Strategic Transit Work Force Planning Model Incorporating Overtime, Absence, and Reliability Relationships

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The optimal size of a transit operating work force is based on the appropriate amount of overtime that can be requested of the work force. Overtime is typically used to fill in for absent operators if no extra operators are available to do the work on regular time. However, relying more heavily on overtime has two risks. First, no operator may be willing and available to work overtime when it is needed. This will result in missed service and hence poor service quality. Second, operators may be absent more often because they can readily obtain overtime work at a significant wage premium. These interrelationships between overtime, absence, and service reliability are examined, and ways in which they influence the overall work force planning problem are shown. It was found that absence is more a habit than a result of a decision process based on past overtime worked. Strong linear relationship was found between absence and overtime. This result makes it possible to include reliability constraints in the strategic work force planning process by setting an upper limit on the amount of overtime that can be planned for a given period. In addition, a two-stage heuristic is developed for solving the strategic work force planning problem. This heuristic is used in a case study of the Massachusetts Bay Transportation Authority bus system to show the importance of various policies with respect to work force planning and management.

Transit work force planning deals with the problem of determining the most cost-effective staffing level for transit operators, those employees directly responsible for operating transit vehicles. Given the importance of service reliability and the uncertainty about both the manpower that will be available and the amount of work to be performed on a given day, transit agencies employ more operators than those actually scheduled for work. These extra operators are usually referred to as the extraboard (also known as the spare board or cover list). Too large of an extraboard will result in low productivity because some operators who do not have any useful work to perform must still be paid. On the other hand, too small of an extraboard implies that a large amount of overtime, at high marginal cost, must be requested from regular operators and furthermore that service reliability will be jeopardized.

In the past decade considerable attention has been focused on ways to improve productivity in the transit industry. Traditionally, strategic work force planning decisions have been made by relying on experience directly or by using rules of thumb that are themselves based on operating experience. Because of the complexity of the problem there have been few attempts to approach this problem analytically until recently, when MacDorman initiated work leading to the TOPDOG software for work force planning (*1–3*).

Over the past 6 years researchers at the Massachusetts Institute of Technology have also made considerable progress in solving this problem by working closely with managers and staff at the Massachusetts Bay Transportation Authority (MBTA). The work has shown that this problem can indeed be approached analytically and that the resulting models can provide a powerful tool for planning and managing a transit work force.

This paper is aimed at better understanding the potential for improved work force management throughout the industry to increase productivity and lower costs. Special attention is given to incorporating labor supply issues in the model, in particular those that relate absence and overtime. In addition, the relationship between overtime and system reliability is investigated. Including these relationships in this type of model makes it more realistic and thus more attractive for implementation.

WORK FORCE PLANNING RELATIONSHIPS

Figure 1 shows these interrelationships among work force planning, requested overtime, employee absence, and service reliability. Overtime may come in two forms: that which is included in the scheduled run, and that which is beyond the run. Requested overtime refers only to the latter form of overtime. In Figure 1 the labor supply issues associated with absence and overtime are indicated by curved boxes. The upper part of the figure shows the classic work force planning problem as described by Koutsopoulos and Wilson (*4*) and by Hickman et al. (*5*).

An important output of the strategic model is the amount of open work (equivalent to the amount of requested overtime) in the system. Open work is the difference between required extra work and extra manpower available. Employee absence, which is a major component of required extra work, depends on the willingness and ability of individual employees to work whereas the manpower available for extra work consists of the extraboard, one of the decision variables in the

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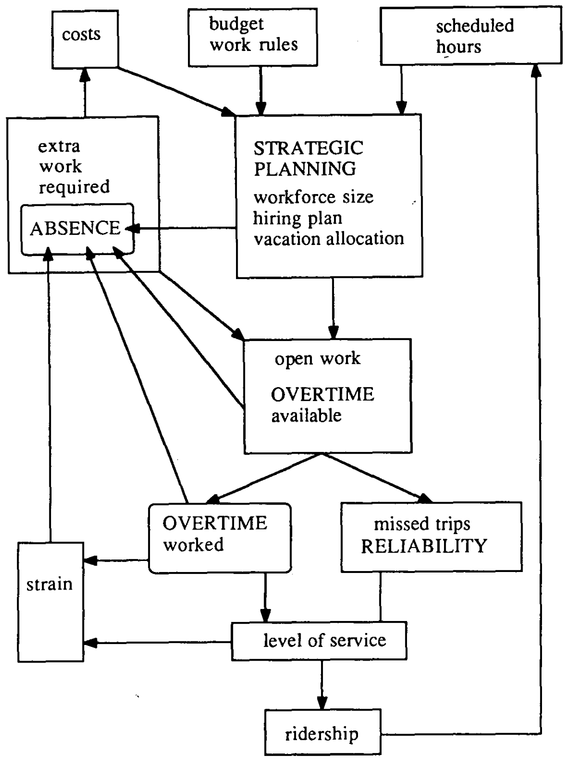

