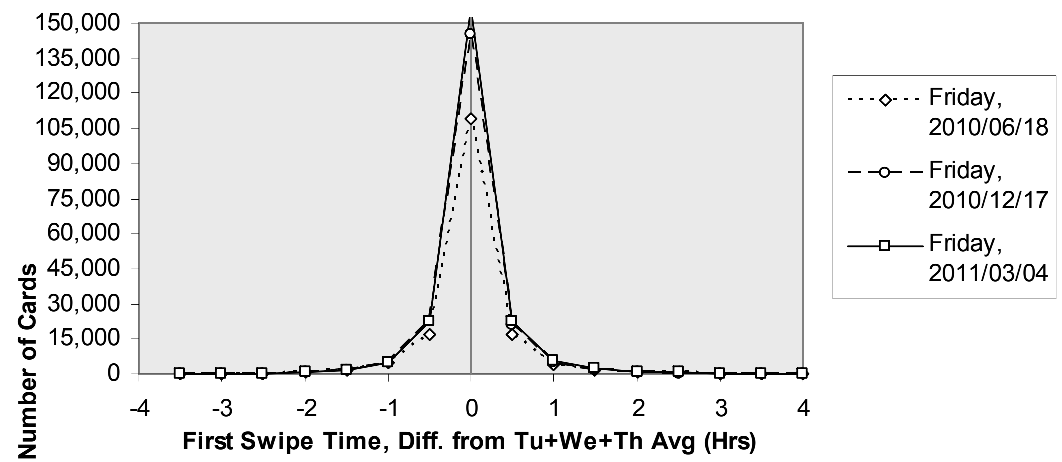


* Scale adjusted to fit the graph (Staten Island and Express, Hourly Ridership plots)

(a)



(b)



(c)

Fraction of Regular Commuters' Friday First Bus Swipe Time Compared to Midweek (TuWeTh) Averages	Friday (Season)	2010/06/18 (Summer)	2010/12/17 (Winter)	2011/03/04 (Spring)
	1+ hour earlier	4.2%	3.3%	3.2%
	Within 1 hour	91.0%	92.5%	92.6%
	1+ hour later	4.8%	4.2%	4.2%

(d)

	Daily First Bus Swipes (6am-10am)			% of Total Tuesday First Bus Swipes		
Tuesday on Week of	**2010/06/15**	**2010/12/14**	**2011/03/01**	**2010/06/15**	**2010/12/14**	**2011/03/01**
Card first seen on all four days between 6am and 10am	156,982	203,612	216,917	27%	32%	32%
TuWeTh, not Fr	67,655	69,119	74,445	12%	11%	11%
TuThFr, not We	30,502	39,713	38,443	5%	6%	6%
TuWeFr, not Th	33,573	37,885	39,130	6%	6%	6%
TuWe, not ThFr	62,776	62,309	67,698	11%	10%	10%
TuTh, not WeFr	32,169	34,751	37,034	5%	5%	5%
TuFr, not WeTh	25,268	25,580	25,041	4%	4%	4%
Tu alone	178,137	168,393	176,717	30%	26%	26%
Total Tuesday first bus swipes	**587,062**	**641,362**	**675,425**			

(e)

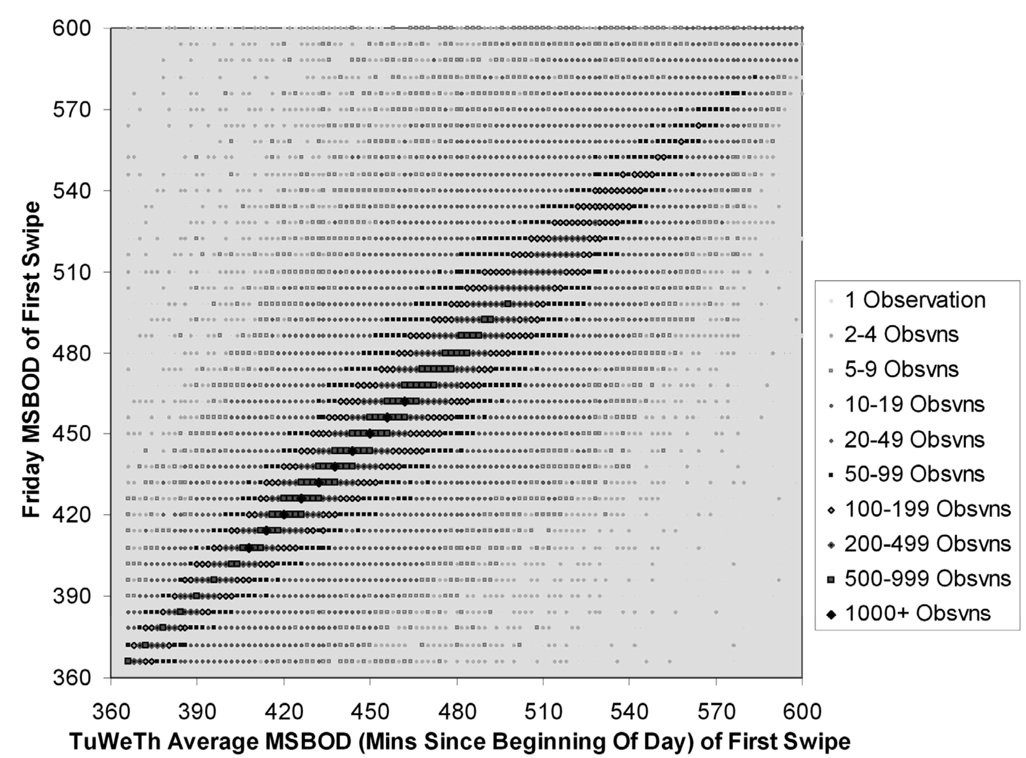


FIGURE 5 Analysis of Morning Commutes
(a) Comparison of Time of First Swipes, Tuesday and Thursday versus Wednesday, Friday, and Saturday; (b) First Swipe Time Comparisons, Midweek versus Fridays in June, December, and March; (c) Very Weak Seasonality in First-Swipe Timings; (d) Patterns of "Missing" Morning Commutes in June, December, and March; (e) Visualization of First Swipe Time Correlation, Midweek versus Friday in June

