Using Spreadsheet Based MILP to Develop a Bus Management DSS for a Texas ISD

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ABSTRACT

In this paper, a successful application of a spreadsheet based model for assigning buses to routes is described. The spreadsheet was developed for a Texas Independent School District and assigned buses to routes in an effort to prevent multiple bus retirements (and purchases) from occurring within the same year. The model solution provides a superior policy compared with the current policy, which is based primarily on (senior) driver preference. The spreadsheet nature of the model offers affordability and ease-of-use; thus, encouraging repeated use or future applications in other ISDs.

INTRODUCTION

Independent school districts (ISDs), large and small, rely primarily on experience when managing their Transportation Department. Primary duties are vehicle maintenance, assigning buses to routes and activities, retiring old buses, and procuring new buses. Several reasons exist for relying on experience and not adopting a more rigorous approach. One reason is simply 'Why bother?'. The potential costs due to poorly managed decisions fail to justify the development and purchase cost for historically expensive decision support system (DSS). Another reason is the lack of expertise required to develop, use, and maintain a quantitative DSS. In this paper, a relatively simple-to-use, affordable, but powerful DSS is presented that has been adopted by the Transportation Department of Tom Bean ISD, a Texas ISD of approximately 800 students and a fleet of 7 buses. The DSS is primarily a Microsoft Excel-based mixed integer linear programming (MILP) model that assigns buses to routings. Despite its diminutive size, the DSS was proven to be a value-added service. Additionally, the DSS is scalable and adaptable for larger ISD or other fleet management systems.

The primary reason for the development of the bus management DSS was a proposal to address the current and future needs of the department. Unfortunately, to satisfy the proposal, no established policy existed for assigning buses to routes or retiring/procuring vehicles. Because of the lack of any strategic policy, assigning routings depended primarily on drivers' seniority and preference. For activities (sporting events, band contests, etc.), the newest available bus with some driver preference determined school activities assignment.

Operating this way only allowed the school to react to problems and not be proactive to prevent future problems. The recent purchasing history represented a potential problem in the future of having to replace three or four buses at once if everything continues at the same pace. Another problem is that the school, understandably so, prefers using the more current model buses when taking the students to school sponsored activities. This will cause some of the current model buses to catch up in mileage with some of the older model buses. Replacing multiple buses at the same time is a very expensive task. Each new bus will cost between $50,000 and $65,000 dollars. With tighter school budgets and less money being received from the state, replacing three or four buses at once may require the school to have to go into debt, raise taxes, or require a bond election.

LITERATURE REVIEW

The assignment model is a balanced transportation problem in which all variables are binary, supplies and demands are equal to one and the cost of assigning each supply point to each demand point is known (Winston, 2004). Its special structure allows elegant, exact and fast solution methods. However, reality often requires additional constraints or a different objection function than minimizing cost in the formulation that prevents application of special structure solution methods. Since the binary variables are required, the problem has a finite number of feasible solutions and is combinatorial in nature. Since combinatorial problems are notoriously difficult to solve, the literature offers many examples of solution methods to the bus routing, assignment, and scheduling problem (Ankolekar and Patel, 1989; Blais et al., 1990; Carraresi and Gallo, 1984; Chen et al., 1990; Corberan et al., 2002; Forbes et al., 1991; Russell and Morrel, 1986; Swersey and Ballard, 1984; White, 1982; Willoughby and Uyeno, 2001). Although lengthy, this list is not exhaustive. Therefore, if and/or when the current model for the ISD becomes more complex and more difficult to solve, more sophisticates solution methods are known to exist.

However, as will be discussed later, an add-in modeling/solving software generates a satisfactory solution both in speed and quality. More importantly for the continued success of DSS is the ease of use. Spreadsheet-based math modeling and optimization has exploded in recent years. Academic popularity is evident in the availability of texts in the subject (Winston and Albright, 2000; Winston, 2001, Jackson and Staunton, 2002, Ragsdale, 2004; Shafer and Meredith, 1998). In most of these, the solvers are *Solver* by Frontline Systems (http://www.solver.com/) or *What's Best!* by LINDO (http://www.lindo.com/).

To summarize, the bus assignment research is well known and documented. However, equally important for successful applications is the ease of use and cost. Spreadsheet solvers are being taught and excellent texts exist. The relevance of this paper is the application of a classic problem in a useful format creating a successful deployment of a quantitative DSS.

MODEL FORMULATION

One approach for developing the model was to implement a simple and straightforward heuristic: assign the oldest bus to the longest route. This policy guarantees that the oldest bus would have the most miles and be retired the soonest. However, this approach had some limitations. Although it guarantees the oldest bus would have the most miles, it tended to accelerate retiring of older buses. Although the goal is to retire the oldest bus and for it to have the highest mileage, it is not known if a bus will be retired in 15, 18, or even 22 years of service. Because of the uncertainty of the retirement age, assigning the longest route to the oldest bus could cause the older buses to receive too much wear in the later years of service, which could cause a problem if the date of retirement had to be extended. Putting more miles on an older bus increases the risk of maintenance problems. Even if this policy was beneficial, it is still incomplete. Assigning activity miles requires additional rules because the school only wants the newer buses used to take kids to activities because of less risk of breakdowns and appearance.