FIGURE 1 Strategic work force planning, absence, overtime, and reliability relationships.

model. However, management decisions on overtime may affect employee absence rates as well as employee willingness to work overtime.

As an illustration, consider the following situation. If the total cost per hour of labor is lower for an overtime employee than for a regular employee, the naive solution would be to rely heavily on overtime. This situation is common in the transit industry because the high cost of fringe benefits can outweigh the 50 percent pay differential for overtime work. The naive solution would be most inappropriate for two reasons. First, at most agencies, employees have the right to decline overtime work if they so choose, and greater reliance on overtime produces more situations in which no employee can work overtime. Whenever this occurs, scheduled service will not be operated, affecting service reliability. Service reliability is an important determinant of passenger satisfaction, and hence can be expected to affect demand as well as political and public support for the system.

Second, if large amounts of overtime are used, levels of employee absence may well increase for two reasons. Some employees may be more likely to be absent after reaching a threshold pay amount for a week, and this level can be reached after fewer hours on the job if overtime is readily available. Other operators may be absent more because of the increased stress and fatigue associated with regularly working longer hours. This may lead to increased risk of accidents as well as reduced service quality as a result of operators' being assigned to unfamiliar routes and irregular hours.

At an aggregate level absence affects overtime availability directly by producing open work; at the disaggregate level overtime availability may affect an individual employee's decision to be absent, which in turn will affect total open work. In this paper the disaggregate relationship between overtime and absence is studied. Prior models (*5*) assumed that absence rates (with known mean and variance) were not a function of the decision variables in the model. If absence is a function of overtime, and overtime is a decision variable of the model, it must be recognized at the strategic level.

ABSENCE-OVERTIME RELATIONSHIP

Employee absence is a significant problem within public transport organizations (*1*,*6*). Perry reported clear links between absence and the liberal availability of overtime work (*7*), and Leahy and Schlegel found that short-term absence was strongly associated with manpower shortages and with operators working on their regular days off (*8*). Perin reported that reducing available overtime was effective in reducing absence (*9*). One piece of evidence to the contrary is from the Twin Cities Metropolitan Transit Commission (*10*), in which increasing the number of operators reduced overtime by about 30 percent without affecting absence.

Theories of Absence

Fishman (*11*) and others have identified the following theories of employee absence:

- Absence is an approach-avoidance behavior. Withdrawal research is based on this premise (*12*), as is most work based on job satisfaction (*13*). Occupational stress may also be included in this category.
- Absence is a result of a decision process. Expectancy models (*14*) and some attitude models (*11*) are based on selecting the action having the most attractive attributes. In the idealized model the employee decides on any day whether or not to work. Economic analysis using utility-maximization or work-leisure trade-off approaches are similar (*15*).
- Absence is a habit. Habit is implicit in the frequent observation that a few workers are responsible for much absence. Predicting absence on the basis of past performance is consistent with, but does not confirm, the habit hypothesis (*16*).

The paper adopts an income-leisure decision model to explore the relationship between overtime and absence.

Income-Leisure Trade-Off

Subjective cost-benefit evaluation by the employee is known as the income-leisure trade-off of work force participation. Under this theory the employee compares the economic and social benefits of work attendance with leisure time and acts accordingly.

Several factors make the leisure-income trade-off more plausible in explaining absence in the transit industry than in some other industries:

- Widespread availability of overtime may allow some employees quickly to recoup wages lost to absence, diminishing the economic benefits of regular work attendance.

• Scheduling inflexibility reduces the operator's ability to take time off when needed for family or other responsibilities, or simply for leisure activities. Some operators may then use sick leave to obtain time off.