FIGURE 6 Route-Level Analyses Results

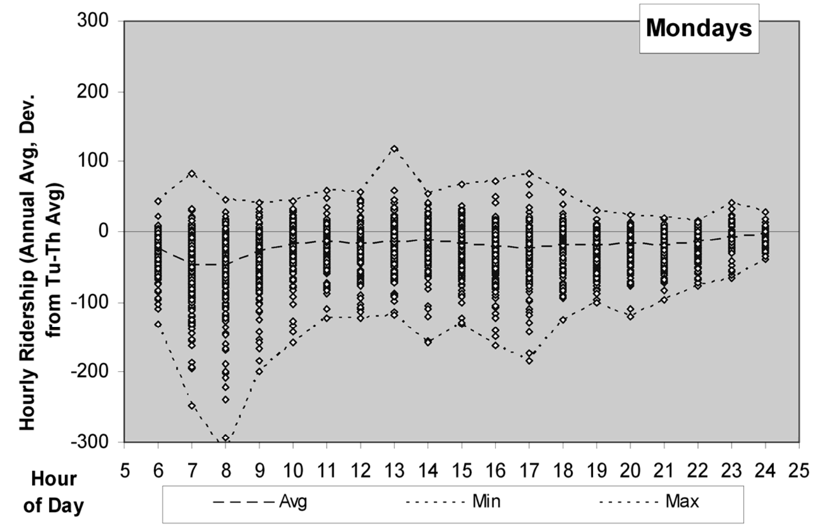
(a) Descriptions of List of Routes Selected for Further Analysis

Route Group	Ridership (2010)	Rank*	Max Load†	Total Ons†	Ons/Ld Ratio†	Name	Description	Rail/Ferry Connections
B1	19,636	28	4,950	13,352	2.7	Bay Ridge/86 St	Circumferential route serving Brighton, Gravesend, Bensonhurst, and Bay Ridge	Brighton, Culver, Sea Beach, West End, and Bay Ridge Lines
B41 (LTD/LCL)	35,887	9	7,605	21,284	2.8	Flatbush Av	Radial route, Marine Park and Bergen Beach to Brooklyn College and Downtown Brooklyn	Nostrand Av and Brighton Lines
B46 (LTD/LCL)	49,673	2	6,843	15,336	2.2	Utica Av	Hybrid route, Flatlands, East Flatbush, Crown Heights to Downtown Williamsburg	Eastern Parkway, Fulton, Myrtle, and Jamaica Lines
M86	26,028	18	10,701	16,836	1.6	86 St Crosstown	Yorkville to Upper West Side	Lex, 8 Av, and Bwy-7 Av Lines
M4 (LTD/LCL)	21,380	25	—	—	—	Washington Heights	Radial, Broadway, Central Park North, and 5 Av	Bwy-7 Av and 8 Av Lines
Q27 (LTD/LCL)	24,147	19	3,430	5,005	1.5	Cambria Heights	Circumferential, Queens Village and Auburndale to Queensboro Community College and Flushing	Flushing Line, and Long Island Rail Road (LIRR) at Queens Village
Q44/20 **	40,228	17/61	7,477	16,778	2.2	Main St/ Cross Bx Expwy	Circumferential, Jamaica and Flushing to College Point, Hugh Grant Circle, and West Farms	Archer Av, Flushing, Pelham, and White Plains Road Lines
BX12 (SBS/LCL)	45,269	3	10,781	23,139	2.1	207 St/ Fordham Road	Crosstown, Inwood and University Heights to Pelham Bay Park and Bay Plaza	Bwy-7 Av, Jerome, Concourse, White Plains Road, Dyre Av, and Pelham Lines
BX19	32,203	11	5,801	20,298	3.5	Southern Blvd/ E 149 St	Hybrid, East Tremont to The Hub, Hostos Community College, and 145 St	Bwy-7 Av, 8 Av, Lenox, Jerome, White Plains Road, and Pelham Lines
S78	6,430	121	1,449	3,127	2.2	Hylan Blvd- St George Ferry	Feeder, Eastern Staten Island to St. George	Staten Island Ferry
S79	8,968	100	2,720	4,705	1.7	Hylan Blvd- Bay Ridge	Feeder, Staten Island via Verrazano-Narrows Bridge	4 Av Subway
X1 ‡	6,181	1	—	—	—	Hylan Blvd Exp	Express, Eastern S.I. to Manhattan	—
X17 ‡	5,582	2	—	—	—	Huguenot/ Annadale Exp	Express, Western S.I. to Manhattan	—