To develop the requested proposal, a spreadsheet based mixed integer linear programming (MILP) optimization model was developed. The model makes annual assignments of a bus to one (at most) route while forcing an older bus to have more cumulative miles than any newer bus. Of specific interest is the objective function. The purpose of the model is to offer a plan that maximizes the distance between any two buses' cumulative miles. Since cumulative miles is the primary indicator of retirement, the result of this objective is to provide a annual, repeatable policy that assures that the time between bus retirements is maximized. This policy staggers bus retirements (about one retirement every three years) offering the best chance to eliminate multiple bus purchases in a single year.

What's Best!, a spreadsheet modeler and solver add-in offered by LINDO (www.lindo.com), was the software used to develop the model. The current model has 74 constraints, 50 decision variables, of which 42 are binary. A commercial license of *What's Best!* costs $495 and solves up to 1,000 constraints, 2,000 variables, of which 200 can be integer. Model solution time is trivial requiring less than a minute. Of course model solution time could significantly increase as buses and routes are added.

Rather than offer the algebraic formulation (available upon request), Table 1 and Figure 1 offer an alternative explanation. Table 1 summarizes the inputs, decision variables, constraints, and objective function. Figure 1 is a snapshot of the MS-Excel worksheet containing the model and documentation.

Parameter	**Description**	**Cell Range**
Input data: Active bus fleet profile	This data set identifies each bus, its age (ranked), and current (pre-solved) miles.	C1:J3
Input data: Routes	This data set identifies each route and annual miles.	A24:B30
Input data: Activity miles	This data set identifies the annual non-route miles for special events. It also lists bus-specific allocation limits (lower and upper). For example, Bus #2 must have less than 2% of all activity miles.	A31:J33
Decision variables	A two-dimensional binary variable. Let *i* be a specific bus and *j* be a specific route. A specific value of this set equals '1' if bus *i* is assigned to route *j*. Otherwise the value equals '0'.	D25:J30
Decision variables	A vector assigning activity miles to bus *i*.	D31:J31
Decision variable	This variable is maximized in the objective function. It is also used in a set of constraints that forces its value to be smaller than any of the miles between any two buses.	D14
Constraints	Each bus must be assigned to (at most) one route.	D37:J37
Constraints	Any bus must have more total miles than any newer bus.	D16:J22
Constraints	Any bus must have at least some user-defined activity miles.	C35:J35
Constraints	Any bus must have at most some user-defined activity miles.	C34:J34
Objective function	Maximize the minimum difference of cumulative miles between any two buses.	D14
Constraints	The objective function decision variable (D14) must be less than the miles between any bus and the next oldest bus.	D13:J13

