A great deal of planning is required to provide safe and reliable bus service on a daily basis. The Metropolitan Council is the regional body responsible for planning the provision of public transportation in the Twin Cities metropolitan region, and for providing oversight of the transit agencies that provide this service. Metro Transit, an agency of the Met Council, is the dominant public-transit provider in the Twin Cities metro area, providing approximately 95% of all transit service. In addition to operating an integrated network of buses, light rail, and commuter rail, Metro Transit also provides assistance and support for those who carpool, vanpool, walk, or bike throughout the Twin Cities.

Budgetary pressures on public financing of transit operations have increased in recent years, leading to greater scrutiny of operational efficiency. Because labor costs are the single largest line item in transit agencies’ budgets, there is strong interest in improving transit-workforce efficiency. However, optimizing efficiency is difficult because the demand for bus service varies by time of day, day of the week, and time of year, and can be affected by unanticipated events. A common practice for coping with this supply-and-demand variability is to have a certain fraction of the transit workforce serve as extraboard drivers—that is, drivers who are not assigned beforehand to regular routes or schedules. Some of these extraboard drivers cover for regular drivers who are on vacation that week or who are out due to an unplanned absence; others are dynamically assigned to open work that becomes available during the workday. Although extraboard drivers are essential for delivering reliable bus service, this flexibility comes at a price. Extraboard drivers are guaranteed full pay for their shift, even though a significant portion of their time may be spent “standing by” while they await an assignment. In addition to scheduling extraboard-driver assignments, transit authorities also match supply and demand by making use of overtime when needed. Thus, a key challenge for Metro Transit management is to find the right balance between the size of the extraboard-driver workforce and reliance on assigning drivers to work overtime, while maintaining their ability to provide all of the needed transit trips for a given day.
Our research, which was performed in collaboration with Metro Transit, had three broad objectives: to develop performance metrics that help monitor bus transit workforce efficiency and support better transit workforce planning; to analyze the tradeoffs between cost and reliability in the choice of extraboard-driver workforce-management practices; and to develop mathematical models that could help improve operational efficiency in assigning and scheduling extraboard drivers. The research upon which this article was based was supported in part by a grant from CURA’s Faculty Interactive Research Program, with additional funding from the Center for Transportation Studies at the University of Minnesota.

The Complexity of Bus Transit Workforce-Management Decisions

Public transportation services are defined by bus routes and schedules, which in turn drive the workforce-planning process. Bus schedules exhibit systematic variation by time of day, day of the week, and time of year. Demand is also affected by events (e.g., a Vikings or Twins game, the Minnesota State Fair), bus accidents and breakdowns, road construction, and planned and unplanned driver absences. Labor contracts typically govern decisions concerning the mix of full-time and part-time drivers, the assignment of drivers to shifts, and the assignment of pieces of work to drivers, which further complicates the planning task.

In the Twin Cities, Metro Transit sets bus timetables quarterly, and commercially available scheduling software converts the timetables into a set of driver assignments. Before the quarter begins, regular drivers select their work schedules from these lists of assignments, so a majority of drivers know their work schedules in advance, and their schedules are generally consistent on a weekly basis throughout the quarter. Transit agencies also allocate a fraction of the workforce to serve as extraboard drivers to deal with variability in daily demand for and supply of bus drivers. Typically, extraboard drivers are full-time employees who are assigned to open work on a daily basis. Thus, extraboard drivers’ shift start times and work assignments are not fixed in advance and may vary from day to day and week to week.

Open work can arise for many reasons. For example, some pieces of work remain open after regular drivers choose their work schedules each quarter. Consider a bus route that is continuously serviced for 10 hours a day. Scheduling software may divide this into two pieces of work, one eight hours in length and the other two hours in length. If a driver chooses the eight-hour piece as part of his/her recurring work schedule, the two-hour piece may remain open when all regular drivers have chosen their work schedules. The two-hour piece is then added to the pool of unassigned work that will be filled by extraboard drivers. Similarly, pieces of work may become available when drivers who picked those assignments in advance take vacations or other planned leaves. Finally, some pieces of work become open in a dynamic and random fashion due to bus breakdowns, unplanned driver absences, special events, and unanticipated traffic delays.