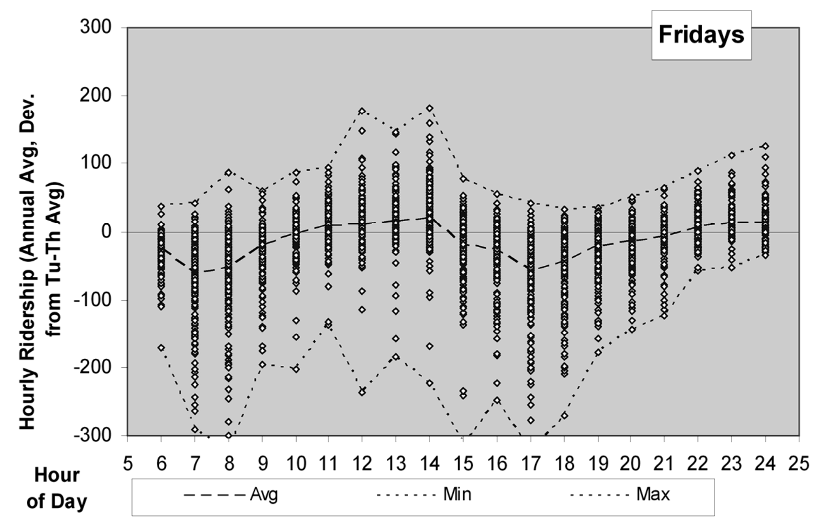
Notes: * Ranks are among 195 local, or among 33 express routes. All ridership includes both local and limited service. † Based on two-day Ridecheck where available. ** Q44 and Q20 are treated as two separate routes for ridership reporting but are operationally and for scheduling purposes variants of one single route. ‡ X17 ridership includes all variants (X17A, X17J, and X17C); X1 ridership does not include other variants in the Hylan Blvd service set (X2-X5, X7-X9.)

Annual Average Hourly Bus Ridership by Route*, Differences between (b) Monday and (c) Friday Averages and Midweek (Tuesday-Thursday) Averages, with Systemwide Average, Maximum, and Minimum

(b)



(c)



Note: * Each data point represents difference in ridership on one route for one hour.

FIGURE 6 (Continued) Route-Level Analyses Results
(d) Average of Annual Hourly Total Bus Ridership by Day-of-Week for Selected Route Groups, Spread between Friday Averages and Midweek Averages

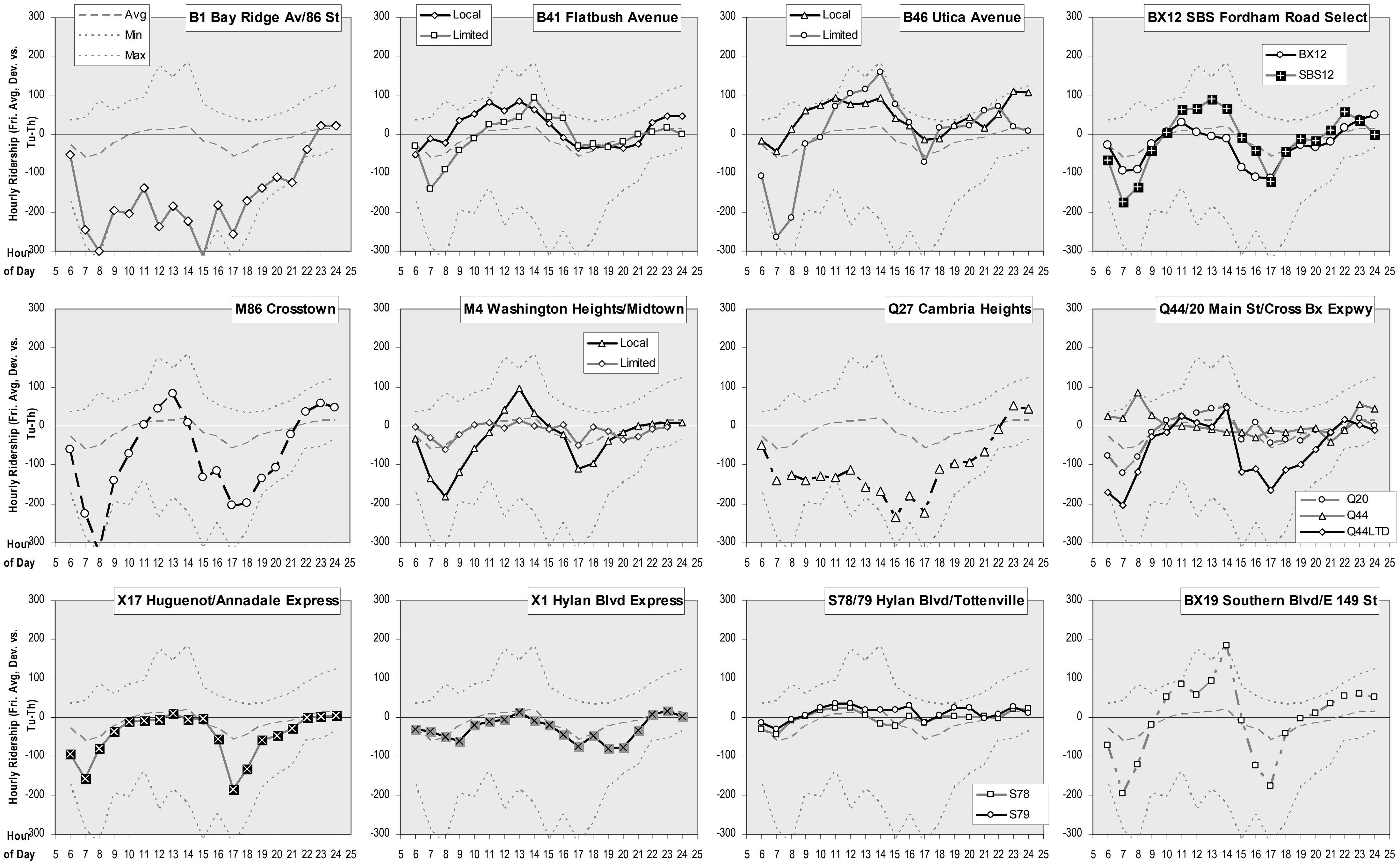


FIGURE 7 Planning-Level Model for Estimation of Systemwide Cost Reductions (a) Ridership Percentage Spreads between Friday and Midweek Averages for Selected Route Groups by Time Period* and Implied Possible Vehicle-Hour Changes from Adopting Differential Friday Schedules