• The stochastic nature of open work and the inability to match available operators to open work can result in a cycle in which operators work overtime and then take time off to compensate, resulting in more absence, resulting in more overtime work, and so on.

• The extraboard encourages employee absence because employees are aware that replacements are available. This problem may be perpetuated by the common practice of basing the extraboard size on past levels of employee absence.

• Working long irregular hours causes fatigue, which is a major component of occupational stress that may induce absence. Occupational stress is not included explicitly in the following model, for the practical reason that it is very difficult to measure; however, it is included implicitly since working overtime may increase stress.

MBTA Case Study

Empirical Results

To test the hypothesis that widespread availability of overtime induces absence, a model of absence as a function of overtime and other factors was developed (*6*). For model estimation, data were obtained from the MBTA for a sample of 274 operators from all bus garages for the period July 1989 to September 1990. The data included number of hours each operator was absent each day, the category of each absence, and the weekly payment for overtime worked (the MBTA allows no more than 15 min of scheduled overtime, therefore most overtime is unscheduled). Absences were classified as voluntary, involuntary, or sick because of the different underlying behavioral processes involved. Sick was kept as a separate category because although it is generally genuine and thus involuntary, occasionally it may be a way for an operator to take what is really a voluntary absence.

Table 1 summarizes the absence and overtime variables, including the number of zero values for one (of seven) MBTA garages. In this data set each observation corresponds to an operator weekly record. The occurrence of voluntary absence is very low: less than 10 percent of all absences. To investigate whether sick absence may include some voluntary absences, the durations of sick absences were studied and it was found that 62 percent of sick absences were single days.

In light of the high percentage of 1-day sick absences and in order to model voluntary absences more realistically, new absence variables were defined as short (voluntary plus single-day sick absences) and long (sick absence of at least 2 consecutive days). This assumes that most long sick absences are genuine and most short sick absences are really voluntary. Some short absences are really involuntary and some long absences are voluntary, but there is no more reliable way to distinguish between the two. These categories are also consistent with the payment category: long absences are paid and short ones are not. A model for short absence is consistent with the underlying theoretical model, which assumes that absences are not paid.

A common problem in econometric studies based on labor data is censoring of the dependent variable that occurs when values in a certain range are infeasible. In this application no negative employee absences can exist, a problem which by the large number of zero absence bows observations. The tobit model developed for censored data (*17*), where the underlying distribution is a mixture of discrete and continuous distributions, was used in this study to deal with these problems.

Either frequency or duration may be used as a measure of absence. In this study, duration is used because it is more consistent with the underlying theoretical model: it is the duration of an absence that determines income.

The length of period at which to look for relationships between absence and overtime could be anytime from a day to a year. However, the hypothesized relationships between absence and overtime are not expected to exist at a daily level, since an operator is very unlikely both to be absent and to work overtime in a single day. But information is lost in analysis periods of a month or more. In this study, the basic time unit selected was 1 week: wages in the MBTA are paid weekly so this is the shortest period of perceived income for the operator.

Estimation Results

The absence model (*6*) estimated in this study is the following lagged time-series model:

$$\text{short}_i = \text{short}_i(\text{short\_1}, \text{short\_234}, \text{short\_past}, \text{long\_1}, \text{long\_234}, \text{long\_past}, \text{invol\_1}, \text{invol\_234}, \text{invol\_past}, \text{ot}, \text{ot\_1}, \text{ot\_234}, \text{ot\_past}, \text{winter90}, \text{spring90}, \text{summer90}, \text{oper\_1}, \text{oper\_2}, \ldots, \text{oper\_}n)$$

where

short_i = short absence in week i;
short_1 = short absence in the immediately preceding week;
short_234 = average short absence during preceding weeks 2 through 4;

TABLE 1 Summary of Absence and Overtime Data

	overtime	voluntary absence	involuntary absence	sick	total absence
mean (hr/wk)	0.65	0.12	0.59	1.50	2.20
s. d.* (hr/wk)	1.86	1.90	3.86	5.90	7.27
% obs = 0	79.5	99.3	95.5	89.5	84.9

* *standard deviation*

short_past = average short absence during preceding weeks 5 through 16 [similar definitions hold for the long (long), involuntary (invol) and overtime (ot) variables];

winter90, spring90, and summer90 = seasonal dummy variables; and

oper_i for i = 1, 2, ... n = operator-specific dummy variables.