Extraboard-driver workforce planning involves three sets of hierarchical decisions.

At the strategic level, transit agencies decide the number of extraboard drivers, vacation allocation, and hiring programs necessary to meet future needs. Typically, transit managers think of and describe their decisions about the size of the extraboard-driver workforce in terms of a percentage of the total driver workforce. For example, Metro Transit’s current target is to have the extraboard-driver workforce be approximately 31–32% of their full-time drivers’ duties.

At the tactical level, transit agencies decide the target number of extraboard drivers to have on duty each day in each planning period. As explained above, these plans are developed on a quarterly basis and regular drivers choose their work schedules from lists of available assignments. These lists include assignments to serve as extraboard drivers. Metro Transit further divides extraboard drivers into AM and PM drivers, which constrains shift start and end times within each group.

Finally, at the operational level, transit agencies assign work daily to extraboard drivers. Some of these assignments are made in advance of the workday. Based on known numbers of AM and PM drivers and those pieces of open work that are known in advance, a dispatcher has to decide which extraboard drivers should be preassigned to which pieces of open work for the next day, how many extraboard drivers should be put on call (standby) for the AM and PM periods to cover unanticipated open work that becomes available that day, and what the shift start times should be for both the preassigned and standby extraboard drivers. Not all open work can be anticipated the previous day and covered by advance assignments, so as open work becomes available during the workday, the dispatcher makes dynamic assignments to available standby extraboard drivers, or to preassigned extraboard drivers who have open windows of time in their work schedules. Remaining pieces of work that cannot be assigned to any of the available extraboard drivers because of conflicts with other assignments or Metro Transit work rules (see sidebar) are made available as overtime work. Drivers bid on overtime work

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Metro Transit Work Rules

Assignment of work to drivers is constrained by a number of work rules. Each piece of work pertains to a particular bus route and corresponds to a specific time period during which a driver must operate a bus on that route. A piece of work is not divisible—that is, it cannot be split between multiple drivers. Drivers are assigned work within a continuous time window, called a spread. Within the spread, drivers cannot be asked to work more than their regular shift hours unless they voluntarily agree to do extra work. Drivers are paid overtime for extra work. Metro Transit drivers may have a spread of up to 12 hours, and a typical driver’s shift includes 8 hours of work. In other words, an extraboard driver may be assigned up to 8 hours of work within a spread of up to 12 hours from his or her shift start time. A driver need not be continuously busy within the 12-hour spread. That is, he or she may be idled without pay so long as work and spread time constraints are not violated.

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and dispatchers make assignments typically based on seniority. When making assignments for the next day, the dispatcher’s challenge is to select shift start times and allocate pieces of work to drivers in a manner that minimizes the amount of overtime used to cover these pieces, based on the number of preassigned extraboard drivers and the number of known pieces of work. Assignments must satisfy spread and work time constraints. In principle, this problem is easy to formulate as a mathematical model, but it is difficult to solve because of the large number of possible assignment combinations. Filling open work that becomes dynamically available during a given workday is much harder because pieces of work come up at different times, and at the time dispatch decisions are made, the amount and timing of future work that may become available are unknown. Under such conditions, the temptation is to make myopic assignments—that is, assignments that do not consider future work becoming available and that minimize overtime use based only on the current assignment that needs to be filled. However, myopic assignments can be costly in terms of overtime accrued (see sidebar).

Analysis and Findings

In this section, we describe our analysis and findings related to our three research objectives: developing performance metrics to monitor bus transit workforce efficiency and support better transit workforce planning; analyzing the trade-offs between cost and reliability in the choice of extraboard-driver workforce-management practices; and developing mathematical models to improve operational efficiency in assigning and scheduling extraboard drivers. For our analysis, we obtained selected datasets from Metro Transit for 2008 to 2010 related to extraboard drivers assigned to each of its five garages: Nicollet, Heywood, Martin J. Ruter (MJR), South Metro, and East Metro. Among other things, these data included for each driver the shift date, the shift start and end times, the paid work time (both regular-pay and overtime), and the amount of productive work done within the paid work time. For our analysis, we selected months and garages to obtain diverse samples from different garages at different times of the year.

