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A Comprehensive Approach for Rolling Stock Planning: Combining Train Performance Simulation and Life Cycle Cost Analysis

Rolling stock has a limited life span during which it can provide efficient service. Faced with today's budget constraints and economic slowdown, all railroad or transit operators will eventually face the following questions: What is the most suitable equipment available to replace the existing equipment for the particular service? What is the most economic way of procuring the required fleet?

To answer those questions, various railroad agencies and transit operators used diversified measures such as capacity demanded by the ridership forecast, performance afforded by the proposed equipment, or the operating and capital cost associated with certain rolling stock configurations. However, comprehensive analyses based on all three factors mentioned above are rare, even though it is agreed that all those factors affect railroad services simultaneously and they all should be considered in the rolling stock planning process.

To fill the gap, this paper describes a comprehensive approach to select long-term rolling stock for commuter services. This approach not only considers the performance of the proposed equipment but also evaluates the life cycle costs of the proposed fleet configuration. A case study of rolling stock planning for a commuter rail service is included to demonstrate the practical application of the suggested approach. Combining the train performance simulation (TPS) and life cycle cost (LCC) analysis, the proposed approach derives an optimal balance between service costs and service quality. Moreover, by incorporating the timing of the new equipment purchases into the life cycle cost, this approach further maximizes the return on capital investment for transit agencies.

by Rongfang (Rachel) Liu, Albert C. Song, and David O. Nelson

Faced with limited budgets and fluctuating travel demand, a number of transit agencies, especially commuter rail service providers, have been challenged to maintain or improve services with no or very limited capital investment (Liu, 2002). As one of the vital elements of transit operations, rolling stock has a limited life span during which it can provide efficient services. Railroad or transit operators generally do not change vehicle types for purely operational considerations. However, when faced with very limited and declining budgets and increasing ridership, some transit agencies are motivated to be creative and proactive. For example, The Long Island Rail Road (LIRR) has incorporated ridership predictions and train performance evaluation in its rolling stock selection process (Strong, 1989). VIA Rail Canada has explored cost management approaches in replacing existing locomotives (Derome and Derome, 1985).

When railroad agencies or transit operators are presented with alternatives, such as purchasing more efficient equipment or refurbishing or modifying the existing equipment (Parsons Brickerhoff, 2002), it may be beneficial to conduct a comparative analysis to select the most cost-effective solutions.

To demonstrate the general principles of the proposed comprehensive approach, the following section presents problem formulation and research background.

Sections 3 and 4 illustrate the modeling structures of train performance simulation (TPS) and major elements of life cycle cost (LCC) analysis respectively. A case study of rolling stock planning for a commuter rail service is included in Section 5. Some findings and suggestions based on this research and related case studies are summarized in Section 6.

PROBLEM FORMULATION

In theory, it is indisputable that a comprehensive analysis will provide the decision makers with the most logical and cost-effective solutions. However, in practice, transit agencies either do not have any incentive for long-range rolling stock planning or could not afford to examine future policies beyond the immediate operational needs. Transit agencies in the United States have inherited the historical role of operators, and operators only. The performance criterion is predominant in evaluating transit agencies; therefore, it also has the highest priority for daily operations. Long-range transportation planning has been rarely conducted for transit operations.

The muddling-through approach does not contribute to the health of the transit industry, especially commuter rail services. Prevailing rolling stock planning practices have left a number of commuter rail services with aging fleets, inefficient operations, and unsatisfied customers. In the long run, such practice may be detrimental to the overall health or even survival of certain operations. Therefore, it is important for large commuter rail services to examine their fleet configurations and plan their long-term rolling stocks with a more scientific and comprehensive approach. As proposed in this study, the logical approach should be a comprehensive evaluation of future ridership demand, characteristics of train performance to satisfy such a demand, and life cycle costs to achieve such performance at a cost that transit agencies can afford.