(1) Route	(2) Hr w/ Max. Riders	(3) Max. Hrly Riders (Tu-Th)	(4) Avg. Diff. (Fri)	(5) % Diff. (Fri)	(6) Svc. Freq. (Mins)	(7) Buses /Hour (bph)	(8) Run Time (Hr)	(9) Veh. Cycle (Hr)	(10) Peak Bus Req.†	(11) Avg. Psgrs /Bus†	(12) Schd. Cap. /Bus	(13) Cap. Util. Ratio	(14) bph Chg‡	(15) Est. Veh-Hr Chg‡	(16) % Veh-Hr Chg
AM Peak (6am-10:59am, 5.0 hours)															
B1	08	1,643	-301	-18%	8	7.5	0.9	2.0	15	109	40	2.7	-1	-10.0	-13%
B41 Local	07	1,141	-10	-1%	6	10.0	1.1	2.5	25	46	40	1.1	0	—	—
B41 Limited	08	1,252	-90	-7%	6	10.0	0.9	2.0	20	62	40	1.6	-1	-10.1	-10%
B46 Local	07	1,319	-44	-3%	7	8.6	1.2	2.6	22	60	40	1.5	0	—	—
B46 Limited	08	2,579	-215	-8%	3	20.0	1.1	2.3	46	56	40	1.4	-2	-23.1	-10%
BX12	08	1,217	-90	-7%	10	6.0	0.9	2.0	12	102	60	1.7	0	—	—
BX12 Select	07	2,646	-173	-7%	6	10.0	0.8	1.7	17	157	60	2.6	-1	-8.4	-10%
BX19	08	2,448	-121	-5%	6	10.0	1.2	2.5	25	97	60	1.6	-1	-12.7	-10%
M4 Local	08	1,558	-181	-12%	8	7.5	1.7	3.8	28	55	40	1.4	-2	-37.8	-27%
M4 Limited	08	497	-62	-12%	13	4.6	1.6	3.4	16	32	40	0.8	-1	-17.1	-22%
M86	08	2,764	-324	-12%	4	15.0	0.5	1.2	18	157	60	2.6	-1	-5.9	-7%
Q27 Local	07	1,377	-141	-10%	3	20.0	1.0	2.1	42	33	40	0.8	-2	-20.9	-10%
Q27 Limited	07	960	-135	-14%	8	7.5	1.1	2.3	18	55	40	1.4	-1	-11.7	-13%
Q20	07	1,175	-121	-10%	9	6.7	1.3	2.8	19	62	40	1.6	-1	-14.1	-15%
Q44 Limited	07	2,793	-202	-7%	5	12.0	1.7	3.8	45	62	40	1.5	-2	-37.8	-17%
S78	07	656	-43	-7%	15	4.0	1.3	2.8	11	59	40	1.5	0	—	—
S79	07	748	-31	-4%	8	7.5	1.1	2.5	18	41	40	1.0	0	—	—
X1	09	376	-62	-16%	6	10.0	1.7	3.8	—	38	57	0.7	-1	-18.9	-10%
X17A/X17J	07	860	-158	-18%	3	20.0	2.0	4.5	—	43	57	0.8	-2	-44.7	-10%
Midday (11am-2:59pm, 4.0 hours)															
B1	14	1,402	-223	-16%	8	7.5	1.0	2.2	16	86	40	2.2	-1	-8.7	-13%
B41 Local	14	1,221	62	5%	7	8.6	1.2	2.6	22	55	40	1.4	1	10.3	12%
B41 Limited	14	949	94	10%	14	4.3	1.1	2.3	10	94	40	2.4	1	9.4	23%
B46 Local	14	882	93	11%	8	7.5	1.2	2.6	20	45	40	1.1	1	10.6	13%
B46 Limited	14	1,721	160	9%	5	12.0	1.2	2.5	30	57	40	1.4	1	10.1	8%
BX12	14	986	-10	-1%	7	8.6	0.9	1.9	16	60	60	1.0	0	—	—
BX12 Select	14	1,631	65	4%	8	7.5	0.8	1.8	14	119	60	2.0	0	—	—
BX19	14	1,863	183	10%	8	7.5	1.3	2.8	21	90	60	1.5	1	11.0	13%
M4 Local**	14	1,382	32	2%	10	6.0	1.8	3.9	23	59	40	1.5	0	—	—
M86	14	1,510	7	0%	6	10.0	0.5	1.1	11	142	60	2.4	0	—	—
Q27**	14	1,445	-168	-12%	7	8.6	1.0	2.1	18	81	40	2.0	-1	-8.4	-12%
Q20	14	839	50	6%	12	5.0	1.4	3.0	15	57	40	1.4	0	—	—
Q44 Limited	14	1,405	46	3%	9	6.7	1.6	3.5	23	60	40	1.5	0	—	—
S78	14	632	-16	-3%	15	4.0	1.3	2.8	11	57	40	1.4	0	—	—
S79	14	620	18	3%	13	4.6	1.3	2.8	13	48	40	1.2	0	—	—
X1	14	336	-9	-3%	20	3.0	1.8	3.9	—	29	57	0.5	0	—	—
X17C	14	187	-6	-3%	40	1.5	2.1	4.6	—	27	57	0.5	0	—	—
PM Peak (3pm-7:59pm, 5.0 hours)															
B1	15	1,419	-313	-22%	10	6.0	1.0	2.2	13	108	40	2.7	-1	-11.0	-17%
B41 Local	15	1,466	27	2%	6	10.0	1.2	2.6	26	57	40	1.4	0	—	—
B41 Limited	17	1,246	-32	-3%	15	4.0	1.1	2.3	9	133	40	3.3	0	—	—
B46 Local	17	1,358	-13	-1%	7	8.6	1.3	2.8	24	58	40	1.4	0	—	—
B46 Limited	17	2,404	-71	-3%	3	20.0	1.2	2.7	54	44	40	1.1	-1	-13.6	-5%
BX12	15	1,209	-85	-7%	8	7.5	0.9	2.0	15	81	60	1.4	-1	-9.9	-13%
BX12 Select	17	2,217	-121	-5%	6	10.0	0.9	2.0	20	110	60	1.8	-1	-10.1	-10%
BX19	17	2,297	-176	-8%	6	10.0	1.4	3.0	30	77	60	1.3	-1	-14.9	-10%
M4 Local	15	1,598	-2	0%	9	6.7	1.8	3.9	26	62	40	1.6	0	—	—
M4 Limited	17	439	-51	-12%	23	2.6	1.6	3.4	9	49	40	1.2	-1	-17.2	-38%
M86	17	2,261	-205	-9%	5	12.0	0.5	1.2	14	161	60	2.7	-1	-5.9	-8%
Q27 Local	15	1,744	-235	-13%	4	15.0	1.1	2.3	35	50	40	1.3	-2	-23.1	-13%
Q27 Limited	18	536	-76	-14%	11	5.5	1.1	2.3	13	42	40	1.0	-1	-11.7	-18%
Q20	15	987	-35	-4%	9	6.7	1.3	2.9	19	52	40	1.3	0	—	—
Q44 Limited	15	1,869	-119	-6%	6	10.0	1.7	3.6	36	51	40	1.3	-1	-18.2	-10%
S78	15	426	-22	-5%	15	4.0	1.3	2.9	11	37	40	0.9	0	—	—
S79	17	712	-14	-2%	9	6.7	1.3	2.8	19	38	40	0.9	0	—	—
X1	17	483	-74	-15%	6	10.0	1.8	3.9	—	48	57	0.8	-1	-19.6	-10%
X17A/X17J	17	653	-184	-28%	3	20.0	2.1	4.6	—	33	57	0.6	-3	-68.8	-15%
Overall															
Local	—	44,592	-2,477	-5.6%	—	—	—	—	—	68	45	1.52	—	-151	-4.9%
Limited	—	25,196	-1,010	-4.0%	—	—	—	—	—	66	43	1.52	—	-159	-8.7%
Express	—	2,895	-493	-17.0%	—	—	—	—	—	45	57	0.79	—	-152	-11.1%
Subtotal/Avg	**—**	**72,683**	**-3,979**	**-4.7%**	**—**	**—**	**—**	**—**	**—**	**65**	**46**	**1.41**	**—**	**-463**	**-7.4%**