Performance Metrics. Ideally, the extraboard-driver workforce should be able to cover all open work—that is, work that is either not selected by regularly scheduled drivers or that becomes open dynamically during the workday. However, that goal is often impossible to achieve because of assignment conflicts and work-rule restrictions. Based on our understanding of the nature of the problem faced by Metro Transit, we proposed four performance measures to evaluate extraboard-driver workforce-planning efficiency:

- **Ratio of available regular** (that is, nonovertime) extraboard-driver work time to the amount of open work. This measure attempts to capture the degree of match between extraboard-driver availability and demand, and can be calculated just for standby extraboard drivers or for all extraboard drivers.

- **Mean cost per hour of open work**, including regular paid time, overtime, and appropriate fringe benefits. This measure monetizes the availability-demand match.

- **Overtime as a fraction of total open work**. This measure, expressed as an average by day of the week, provides greater insight into overtime usage patterns for each weekday.

- **Extraboard-driver utilization**, defined as the ratio of open work actually covered by regular-time (nonovertime) extraboard drivers to the amount of available regular-time (nonovertime) extraboard-driver work. This measure can be calculated just for standby drivers or for all extraboard drivers.

In addition to these performance measures, we also developed demand, availability, and overtime profiles to gain insight into the difficulty of planning problems faced by different garages or different transit agencies. To develop such a profile, we chose a particular day of the week, divided bus operation time into 15-minute time increments, and counted the number of pieces of work that needed to be covered during each time increment. We also counted the number of extraboard drivers available (whether idle or working) who were paid regular-time wages during that time period. For example, if a profile concerns Wednesdays during the March–June quarter in 2009, then all counts of the number of work pieces and drivers on all Wednesdays during that time period were added to obtain the demand and availability profile. Similarly, we obtained the count of drivers being paid overtime to obtain an overtime profile. These profiles would reveal if demand patterns have sharper peaks in some garages, which would make it more difficult to realize higher utilization of standby drivers. The relationship between demand peaks and overtime usage can be explained as follows: more drivers need to be on duty simultaneously at peak times to cover the higher demand. This need limits the ability to schedule shift start times in a manner that provides consistently high coverage throughout the day, because
drivers who cover piece of work during the AM peak often cannot also cover work during the PM peak due to work- and spread-time constraints.

Average performance statistics for standby extraboard drivers by weekday for the Nicollet and Heywood garages from March to June 2009 revealed some interesting differences in workforce-management practices between these two garages (Table 1). Nicollet had a ratio of available regular work time to open work that equaled or exceeded 1, whereas Heywood had a ratio that was consistently less than 1. These data mean that Nicollet scheduled more extraboard drivers to be on standby, relative to the total amount of work that became open during a given workday. In contrast, Heywood scheduled fewer regular-time standby driver hours, resulting in a higher ratio of overtime to total open work for the Heywood garage. Interestingly, the standby extraboard driver-utilization rate was not greater for Heywood, as one might anticipate. This result suggests that either the work pattern for Heywood is such that many pieces of work overlap, making it logistically impossible to use standby extraboard drivers to fill open work, or that standby drivers are not assigned all feasible work assignments as they become available in order to reserve capacity for times of the day when the dispatcher may experience difficulty finding drivers willing to take overtime assignments. Notwithstanding these differences, the cost per hour of open work performed on a given workday was not statistically different between the garages.2

These examples reveal important policy implications for transit agencies. Many transit agencies only calculate the extraboard drivers’ utilization to ascertain the efficiency of their operations. The examples above demonstrate that this analysis is insufficient to evaluate efficiency. Based only on a utilization metric, the Heywood garage would appear less efficient because it had lower standby extraboard-driver utilization. However, it also scheduled fewer extraboard drivers and used more overtime. The latter is typically more efficient because drivers are paid only for productive time. Because Heywood’s strategy results in statistically similar

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2 We performed a paired-unit cost-difference t-test for all days in the March–June 2009 quarter and found a p-value of 0.32, which suggests that the unit differences in daily costs are not statistically different.
costs per hour of work performed, it is in fact operationally just as efficient as Nicollet.