The model examines whether absence in a particular time period is affected by prior absence of different types as well as by prior overtime worked. The operator-specific dummy variables account for the myriad differences among operators that may influence absence behavior.

Models were estimated separately for a sample of about 40 operators for each garage. The time period in these models is 1 week, although estimating models for different periods of up to 4 weeks led to the same conclusions.

The main conclusions from the estimation results follow:

- Most of the explanatory power in the model is due to the operator-specific dummy variables, for which virtually all coefficients were significant with t-statistics in the range of -1.9 to -5.5. Only 9 out of the 274 operator-specific dummy variable coefficients were not significant.
- None of the lagged overtime variables was significant in explaining current absence, and most tend to be negative, suggesting that those who work overtime tend not to be absent.
- Short_1 always has a positive coefficient that is generally significant, suggesting that operators who were absent in the previous week are more likely to be absent in the current week than those who were not absent in the previous week. This is because some short absences in any week are in fact the continuation of absences in the preceding week. The long_1 variable also has a significant positive coefficient for exactly the same reason: if a long absence in the prior week carries over and ends on the first day of the current week, this latter absence will be classified as a short absence. The other lagged long variables and involuntary lagged absence variables have mixed results, but are mostly insignificant, suggesting that there are no clear relationships between voluntary and involuntary absences including sickness.
- Short_past has negative and significant coefficients. This may be due to the disciplinary policy that limits the total amount of absence that can be taken without having a significant effect on the employee's career in the agency.
- The current-week overtime tends to have a negative coefficient (although only weakly significant) since someone who works overtime can not be absent at the same time, reducing the probability of absence in the same week.
- The winter and spring dummy variables are generally not significant, suggesting that absence in these seasons is not significantly different from absence in the fall. However, the summer dummy variable is positive and significant in three of the seven garages, suggesting that in these garages operators tend to be absent more in the summer.

Interpretation

These estimation results suggest that absence is best interpreted as a habit, that operators differ in their absence rates, and that operators who tend to be absent will always tend to be absent, independent of whether or not they recently worked overtime. If there is any relationship, it would be that those who tend to work overtime also tend to be absent less.

However, studies of absence are very complicated and the data available for this study do not resolve all of the potential problems. For example, even though absences were classified into several categories, it is sometimes difficult to make a clear distinction between voluntary and involuntary absence. Therefore, the lack of a relationship between overtime and absence in our data does not necessarily mean that such a relationship does not exist. There are several other reasons that we may not be able to observe such a relationship even if it does exist. First, we are missing many potentially important variables in the model such as non-labor income and personal and family characteristics, especially financial needs and responsibilities. Second, the level of overtime on the surface system of the MBTA is only about 1.5 percent of scheduled hours, which means that on average each operator works less than 1 hr of overtime per week. Therefore, many operators will not have the option of working any overtime, and it may be that overtime is not available to operators with many absences.

Recall that the two main reasons suggested for absence in the transit industry are the income-leisure trade-off and occupational stress. One reason for the lack of the expected relationship between overtime and absence in the data might be that those two factors affect different operators. As work is chosen according to seniority, the junior operators are more exposed to stress than senior operators, but junior operators seldom have the option of working overtime, since it is offered on the basis of seniority. The senior operators have overtime available, but they are not exposed to the same level of stress as the junior operators. Another explanation might be that because of the relatively high wage rate at the MBTA and the large portion of fringe benefits in total income, employees can afford to buy themselves more leisure time without making up for the lost income with overtime.

Finally, other factors that affect operator absenteeism, such as disciplinary policies or attendance awards, are not included in this analysis because they are the same for all employees of the MBTA. However, such factors may militate against absenteeism no matter how much overtime is available.

OVERTIME-RELIABILITY RELATIONSHIP

Open work occurring at any time will result in either missed service or overtime, with the split depending on the availability and willingness of operators to work overtime. Accordingly, there should be a relationship between the amount of open work and the resulting reliability, where reliability is defined as the percentage of scheduled trips actually operated.