When considering the decision to invest large sums of money in a major transportation capital project or procurement, it is imperative for transportation executives to be confident that it will improve their system operations and it will meet the requirements of their particular situation. Short of actually undertaking construction or procurement, one viable tool to achieve this comfort level before making significant funding commitments is to undertake a computer simulation of the proposed system (Liu, 2001). The simulation uses specific criteria and replicates expected conditions of the proposed facility and performance characteristics of the equipment.

In the transportation community, travel demand forecast model, operation analysis/ simulation model, and any hybrid of both have played important roles in major investment decisions and operation improvements. For example, train performance calculators have been utilized in evaluating a wide variety of transit modes, such as light rail transit (Transportation and Distribution Associates Inc. 1987), heavy rail (Transtech International Incorporated, 1984), and high-speed rail (Holowaty, 1998). The models made great contributions to transit operation improvement, energy consumption reduction, and overall realization of social and monetary benefits of transit services.

On the other hand, a single dimensional objective, train performance evaluation overlooks another important factor - cost. The capital costs of railroad equipment, especially rolling stock, are enormous. For example, there are currently two basic passenger train configurations in the United States, multiple unit and locomotive-hauled coaches. A multiple unit train is made up of a number of self-propelled passenger cars. Two or three passenger cars may operate together and are often referred to as “married pairs” or “triplets.” There are two subcategories of multiple unit trains, which are electric multiple unit (EMU) for an electrically powered multiple unit and diesel multiple unit (DMU) for a diesel powered multiple unit. The latter sub-category is primarily used outside the U.S. As presented in the following case study, an EMU may cost three to four million dollars, while a locomotive alone may cost six to seven million dollars, depending on the quantities ordered and particular design specifications. Furthermore, the operation and maintenance (O&M) costs of different equipment vary significantly. Therefore, it is vital for railroad agencies and transit operators to understand the total life-span costs in addition to the performance of the proposed equipment.

In this research, the authors propose a comprehensive approach that not only examines the performance of the proposed rolling stock but also estimates and compares the life cycle costs of a total fleet when different equipment configurations are analyzed. An iterative process was implemented to optimize the fleet configuration so adequate transit services will be provided while life-cycle cost is minimized.

TRAIN PERFORMANCE SIMULATION

Train performance simulation (TPS) is not an innovation. Various transit operators and consultants have used application packages, such as Rail, Rail Plan, or Railsim, for operational planning and scheduling. However, it is difficult to locate, in the existing literature, documented approaches to combine train performance evaluation and life cycle cost for fleet management or rolling stock planning. The proposed combination is not a simple addition or supplemental analysis, but an optimization process which balances capital and operating costs of providing transit services and the quality of services provided.

Very few systematic simulation approaches can be found in recent transportation journals (Holowaty, 1998). More than two decades ago, there was a cluster of papers documenting TPS usages in North America (Howard, Gill, and Wong, 1981; Canadian National Railways, 1969; Canadian Institute of Guided Ground Transport, 1981); Europe (Smith and Blair, 1981); Australia (Albernaz, 1978); and Asia (Inada, Koga, and Tanifuji, 1975; Yasukawa and Todoriki, 1974). However, most of those applications are clearly out-of-date when compared to today's Windows-based, database-embedding, and graphic-extensive software packages. For example, one particular study (Canadian National Railways, 1969) explains the usage of punch cards and source tapes which are clearly museum items. The lack of adequate documents in the current literature demands a brief overview of train performance simulation processes which is presented in the following section.

Train Performance Simulation Modeling Structure

There are three basic elements of the simulation model: input data, internal algorithm, and output report. The input data includes physical layout of the track system, including vertical alignment, horizontal curves, and super-elevations; equipment characteristics such as length, weight, number of axles, and tractive effort curves, and other information such as station locations.

The second major element of the TPS is the internal processing algorithm. The model replicates the logical sequences of the train movements, accelerating, decelerating, passing, changing tracks, or stopping by using a series of experimental equations developed during the past 100 years by the railroad industry. For example, the Davis Equation has been perfected through various experiments with diversified equipment to represent train resistance.