FIGURE 7 (Continued)
(b) Column Definitions for Variables Used in the Model

Column	Name	Definition
1	Route	New York City Bus public route (Local/Limited routes separated where data is available)
2	Hour with Maximum Riders	The hourly period ('07' is 07:00~07:59) during which highest number of average riders were observed (per AFC) on that route compared to other hourly periods within the specified time segment, e.g. AM Peak (6am-10:59am)
3	Maximum Hourly Riders (Tue-Thu)	Average number of boardings observed (regardless of location) on that route during the busiest hourly period (Column 2) for Tuesdays, Wednesdays, and Thursdays in the study period (7/1/2010–4/30/2011).
4	Average Ridership Difference (Fridays)	Difference in average boardings during that hour between Fridays in study period, and Tuesdays thru Thursdays (Column 3).
5	% Difference (Fri)	Percentage difference in average boardings between Fridays and Tuesdays thru Thursdays (Column 4 ÷ Column 3), see also Figure 6(d).
6	Service Frequency (Minutes)	Approximate average service headway (per public schedule) for buses operating on that route during that hour in study period.
7	Buses per Hour	Service frequency expressed as bus throughput in one direction past one location on the route. (60 Minutes ÷ Column 6.)
8	Running Time (Hours)	Average one-way weekday running time from origin to destination (per operational schedule) for buses operating on that route during that hour.
9	Vehicle Cycle (Hours)	Average round-trip running time, plus typical allowed recovery time (10% of Column 8) at both termini. Manually adjusted where necessary, as per current scheduling practice (e.g. to provide extra recovery time for routes operating with heavy traffic congestion.)
10	Current Bus Requirement†	Total bus requirement on that route during that hour to provide specified level of service, computed from buses per hour (Column 7) × vehicle cycle (Column 9). Verified against internal statistical reports from scheduling software.
11	Average Hourly Passengers per Bus†	Average hourly boardings per bus in service (Column 3 ÷ Column 10). Required for estimating the capacity utilization ratio (Column 13).
12	Scheduled Capacity per Bus	Based on the vehicle type operating on that route, the schedule capacity is either 40 (single), 60 (articulated), or 57 (express).
13	Capacity Utilization Ratio	Count of times where each seat is "turned over" during an hour (i.e., Column 11 ÷ Column 12). Verified against "Ridecheck" reports that forms part of the input to the scheduling process, where available.
14	Bus per Hour Change (Fridays)‡	Estimated bus throughput (service frequency) change that could be effected on Fridays based on AFC load differences under the conservative assumption that each in-service bus departures carry average number of passengers per hour per bus (Column 11) with load differences evenly distributed across the peak and non-peak directions. The peak-direction load difference is therefore half of average ridership difference (Column 4 ÷ 2). The required bus per hour, which is governed by peak direction demand, is reduced by load difference (half of Column 4) divided by average hourly passengers per bus (Column 11).
15	Vehicle Hours Change (Fridays)‡	Vehicle hours saved/added on Friday if bus per hour change were applied to the current schedule. Computed from bus per hour change (Column 14) × number of hours in the specified time segment (e.g. AM Peak is 6am-10:59am, therefore is 5 hours long) × vehicle cycle (Column 9).
16	% Vehicle Hours Change	Vehicle hours change as a fraction of total vehicle hours supplied to operate that route during the specified time segment. Computed from vehicle hour change (Column 15) divided by total bus requirements (Column 10) × number of hours in the specified time segment.