It is necessary to understand the relationship between open work and missed trips if the reliability concern is to be included in the work force planning process. These relationships, which exist at the operational level of the problem, can have a significant impact on the best strategic-level solution. Hickman et al. (*5*) and Shiftan and Wilson (*6*) showed how to estimate the daily expected open work as a function of work force size, scheduled work, and other factors. Using this function, a relationship between open work and missed trips would enable one to estimate the expected daily number of missed trips and hence service reliability.

The data used for the empirical analysis are for the seven bus garages of the MBTA during the period January 1989 through May 1990. The data were extracted from manpower utilization reports that are completed weekly by each garage manager. From these reports daily figures on hours of overtime worked and missed trips were used to investigate the relationship between open work and missed service. Open work was defined to be the sum of total overtime worked and missed trips. On average there were 16 hr of overtime worked, 5.3 hr of missed trips, and 21.3 hr of open work per day per garage.

In the model systemwide missed trips are estimated as a function of the systemwide open work. Since open work is defined to be the sum of missed trips and overtime worked, missed trips appears both as a dependent variable and as an explanatory variable. The method of instrumental variables was used to overcome the bias and inconsistency otherwise associated with using ordinary least squares in such cases.

Figure 2 shows the different observations, where each observation is 1 day, and the following linear model that best fit the data:

$$MT = 0.248 * OW \qquad (R^2 = .58)$$
$$(t = 23.0)$$

where OW is the systemwide daily hours of open work and MT is the systemwide daily hours of missed trips. Both constant and quadratic terms were insignificant in adding explanatory power to the model.

The results show a strong linear relationship between systemwide open work and the number of missed trips, although it is expected that as the level of open work increases, this relationship will no longer be linear. At some level of open work most operators will be satisfied with their level of overtime, and so it will be increasingly difficult to find an operator who is willing to take on additional work, as operators become more selective in accepting overtime.

WORK FORCE PLANNING ALGORITHM

Total transit operator work force cost includes overtime pay, regular wages, and fringe benefit costs. For a given work force size the determination of regular operator costs (wages and fringe benefits) is relatively straightforward, but the estimation of expected overtime is quite complex. The difficulty arises from the fact that some open work is completely unpredictable since it is not known which operators will be absent from work and, as a result, when extra work will be required. Consequently, overtime is a function not only of extraboard size but also of the incidence of open work over the course of a day and the utilization rate achievable for extraboard operators.

Direct incorporation of all the factors that affect overtime in a single analytical model is very difficult, so Hickman et al. (*5*) developed a semiempirical model consisting of two terms: an analytical term and an empirical term. The analytical term represents regular overtime, and the empirical term [modified by Shiftan and Wilson (*6*)] represents excess overtime. Regular overtime is the minimum overtime possible, given a fixed extraboard size, under ideal conditions. In other words it is the overtime resulting when the extraboard is fully