The differences in planning strategies can perhaps be better understood by examining the availability, demand, and overtime profiles for a particular weekday. When we disaggregated statistics for all Wednesdays in March–June of 2009 for the Nicollet and Heywood garages, we found that Heywood had much higher and narrower AM and PM demand peaks (Figures 1 and 2). The daily maximum number of work pieces to be covered during this three-month period is 15 for Nicollet and 28 for Heywood (data not shown), suggesting that the differences in planning strategies used by the two garages to cover open work may be consistent with structural differences in same-day demand between the two garages.

Next we considered statistics for all extraboard drivers (preassigned and standby) combined. Table 2 shows two sample comparisons for Nicollet and Heywood garages for December 2009 and June 2010, respectively. The overall ratio of available regular work time to open work is similar for the two garages, although the overall and standby extraboard driver–utilization rate is greater at Nicollet. Conventional wisdom would suggest that this should make Nicollet cheaper because the hourly overtime wage rate is higher. Surprisingly, Heywood’s extraboard-driver operation was not statistically significantly more expensive in terms of costs per hour of open work, which results from the fact that all overtime is productive work, whereas drivers usually are not productive 100% of the time for which they receive regular pay. We investigated this issue in greater detail as described in the next section.

Cost-Reliability Tradeoffs. We next examined the cost-reliability tradeoffs as a function of the number of standby extraboard drivers. If the management team of a transit agency was interested in a quantitative approach to choosing the number of standby extraboard drivers, we wanted to explore how transit managers should think about solving this problem. On one hand, if they chose a small number of standby drivers relative to the number needed to cover the typical amount of work, it is likely that most of the extraboard drivers’ paid time would be utilized, but the agency would probably incur substantial overtime costs. Moreover, service might be unreliable because of the uncertainty of drivers’ availability for overtime assignments. On the other hand, if the agency chose a relatively large number of standby drivers, it would not be able to fully utilize the paid time of all of these drivers, but overtime costs would likely be lower and service reliability should be higher.

To capture these tradeoffs, we performed a simulated experiment. We chose a particular weekday (Wednesday) during a particular quarter (March–June 2009) for a particular garage (Nicollet). We then selected a small number of drivers and assigned same-day work to these drivers so as to minimize overtime use. (Note that in reality, each piece of work that arises during a workday is assigned sequentially—that is, one at a time—and therefore it may not be...

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**Figure 1. Driver Availability, Demand, and Overtime Profile for Wednesdays at the Nicollet Garage, March–June 2009**

**Figure 2. Driver Availability, Demand, and Overtime Profile for Wednesdays at the Heywood Garage, March–June 2009**
possible to achieve as high a utilization rate of standby drivers as we obtained with perfect foresight.) We repeated this exercise for each Wednesday in our sample and calculated the mean cost per hour of work, mean overtime used (in minutes), and the maximum number of work pieces that would have to be covered by drivers on overtime at any time during the day (called overtime stacking). We used mean cost per hour of work as a proxy for efficiency and mean overtime stacking as a proxy for reliability. Then we performed the calculations again assuming one more standby driver to be available, and continued adding one driver at a time until the cost per hour of work (efficiency) increased at a monotone (near-linear) rate and overtime stacking (reliability) remained largely unchanged.