Notes: * Evening and overnight periods not evaluated due to policy headway requirements precluding the possibility of thinning out service. ** M4 and Q27 Limited service does not operate in the midday period. † X1 and X17 average passengers per bus were manually adjusted due to unique traffic patterns (morning inbound to Manhattan only), and crewing arrangements (early trips are deadheaded back to Staten Island to make a second morning inbound trip) in the current schedule. ‡ Estimated vehicle-hours based on simple assumptions about crewing and vehicle blocking.

FIGURE 8
Estimation of Approximate Systemwide Cost Impacts based on Selected Bus Route Groups

(a) Published Annual Service Reduction Savings for Estimating Cost Reduction per Vehicle Hour

Service Group	Route Restructuring Package	Wkdy† Savings ($ mil.)	Wknd† Savings ($ mil.)	Service Group	Route Restructuring Package	Wkdy† Savings ($ mil.)	Wknd† Savings ($ mil.)
Express	X25	-0.1	0.0	Manhattan	Lower East Side	-0.7	-0.1
	X32	-0.3	-0.1		North-South	-2.8	-0.6
	X20	-0.3	-0.1		M10	-0.9	-0.2
	X18	-0.4	-0.1		M42	-0.2	0.0
	X16	-0.5	-0.1		M98	-0.7	-0.1
	X29	-0.8	-0.2		M104	-0.8	-0.2
	X51	-0.7	-0.1		M18	-0.9	-0.2
	X90	-0.7	-0.1		M27	-1.3	-0.3
	X27-X37 X28-X38	-0.4	-0.1		M30	-0.6	-0.1
					M8	—	-0.4
	X13-X14	-0.2	0.0		M50	—	-0.4
	X1-X9	-1.2	-0.2		Manhattan Span Changes*	-0.7	-0.1
	X27/X28	—	-0.9				
Bronx	Co-op City	-2.3	-0.5	Queens	Whitestone	-1.2	-0.2
	Eastern Bronx	-0.8	-0.2		Q26 Off-Peak	-0.4	-0.1
	BX39-BX41	-0.9	-0.2		Q42 Off-Peak	-0.2	0.0
	BX55	-0.4	-0.1		Q74	-1.0	-0.2
	BX20	-0.5	-0.1		Q75	-0.9	-0.2
	BX34	—	-0.6		Q79	-0.6	-0.1
	Barretto Park Pool Shuttle	—	-0.1		Q31	—	-0.4
					Q76	—	-0.3
	Bronx Span*	-0.3	-0.1		Queens Span*	-0.1	0.0
Brooklyn	Brownstone Brooklyn	-2.5	-0.5	Staten Island	New Brighton	-0.5	-0.1
					S40/90	-0.1	0.0
	Bay Ridge	-2.3	-0.5		Grymes Hill	-0.2	0.0
	B3	-0.3	-0.1		S67	-0.4	-0.1
	B4	-0.7	-0.1		S54	—	-0.5
	B12	-1.3	-0.3		S76	—	-0.3
	B13	-0.4	-0.1		S.I. Span Changes*	-0.3	-0.1
	B48	-0.8	-0.2				
	B64	-0.8	-0.2				
	Q24‡	-0.6	-0.1				
	B23	-1.0	-0.2				
	B39	-0.9	-0.2				
	B51	-0.7	-0.1				
	B2	—	-0.3				
	B24	—	-0.5				
	Brooklyn Span*	-0.8	-0.2				
				System Total		**-38.8**	**-12.5**

* Span of service changes were costed as a borough-wide total and not on an individual route basis.
† For Route Restructuring Packages that affect both weekday and weekend service, resource reductions were allocated.
‡ Q24 serves both Brooklyn and Queens but is operationally part of the Brooklyn North division.

Source: 2010 NYC Transit Service Reductions – Revised. New York, N.Y., March 19, 2010 (*5*).

FIGURE 8 (Continued)

(b) Daily Vehicle Hours by Schedule Type—2009 (Before)/2010 (After) Service Reductions

Day Type	Average Day Count	NYCTA		MaBSTOA		New York City Transit Total			
		2010	2009	2010	2009	2010	2009	Chg	%Chg
Weekday	183	29,952	31,017	16,611	17,944	46,563	48,961	-2,398	-5.2%
School Closed	78	28,730	29,889	16,515	17,847	45,245	47,736	-2,491	-5.5%
Saturday	52	18,659	19,865	11,550	12,821	30,209	32,686	-2,477	-8.2%
Sunday	52	14,979	15,769	9,343	10,319	24,322	26,088	-1,766	-7.3%

(c) Annual Vehicle Hours (Millions)[1]

Day Type	2010	2009	Chg	%Chg
Weekday	12.05	12.68	-0.63	-5.3%
Weekend	2.84	3.06	-0.22	-7.8%
Overall	**14.89**	**15.74**	**-0.85**	**-5.7%**

(d) Service Reduction Savings

Day Type	Cost Chg (Mil)[2]	Cost Reduction /Veh-hr[3]	NTD Cost /Veh-hr[4]
Weekday	-$38.8	$61.27	—
Weekend	-$12.5	$56.47	—
Overall	**-$51.3**	**$60.03**	**$99.31**

Notes: [1] Appropriate Sumproduct from Fig. 8(b). **[2]** From Fig. 8(a). **[3]** Cost Chg from 8(d) ÷ Veh-hr Chg from 8(c).
[4] Federal Transit Administration's (FTA) National Transit Database (NTD), NYCT Motor Bus Operating Cost per Veh-hr (2009).