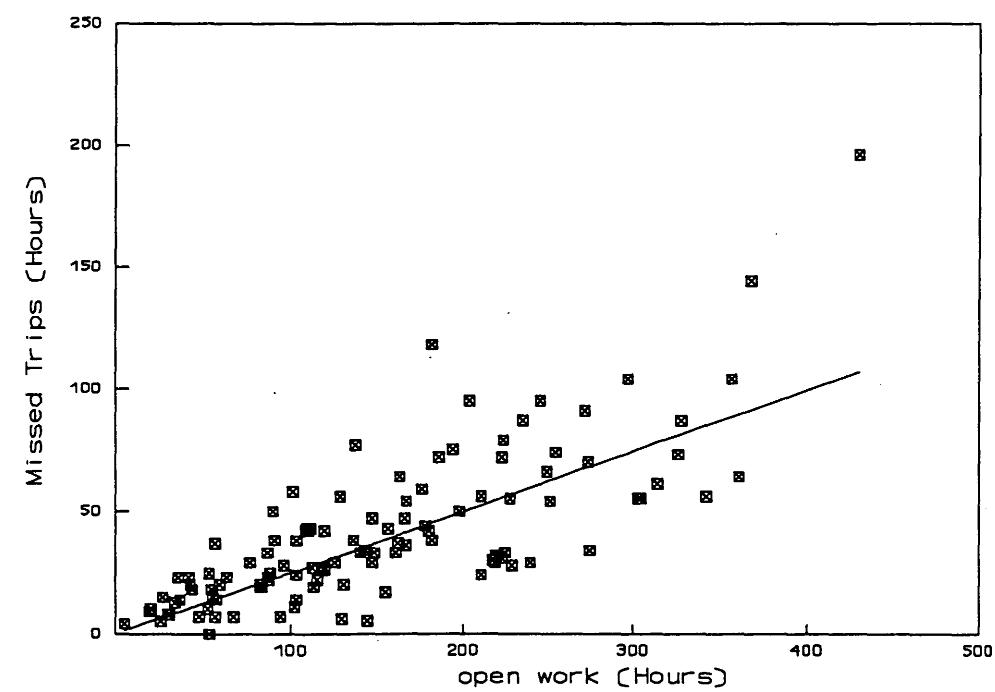

FIGURE 2 Missed trips as a function of open work.

used to meet required extra work, and only work over and above the extraboard size requires overtime.

Since the time of incidence of some open work is completely unpredictable, overtime may be required even if the total amount of required work is equal to the number of available operators. Even if the available cover is optimally allocated over the day, because the times of occurrence of open work are uncertain at the time that cover duties are assigned, it is quite likely that on the same day that overtime will be needed to cover some open work, all extraboard operators will not be fully used (*18*). Excess overtime captures this inevitable imperfection in assigning extraboard personnel to open work and approximates the difference between the actual and regular overtime.

Constraints

With this empirical approximation the strategic work force planning problem can be formulated as a constrained optimization problem with minimization of total annual expected work force costs as the objective.

Five basic constraint sets are included in the optimization problem. The first constraint set defines the number of full-time and part-time operators available in each period, as a function of the hiring decisions and the vacation allocation. The second constraint set represents the contractual limit (if any) on the maximum ratio of part-time to full-time operators. The third constraint set requires that the total hiring across all periods equals the total expected attrition, based on the assumption that the system is in steady state. The fourth constraint set guarantees that the vacation allocation satisfies the vacation liability for both part-time and full-time operators. The final constraint set guarantees that the expected overtime hours used in any period do not exceed a certain percentage of the total required work hours in that period. This constraint is included to ensure service reliability as described earlier. Additional constraints may be defined by each agency according to their policy or labor contract.

The strategic level model thus consists of a nonlinear objective function and nonlinear constraints. Hickman et al. (*5*) used a nonlinear optimization package (MINOS) to solve this problem. In this research a two-stage heuristic algorithm has been developed to solve the problem by decomposing it into multiple single-period subproblems and a simplified multiple-period problem as shown in Figure 3. The single-period problem is to find the optimal number of operator hours for each period using the exact objective function but making some assumptions on the vacation allocation over the year and the ratio of part-time to full-time operators. If the optimal number of operator hours does not satisfy the overtime or reliability constraints, it is raised to meet these constraints. The multiperiod problem is to find a feasible solution satisfying all the problem constraints with a linear objective function minimizing the differences between the actual operator hours available for each period and the optimal single-period results. This approach results in significant simplification of the problem. The algorithm can readily be implemented on a personal computer, making the model easier to use within an agency as well as capable of solving larger problems.

MBTA Case Study

A case study based on the MBTA bus system shows that the solutions obtained by the heuristic algorithm are extremely close to those obtained by MINOS with a maximum difference in total work force costs of less than 0.5 percent (*6*). It is, therefore, reasonable to conclude that the simplification in the problem formulation does not come at an unacceptably high cost in terms of solution quality.

The model described in this paper can be used to evaluate different work force management strategies and policies. The type of issues that this model can usefully address by calculating expected costs and other implications are alternative hiring plans, alternative vacation allocations across the year, impacts of changes in vacation liability, and changes in the reliability objective and in the ratio of part-time to full-time operators. Some of these issues are not solely in the management domain since they are subject to collective bargaining. In this case the model can be valuable by determining the cost of different strategies in order to consider the relative merits of different options during the collective bargaining process.

The intent of this case study is to show the potential use of the model in helping management with strategic decisions, mainly concerning the use of overtime and its effect on system reliability and cost. This case study is loosely based on the bus system of the MBTA.

Constant Hiring and Constant Vacation

Four scenarios, all of which reflect plausible management policies on hiring and vacation allocation, are tested in this section. These scenarios are

1. No additional constraints (the base case),
2. A constant level of hiring in each period,
3. A constant allocation of vacation over the year, and
4. A constant vacation allocation and constant hiring per period.