Table 1. Model Formulation Parameters

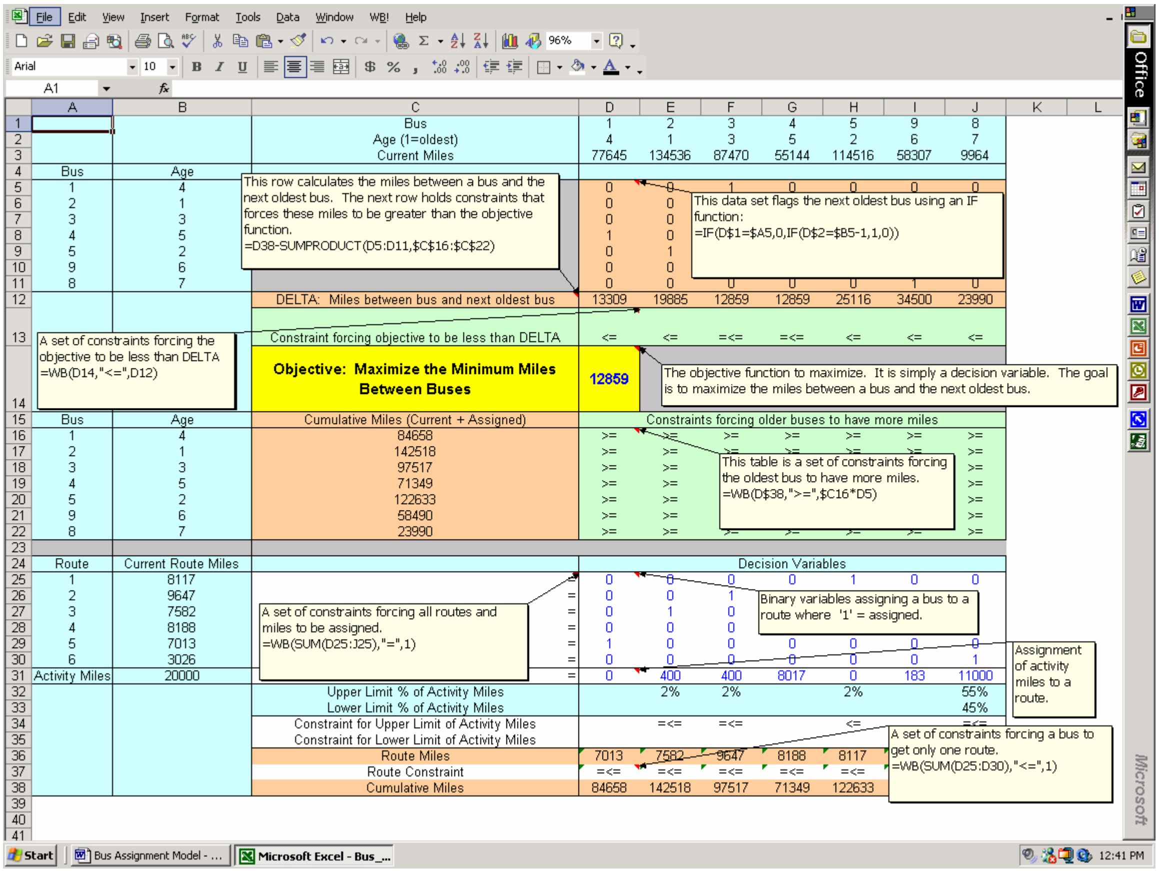

Figure 1. Spreadsheet Model

RESULTS AND BENEFITS

Figure 2 shows extrapolated mileage based on current assignments versus using the DSS. Of note is that the present policy potentially creates problems for buses 2, 3, 4, and 5. Buses 4 and 5 are accumulating miles more quickly than bus 3; thus, buses 2 through 5 may have to be retired during the same year. Retiring more than one bus in the same year could cause budgeting issues. In contrast, the model solution alters routings from year to year; thus keeping the difference between cumulative miles equally spaced from bus to bus.

Based on the model, the bus purchase policy was that the ISD purchase a new bus every three years, and that they retire a bus that has been in service for eighteen years. Using the model ensured the policy's effectiveness, helping the school justify buying a bus on a regular basis. During presentation to the school board, demonstration of the model formulation was not required. However, the school board members were impressed with the model's ability to show that adherence to the plan generated a stair-stepping effect with respect to age and mileage; thus avoiding purchasing 3 or 4 buses at one time. The proposal was approved unanimously by the school board.

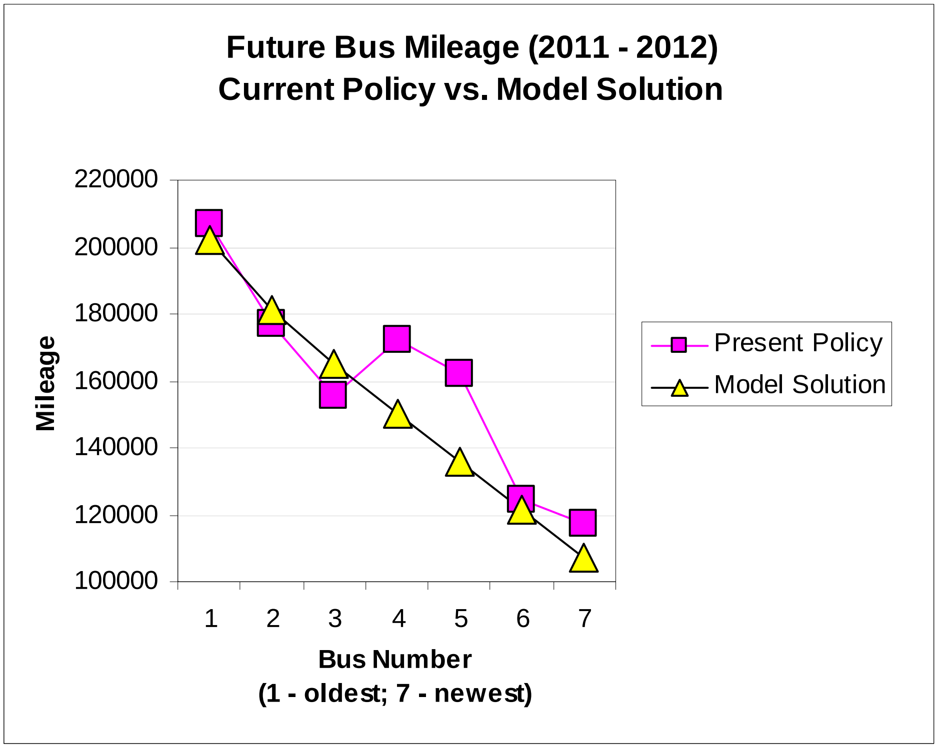

Figure 2. Current Policy vs. Model Solution

CONCLUSION

In this paper, a relatively simple-to-use, affordable, but powerful DSS is presented that has been adopted by the Transportation Department of Tom Bean ISD. The DSS is primarily a Microsoft Excel-based mixed integer linear programming (MILP) model that assigns buses to routings. Despite its diminutive size, the DSS was proven to offer a superior solution than the current policy based on (senior) driver preference. The current policy creates potential problems in the next 5 to 10 years by accelerating bus retirements and creating the possibility of multiple retirements in the same year. Based on the use of the DSS, policies within the ISD have been modified. The DSS could be applied at other ISDs that cannot afford an expensive system.

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