The third element of the TPS model is the output report. After executing the simulation module with the required input data, the simulation package is capable of supplying a series of summary reports, which depict the performances of each consist or equipment configuration along the defined alignment.

Model Calibration

The first step in train performance simulation is to construct a baseline operation for the subject service according to the operating schedule. The input data is usually abstracted from track chart, timetable, and operating rules (Liu, 2001). The network for the subject service includes the physical alignment of the tracks, passenger stations, and interlocking locations. Interlocking is an arrangement of signals and track switches “interlocked” in such a way that their movements must succeed each other in a predetermined order so that an “all clear” indication cannot be given to trains that are simultaneously on conflicting routes. They are found at a crossing of two railways, a drawbridge, a junction, or entering or leaving a terminal or yard. The operating scenario is reflected in the model by incorporating the dispatching logic, equipment type, and time schedule for each train.

In our case study, the New Haven Line (NHL) traverses 73 miles from Grand Central Terminal (GCT) in New York City to New Haven, Connecticut. There are generally four tracks for most of the NHL with only three tracks in the eastern portion of the line. During peak hour operations, three tracks are used for the peak demand direction, and one for off-peak direction. The express tracks are also shared by Amtrak Northeast Corridor passenger services for approximately ¾ of the route.

NHL services have diversified train consists and stopping patterns. The local and express service does not follow the traditional simple all stop or skip-stop patterns, rather, during peak hours many trains are designed to serve one or more zones and then run express to or from GCT**.** These trains are local within their zones and express between their zones and GCT.

The analysis tried to cover as many stopping patterns and train consists as possible within the given constraints to evaluate the overall NHL equipment capability. In order to provide the most effective number of simulation runs, the NHL services were grouped, based on the station spacing, into three different categories:

- Local: average station spacing less than 2.5 miles
- Regional: average station spacing between 2.5 and 4 miles
- Express: average station spacing greater than 4 miles

Once the physical network was coded into the TPS model, the actual equipment type and characteristics were entered into the rolling-stock library. Although the existing rolling stock for NHL is composed of three types of EMUs, M-2, M-4, and M-6, where M-2 denotes older generation of EMUs, M-6 newer, and M-4 in between, the study used M-6 specifications to represent the most modern type of the existing equipment.

To replicate train movement for a particular type of equipment, one of the key inputs is the tractive effort curve. The NHL has two different electrical power supply systems, alternating current (AC) catenary and direct current (DC) third rail. “Catenary” is a system of wires suspended between poles and bridges supporting overhead contact wires. The power is collected by a pantograph that is mounted on the roof of the locomotive or multiple units and slides along the contact wire. “Third Rail” is an electrical conductor located alongside the running rail from which power is collected by means of a sliding contact shoe attached to the truck of the electrically powered locomotive or multiple units. Along the NHL, the AC catenary system changes over to DC third rail near Mount Vernon Station. Therefore, two tractive effort curves were used in the simulation; one for AC powered operation, and another for DC traction. Besides the tractive effort curves, all of the parameters described in earlier sections of the paper were specified for each equipment type.

After an iterative process, the study simulated about 33% of the existing operating trains. Those simulation runs were spread evenly between in-bound and outbound directions, local and express services, but concentrated on the peak hour services.

Related Assumptions

It is important to include ridership growth and fleet configuration in the train performance analysis since the objective of this study is to conduct long-range rolling stock planning for a commuter rail agency. Travel demand or future ridership growth is the driving force behind the upgrading or expanded vehicle fleet for transit providers. The ultimately selected fleet type, size, and composition are largely based on future travel demand, especially the morning peak ridership demand. According to the most recent Fleet Management Plan of the Connecticut Department of Transportation (2000), ridership for NHL during the morning peak period will grow at an average rate of 1.5% per year, which is consistent with recent historical growth. This growth in ridership will require CDOT to add passenger vehicles to the current fleet.