For all four cases a 1.5 percent overtime constraint was applied, which is the current rate of overtime in the bus system of the MBTA.

Table 2 shows the most important results for the four scenarios including the work force size (average full-time and part-time operators available for work, excluding operators on vacation), expected overtime as a percentage of scheduled hours, expected costs (schedule, overtime, and total), and expected reliability. The results show that the constant hiring constraint alone does not impose additional cost. Although the hiring plan is different, compensating adjustments in the vacation allocation remit in the same hours available for work for all periods in both scenarios. These two scenarios suggest that multiple optimal solutions may exist. This is characteristic of the specific MBTA cost characteristics, work rules, and management policies and may not hold for other transit systems.

The constant vacation allocation case requires more operators and increases the total cost from \$97.8 million to \$99.6 million, an increase of 1.8 percent. Combining the constant

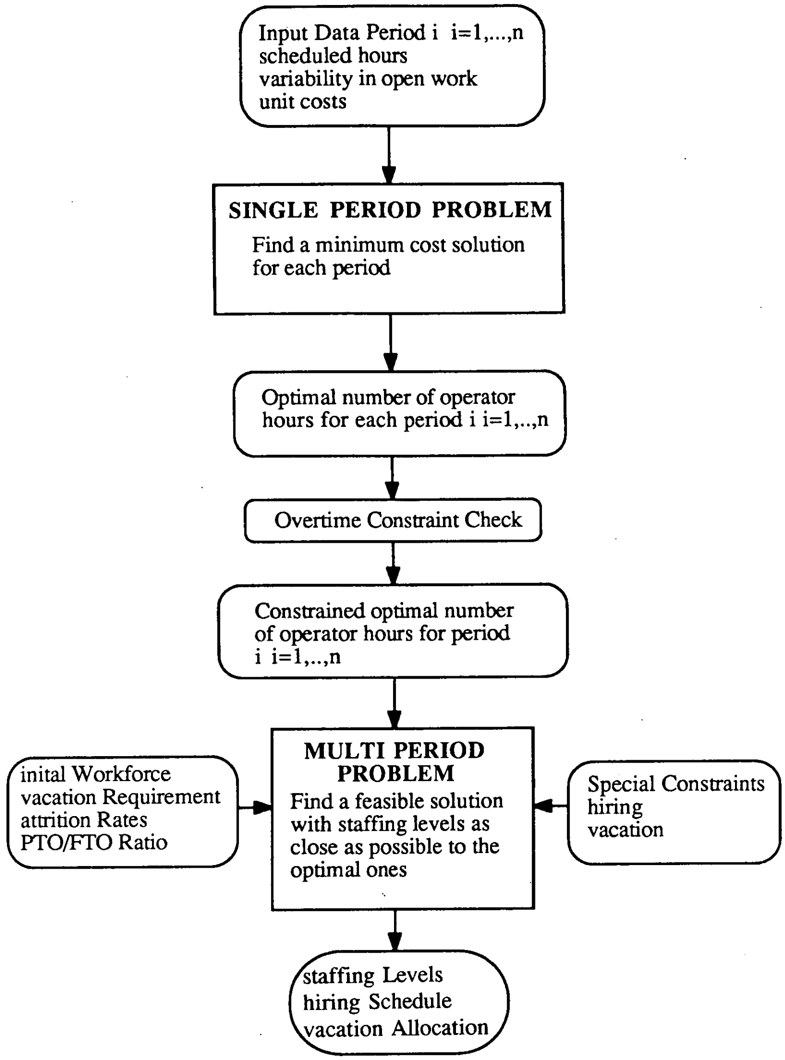

FIGURE 3 Work force planning algorithm.

vacation and constant hiring constraints further increases the total cost to $101.2 million. It should be noted that the cost increase is a result of a higher level of manpower and therefore a higher level of reliability is obtained. The total cost is only labor cost and does not consider unreliability costs. Incorporation of unreliability cost would require a study of the monetary value of unreliability, which is beyond the scope of this work.