(e) Anticipated Vehicle-Hour Changes from Friday Exception Scheduling (Fridays Only)

Route Groups[5]	Cycle basis Veh-hr Chg [A]	Est. %Chg [B]	Schd. Veh-hr [C]	Schd. basis Veh-hr Diff [D]	Route Groups[5]	Cycle basis Veh-hr Chg [A]	Est. %Chg [B]	Schd. Veh-hr [C]	Schd. basis Veh-hr Diff [D]
B1	-29.7	-14%	332	-45.4	M86	-11.7	-6%	255	-14.1
B41(Lcl/Ltd)	9.6	2%	655	11.3	Q27 (Lcl/Ltd)	-75.8	-13%	551	-65.5
B46 (Lcl/Ltd)	-16.0	-2%	877	-14.3	Q44/20	-70.0	-9%	923	-81.8
BX12	-9.9	-5%	208	-9.8	S78	—	0%	280	—
BX12 (Select)	-18.5	-8%	296	-21.7	S79	—	0%	279	—
BX19	-16.5	-5%	421	-18.5	X1 (X1-X9)	-38.5	-9%	1,069	-90.5
M4 (Lcl/Ltd)	-72.1	-15%	454	-63.8	X17 (X17/X19)	-113.5	-12%	553	-63.9
					Overall (14 Rtes)	**-463**	**-7.4%**	**7,153**	**-502**
					Systemwide[6]	**-3,012**	**—**	**46,563**	**-3,437**

Routes Analyzed: 14† **Sys. Total:** 195 Reg. + 33 Exp. = 228
† Equiv.: 6.1% of Routes; 14.4% of Ridership; 15.4% of Veh-hr.

Notes: [5] 14 routes selected for exploratory analysis. **[6]** Overall sum ÷ 15.4%. **[A]** From Fig 7(a), route sum of Column 15.
[C] From Hastus scheduling software, system statistics report. **[D]** Equals [B]×[C]×95% (assuming 5% deadhead veh-hr).

(f) Forecast Vehicle Hours by Schedule Type (With Friday Exceptions)

Day Type	Average Day Count	Daily Vehicle Hours			Annual Vehicle Hours (Millions)[9]			
		2010[7]	2010 w/ Fri. Exc.	Est. Chg[8]	2010	2010 w/ Fri. Exc.	Est. Chg	Est. %Chg
Wkdy (M-Th)	147	46,563	46,563	—	6.84	6.84	—	—
School Closed	62	45,245	45,245	—	2.81	2.81	—	—
Friday	52	46,563	43,171	-3,437	2.42	2.24	-0.18	-7.4%
Saturday	52	30,209	30,209	—	1.57	1.57	—	—
Sunday	52	24,322	24,322	—	1.26	1.26	—	—
Overall					**14.91**	**14.73**	**-0.18**	**-1.2%**

(h) Operating Budget, Buses (Millions)

2009 (NTD)	2010 (NTD)	2010 (Fri. Exc.)[10]
$2,217	$2,211	$2,198

(g) Estimated Annual Cost Impacts (Millions)

Method	#1	#2	#3	#4	Avg.
Cost Chg.	-$9.6	-$11.0	-$16.9	-$15.6	-$13

Notes: **[7]** From Fig. 8(b). **[8]** From Fig. 8(e), Column [D]. **[9]** Daily Value × Day Count. **[10]** Average of four methods.
Method #1: Est. Friday Veh-hr Chg (cycle basis) multiplied by count of Fridays and Weekday Cost Factor per Veh-hr ($61.27).
Method #2: Est. Friday Veh-hr Chg (schedule basis) multiplied by count of Fridays and Weekday Cost Factor per Veh-hr.
Method #3: NTD 2010 Actual Motor Bus Operating Expense ($2.211 billion) multipled by Variable Cost Fraction (64.7%, MTA Financial Plan 2010 Actual), then multiplied by %Chg in Annual Veh-hr.
Method #4: Est. Friday Veh-hr Chg (cycle basis) multiplied by count of Fridays and NTD Operating Cost per Veh-hr ($99.31).

FIGURE 9
Estimation of Approximate Crewing Impacts based on Selected Bus Route Groups