After forecasting the morning peak ridership for the next 30 years, the number of passenger vehicles that will be required in the daily morning lineup was derived using the following equation:

$$N = \frac{D}{CL} \qquad (1)$$

Where:

- N: Number of vehicles for the morning peak lineup
- D: Morning peak hour travel demand
- C: Seating capacity for each vehicle type
- L: Loading factor, 95% for NHL.

Model Validation

The simulation results closely resemble the timetable, although the running times are generally less than those shown in the timetable. As documented in Table 1, the run time difference between TPS and published timetable ranges from 4 to 17 minutes, averaging about 16%. The differences are primarily due to two reasons. First, this simulation is only an individual train performance calculator, it does not account for any network operations. For example, if a train has to wait for its turn to pass a certain interlocking, the waiting time is not accounted for in its running time. Second, it is common practice to include some recovery time in the published timetable for each run so the service can still accomplish its published goals when minor disturbances occur.

A close examination of the TPS output indicates that run time simulation and speed profile represent the typical train services along the NHL. Since the goal of the study was to evaluate the performance of different equipment, the key is to keep a consistent network profile and consist size when evaluating each equipment type. An absolute duplication of the timetable is less important. Therefore, the existing run time based on TPS was established as the base line for the project.

LIFE CYCLE COST ANALYSIS

Life cycle cost (LCC) analysis is a method of analyzing the cost of a system or a product over its entire life cycle (Relex Software Corporation, 2002). LCC enables the researcher to define the elements included in the life cycle of a system or product, and assign equations to each element. These equations represent the cost of that particular element. In the case of rolling stock planning for commuter services, capital expenditure for acquiring the rolling stock and operating costs of utilizing the rolling stock would be the two major elements of the LCC.

LCC represents the annual operating and maintenance cost as well as capital investment over the life cycle of the project, in this case it is defined as 30 years from the current year (2000). During the defined life cycle, vehicle procurement will be limited to that needed to accommodate increases in ridership. Ultimately, all of the existing EMU fleet will require replacement. This major capital investment cannot be avoided. However the investment may be minimized or optimized to achieve the most economic benefit or service improvement to riders.

Table 1: Run Time Comparison

Operating Direction	NHL Time Table in hours and minutes	Existing EMU in hours and minutes	Run Time Difference in minutes	Percent Difference
Inbound	0:33	0:22	0:10	32%
	0:38	0:27	0:10	27%
	0:55	0:46	0:08	15%
	0:41	0:30	0:11	27%
	1:33	1:20	0:12	14%
	0:51	0:39	0:12	24%
	0:38	0:28	0:10	27%
	1:33	1:20	0:13	14%
	1:35	1:25	0:09	10%
	1:34	1:25	0:08	9%
	1:27	1:22	0:04	6%
	1:13	1:08	0:04	7%
	0:49	0:41	0:07	14%
	1:30	1:24	0:06	7%
	0:32	0:24	0:07	25%
	1:05	0:58	0:07	11%
	0:39	0:31	0:07	18%
	1:39	1:25	0:14	14%
	0:56	0:46	0:10	18%
	0:56	0:52	0:03	7%
	1:16	1:07	0:08	11%
	0:57	0:45	0:11	20%
	0:48	0:38	0:10	21%
	1:41	1:26	0:14	15%

Table 1: Run Time Comparison (continued)

Operating Direction	NHL Time Table in hours and minutes	Existing EMU in hours and minutes	Run Time Difference in minutes	Percent Difference
Outbound	1:35	1:19	0:15	16%
	1:35	1:21	0:13	14%
	1:03	0:48	0:15	24%
	0:53	0:37	0:15	29%
	0:41	0:28	0:12	31%
	1:37	1:19	0:17	18%
	0:56	0:53	0:02	4%
	0:32	0:22	0:09	30%
	1:00	0:55	0:04	8%
	1:18	1:03	0:14	19%
	0:53	0:40	0:13	25%
	0:36	0:27	0:09	25%
	1:37	1:24	0:12	13%
	0:39	0:33	0:05	15%
	0:32	0:24	0:07	23%
	0:59	0:48	0:10	18%
	0:40	0:31	0:08	20%
	1:03	0:52	0:10	17%
	0:56	0:46	0:09	17%
	1:16	1:05	0:10	13%
Average:	**1:03**	**0:53**	0:10	16%

Capital Cost

Rail transit capital costs contain two of the main cost elements, vehicles and maintenance, as well as guideway, track, power, station, signals and communications, and other capital expenses. However, to simplify the estimate, this analysis only concerns the incremental expenses of acquiring proposed rolling stocks under each scenario.