Results of our analysis indicated that, as one would expect, both overtime minutes and overtime stacking decrease as the number of standby drivers increases (Figures 3 and 4). However, after scheduling 16 standby drivers, additional drivers have a relatively small effect on overtime stacking. That is, if the reason for having more extraboard drivers is to reduce dependence on drivers’ willingness to work overtime and thereby reduce the risk of loss of reliability, then one would not schedule more than approximately 16 standby drivers on Wednesdays to cover open pieces of work arising that day at the Nicollet garage.

From a policy perspective, the simulated experiment suggests that a greater reliance on overtime might, in fact, be more efficient. This is counterintuitive, because regular pay is generally lower and therefore it is assumed that it is more economical to assign work to regular shifts. However, several reasons explain why this analysis cannot be applied directly. First, we assumed perfect knowledge beforehand concerning pieces of work that need to be covered by standby drivers. In reality, the number of standby drivers and their start times need to be chosen in advance without this know ledge. Second, dispatchers worry about overtime availability at certain hours (e.g., during the AM peak) when it may be difficult to get drivers to accept overtime assignments, thereby reducing reliability. Thus, measuring overall overtime stacking does not capture dispatchers’ true objectives. Nonetheless, this analysis should encourage a deeper study of quantitative methods for determining the number of standby drivers and their report times. Future efforts may need to consider overtime stacking separately for AM and PM peak periods.

**Work Assignment and Shift Scheduling.** Finally, we developed an approach for scheduling drivers’ shifts and assigning work to drivers that satisfies the driver work rules at Metro Transit. This approach can be adapted to serve the needs of other transit agencies that may face different constraints. We developed two algorithms—one for solving the problem of advance assignments (that is, extraboard-driver assignments made before the next workday) and the other for solving the problem of dynamic assignments (extraboard-driver assignments made during the same workday). These problems belong to the class of so-called NP-complete problems, which are known to be difficult problems to solve. Therefore, our approach is not guaranteed to solve all instances of the problem with optimal results in a finite amount of time. However, in all practical instances, our approach was able to solve the operational-level problems quite quickly.

Our algorithms assumed that decisions regarding the number of

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3 Reliability can be measured in other ways—for example, in terms of the total overtime used. We chose overtime stacking because if a particular work-piece assignment approach requires many overtime drivers simultaneously, then this may lead to dropped service on account of driver unavailability.

extraboard drivers and their division into standby and preassigned categories have been made. The task for these algorithms is to assign work and determine shift start times of extraboard drivers. Although in this article we do not present the details of the algorithms developed to solve these problems, we do provide the general structure of these algorithms in diagrams showing the objective, the inputs, and the outputs for each stage of decision making (Figure 5).

We determined performance metrics from applying our algorithm to data for the Nicollet garage for December 2009 and the Heywood garage for June 2010 (Tables 3 and 4). On average, our approach can reduce overtime usage by 21.3 hours per day (22% of current usage) at Nicollet and 15.0 hours per day (12% of current usage) at Heywood. This reduction is achieved by using more overtime to cover the AM peaks at the advance-workday assignment stage, which allows our algorithm to cover most of the PM peak demand by using paid hours of preassigned extraboard drivers. This approach produces a net benefit because the amount of overtime saved in the PM peak is greater than the extra overtime used to cover the AM peak. We expect that the implications of our approach for each garage’s operations may be different because, as we have already shown, different garages have different demand patterns.

Upon testing our approach on data from the three other garages we studied, we found that the savings were substantially smaller for smaller garages. A possible explanation for this result is that when fewer pieces of work need to be assigned, a manual approach may be nearly as good as that based on mathematical models and computer algorithms. However, except for one small garage with 1% savings, all other garages showed an overtime savings potential of 5% or higher. The cost savings among the three largest garages was in the 7–22% range.

Conclusions and Recommendations
The proof-of-concept for improving operational decisions described in this article is based on applying our approach to historical data. It is possible that our approach does not capture all of the complexities in developing a markup schedule for advance-workday and dynamic same-day assignments, and therefore the actual savings may be smaller. Still, for the three largest garages operated by Metro Transit (Nicollet, Heywood, and East Metro), our approach has the potential to save 7–22% in overtime costs.