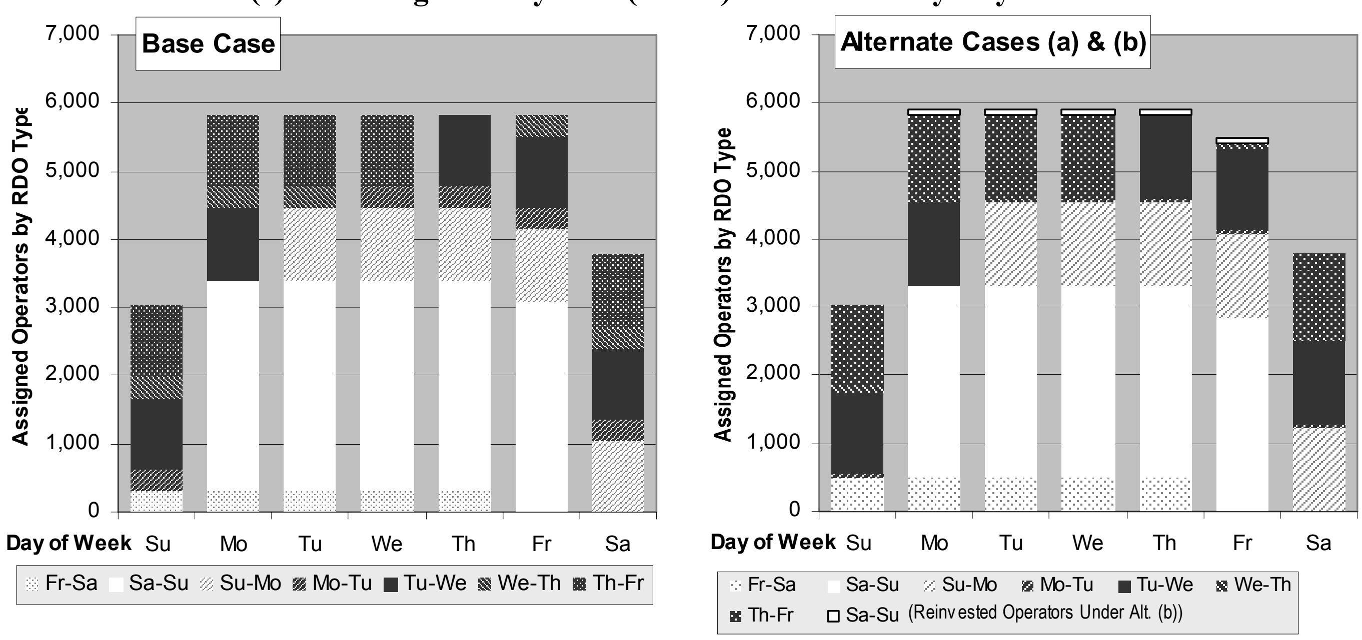
(a) Required Coverages (Runs by Day-of-Week) in Simple Crew Model

	Required Operators by Day of Week						
Scenario	**Sun**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**
Base Case	3,041	5,821	5,821	5,821	5,821	5,821	3,777
Alternate Case (a)	3,041	5,821	5,821	5,821	5,821	5,397	3,777
Alternate Case (b)	3,041	5,907	5,907	5,907	5,907	5,477	3,777

(b) Regular Day-Offs (RDOs) Assignment Results from Simple Crew Model

Days Off	**Fr-Sa**	**Sa-Su**	**Su-Mo**	**Mo-Tu**	**Tu-We**	**We-Th**	**Th-Fr**	**Total**
Days Worked	**Su-Th**	**Mo-Fr**	**Tu-Sa**	**We-Su**	**Th-Mo**	**Fr-Tu**	**Sa-We**	**Jobs**
Base Case	**313**	**3,095**	**1,049**	**313**	**1,051**	**313**	**1,051**	**7,185**
Alternate Case (a)	**483**	**2,840**	**1,219**	**60**	**1,219**	**59**	**1,220**	**7,100**
Difference	*170*	*-255*	*170*	*-253*	*168*	*-254*	*169*	*-85*
Group Subtotals		85			-170			
% Change		1.2%			-2.4%			
Alternate Case (b)	**485**	**2,922**	**1,222**	**56**	**1,222**	**55**	**1,223**	**7,185**
Difference	*172*	*-173*	*173*	*-257*	*171*	*-258*	*172*	*0*
Group Subtotals		172			-172			
% Change		2.4%			-2.4%			

(c) Crew Regular Day-Offs (RDOs) Distribution by Day-of-Week



(d) Resources and RDO Impacts of Adjusting Friday Service Under Typical Transit Scenarios of Saturday and Sunday Service Levels (Assuming 400 Weekday Runs Covered)

	Service Level Relative to Weekday			Jobs (Brackets Show Change Relative to Base—Friday Service at 100% of Weekday Levels)				
Scenario No.	**Sat**	**Sun**	**Fri**	**(A) Total Jobs**	**(B) Sa-Su RDO**	**(C) Fr-Sa/Su-Mo RDO**	**(D) Midweek RDO**	**Equiv. Excess Crews**
			105%	520 (6)	180 (7)	100 (-15)	240 (14)	0
			Base	**514**	**173**	**115**	**226**	**1**
#1	75%	67%	95%	507 (-7)	168 (-5)	125 (10)	214 (-12)	0
			90%	500 (-14)	160 (-13)	140 (25)	200 (-26)	0
			85%	500 (-14)	140 (-33)	160 (45)	200 (-26)	7
			105%	514 (7)	194 (8)	92 (-16)	228 (15)	1
			Base	**507**	**186**	**108**	**213**	**0**
#2	67%	67%	95%	500 (-7)	180 (-6)	120 (12)	200 (-13)	0
			90%	494 (-13)	174 (-12)	133 (25)	187 (-26)	1
			85%	489 (-18)	173 (-13)	138 (30)	178 (-35)	2
			105%	500 (6)	221 (8)	81 (-13)	198 (11)	1
			Base	**494**	**213**	**94**	**187**	**1**
#3	67%	50%	95%	489 (-5)	202 (-11)	109 (15)	178 (-9)	2
			90%	489 (-5)	182 (-31)	129 (35)	178 (-9)	8
			85%	489 (-5)	162 (-51)	149 (55)	178 (-9)	14
			105%	486 (6)	248 (8)	66 (-14)	172 (12)	0
			Base	**480**	**240**	**80**	**160**	**0**
#4	50%	50%	95%	474 (-6)	232 (-8)	94 (14)	148 (-12)	0
			90%	468 (-12)	224 (-16)	108 (28)	136 (-24)	0
			85%	467 (-13)	207 (-33)	127 (47)	133 (-27)	5