This case demonstrates the value of the model by showing that inappropriate vacation allocation may have a high cost. Whereas in the unconstrained case the model makes use of the reduction in scheduled hours over the summer by allo-

TABLE 2 Results of Constant Hiring and Constant Vacation Constraints

	base case	constant hiring	constant vacation	constant hiring & vacation
FT oper	1256	1256	1291	1316
PT oper	654	654	666	685
overtime (%)	1.5	1.5	0.9	0.3
ot cost *	1.4	1.4	0.9	0.3
reg cost *	96.4	96.4	98.8	100.9
tot cost * (%)	97.8	97.8	99.6	101.2
reliability	99.6	99.6	99.8	99.9

* *All costs are in millions dollars*

cating more vacations to it, constant vacation allocation is inefficient.

Sensitivity to Overtime/Reliability Constraint

A set of cases was run to investigate the impact of different constraints on overtime and, by implication, different levels of the reliability objective. Table 3 shows the results of these runs. The first column repeats the results for the base case of the 1.5 percent overtime constraint, and the second column shows the results without any constraint on overtime. The minimum-cost solution is obtained when 12.2 percent of the required work is expected to be covered by overtime. In this case the overtime cost is higher but regular cost is lower, resulting in a net annual savings of $1.3 million (1.4 percent). However, one implication of the increased overtime is a significant reduction in reliability from 99.6 to 97 percent. It should be noted that this level of overtime is well beyond the range of data used in estimating the reliability model, and actual reliability is likely to be even lower.

The third column of Table 3 shows the result for an overtime constraint of 1 percent. Total cost increases by $0.4 million (0.4 percent) and reliability increases from 99.6 to 99.8 percent. In other words, missed service is cut in half, a cost increase of 0.4 percent. The fourth column shows the results for a 5 percent overtime constraint, which are intermediate between the base case and the unconstrained case in term of both cost and reliability.

SUMMARY

For a strategic work force planning model to be realistic, applicable, and useful for transit agencies it should recognize the potential importance of labor supply issues. In this paper the relationships between absence, overtime, and reliability have been studied for the MBTA. Such relationships can have important implications on transit management policies and strategic planning since the availability of overtime is a direct function of strategic work force planning decisions. Specifically, these relations are important in determining the optimal size of the extraboard.

To study the relationship between overtime and absence a disaggregate model of absence was developed as a dynamic form of motivated behavior, a problem in time allocation across activities. This model was estimated with panel data of surface transit operators from the MBTA to test the hypothesis that widespread availability of overtime may induce absence. The results suggest that absence is more a habit than the result of a decision process based on overtime worked. If this is so, reducing overtime will not necessarily reduce absence, and the key to reducing absence may be a system that predicts which employees tend to be absent.

The relationship between overtime and reliability was studied using aggregate data from the MBTA bus system. The results show a strong linear relationship, which makes it possible to include reliability constraints in the strategic problem by setting an upper limit on the amount of overtime that can be planned for any period.

A two-stage heuristic algorithm has been developed to solve the work force planning problem by decomposing it into multiple single-period subproblems and a simplified multiple-period problem. This approach results in significant simplification to the problem so that the algorithm can readily be implemented on a personal computer.

A case study based on the bus system of the MBTA shows the potential use of the model. The impacts of various policies that the MBTA might consider—such as constant hiring increments on a periodic basis, allocating vacations according to a predefined pattern over the year, or limiting the amount of overtime required in any period to a specified level—were analyzed using the model and considering both cost and system reliability. Sensitivity analysis showed the validity of the model and the algorithm for a range of parameters and the effect of different parameters on the solution. This set of analyses makes clear the value of such a model both in ongoing work force management and in policy formulation. The model has been applied to the MBTA, but its structure is flexible and can readily be transferred to other agencies and accommodate different work rules and policies.

ACKNOWLEDGMENTS

The research described in this report was made possible by the financial support of the Regional 1 University Center Program and the MBTA.

TABLE 3 Results for Different Overtime Constraints

	base case 1.5% ot	no ot const	1% ot const	5% ot const
FT oper	1266	1104	1267	1202
PT oper	654	575	660	625
overtime (%)	1.5	12.2	1.0	5.0
ot cost *	1.4	11.8	1.0	4.8
reg cost *	96.4	84.7	97.2	92.2
tot cost *	97.8	96.5	98.2	97.0
reliability (%)	99.6	97.0	99.8	98.8

* *All costs are in millions dollars*

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Publication of this paper sponsored by Committee on Transit Management and Performance.