After a transit agency makes decisions concerning the size of its extraboard workforce, nonovertime wages for those extraboard drivers are a sunk cost. Therefore, the agency would benefit from reducing the amount of overtime used because any overtime wages are additional costs. However, if the agency is contemplating how many extraboard drivers to assign in the first place, our research found that strategic use of more overtime with commensurately fewer extraboard drivers might lower the agency’s costs. Our research highlighted the complexity inherent in choosing the right number of extraboard drivers, their division into standby and preassigned duties, and report times of standby drivers. It also provided justification and building blocks for addressing these problems. Finally, this study underscored the need to move away from the policy of using driver utilization as the sole measure of efficiency of extraboard-driver operations. Instead, we recommend the use of the four performance metrics identified here that together provide a more meaningful way to evaluate planning decisions.

The methods described in this paper were developed to help improve extraboard operations at Metro Transit. However, these techniques could be adjusted to account for different work rules, overtime costs, and overtime availability and used to help other large transit agencies that have a database of operational data and face similar questions about operational decisions.

Finally, there are a number of fruitful directions for future research related to the issues considered in this article, including the pursuit of data-driven optimization models that provide answers to the following questions: How many bus drivers should a transit agency employ? How many drivers should be assigned extraboard duties? How many of these extraboard drivers should be put on standby duty by AM and PM shift categories? What should be the shift start time of each standby operator? Such models could gain widespread acceptance if they were embedded in existing commercial software used to make driver duty assignments and track extraboard driver utilization. Many transit agencies have
invested in such software in recent years, but current versions of software do not include tools for improving workforce management.

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Table 3. Comparison of Performance Metrics for Actual and Algorithm Extraboard-Driver Assignments for the Nicollet Garage, December 2009

<table>
<thead>
<tr>
<th>Weekdays (21)</th>
<th>Weekends (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>Algorithm</td>
</tr>
<tr>
<td>Total work (hours)</td>
<td>339</td>
</tr>
<tr>
<td>Work covered by extraboard drivers (hours)</td>
<td>262</td>
</tr>
<tr>
<td>Total overtime (hours)</td>
<td>110</td>
</tr>
<tr>
<td>Ratio of available regular work time to the amount of open work</td>
<td>0.83</td>
</tr>
<tr>
<td>Mean cost per hour of open work</td>
<td>$46.40</td>
</tr>
<tr>
<td>Overtime as a fraction of total open work</td>
<td>0.32</td>
</tr>
<tr>
<td>Standby extraboard driver–utilization rate</td>
<td>59.4%</td>
</tr>
<tr>
<td>Overall extraboard driver–utilization rate</td>
<td>81.8%</td>
</tr>
</tbody>
</table>

Note: The figures in parentheses in the header row indicate the number of days of each type in our analysis.

Table 4. Comparison of Performance Metrics for Actual and Algorithm Extraboard-Driver Assignments for the Heywood Garage, June 2010

<table>
<thead>
<tr>
<th>Weekdays (22)</th>
<th>Weekends (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>Algorithm</td>
</tr>
<tr>
<td>Total work (hours)</td>
<td>397</td>
</tr>
<tr>
<td>Work covered by extraboard drivers (hours)</td>
<td>294</td>
</tr>
<tr>
<td>Total overtime (hours)</td>
<td>133</td>
</tr>
<tr>
<td>Ratio of available regular work time to the amount of open work</td>
<td>0.88</td>
</tr>
<tr>
<td>Mean cost per hour of open work</td>
<td>$49.00</td>
</tr>
<tr>
<td>Overtime as a fraction of total open work</td>
<td>0.34</td>
</tr>
<tr>
<td>Standby extraboard driver–utilization rate</td>
<td>55.0%</td>
</tr>
<tr>
<td>Overall extraboard driver–utilization rate</td>
<td>75.6%</td>
</tr>
</tbody>
</table>

Note: The figures in parentheses in the header row indicate the number of days of each type in our analysis.