Detailed cost estimates for individual locomotives and coaches based on engineering specifications were obtained to reflect the total cost of each scenario. A number of commuter rail providers in the New York area, especially those who acquired single level coaches in recent years, were surveyed to derive a cost estimate for single level coaches (Parsons Brinkerhoff Inc., 2002). The seating capacity of the surveyed vehicles ranges from 99 to 135. The prices range from 1.1 million to 1.73 million in constant 2000 dollars. An average price of $1.35 million for single level coaches has been derived and utilized in the capital cost analysis.

A similar survey has been conducted for bi-level coaches (Parsons Brinkerhoff, Inc. 2002). To minimize difficulties in negotiating the small cross sections along NHL tunnel, the vehicle engineers suggested that bi-level coaches made by Kawasaki are the most likely candidates. The average cost of this model is around $2.25 million, based on costs experienced by a number of agencies, such as MBTA in Boston, LIRR in New York, and MARC in Maryland. Therefore, a price of $2.25 million has been used for bi-level coaches in this analysis. Following consultations with CDOT, manufacturers, and other commuter rail operators, the research team compiled the capital cost as presented in Table 2A.

Table 2A: Capital Cost Assumptions

Equipment Types	Unit Price Millions of 2000 Dollars
New EMU	$3.50
New single level coach/ cab car	$1.35
New bi-level coach	$2.25
New locomotive	$6.50
Rebuild/renewal of EMU	$0.50
Rebuild/renewal of coach	$0.20
Rebuild/renewal of locomotive	$1.00

Source: KKO and Associates, 2001.

Operation and Maintenance (O&M) Cost

Operation and Maintenance (O&M) costs are particularly important for transit projects since they can constitute as much as 80 percent of annual expenditures to operate a service (Meyer and Miller, 2001). Two common approaches for O&M cost estimate are cost-allocation models and resource build-up models. Cost allocation models are usually used in existing operations, where previous operation and maintenance expenditure are allocated to appropriate categories. On the other hand, resource build-up models are applicable to new services so the total operation and maintenance costs are estimated based on the individual line items of the overall operations.

The cost-allocation model was applied in this analysis since Metro-North Railroad, the operator of the NHL, has considerable historical cost records. Every budget item was assigned to one of the several transit service variables. The costs for each variable are summed and then divided by the total amount of service to obtain an aggregated unit cost. Unit prices were derived based on the existing and anticipated operations of different equipment. Table 2B provides specifics on the cost elements, factors, and drivers employed in the forecasting of the relevant operating costs.

Table 2B: Allocation of the O&M Costs

Cost Elements	Annual Cost Factors	Cost Driver
Vehicle Maintenance	$52,400 per new EMU	New EMUs in fleet
	$24,200 per coach	Coaches in fleet
	$100,000 per electric locomotive	Locomotives in fleet
	$51,300 per M-2	M-2s in fleet
	$55,750 per M-4	M-4s in fleet
	$50,300 per M-6	M-6s in fleet
Facilities and Support	$102,500 per new EMU	New EMUs in fleet
	$47,300 per coach	Coaches in fleet
	$195,400 per electric locomotive	Locomotives in fleet
	$100,300 per M-2	M-2s in fleet
	$108,500 per M-4	M-4s in fleet
	$98,200 per M-6	M-6s in fleet
Propulsion Energy	Variable	Fleet configuration including length
Switching Costs (Maintenance facility)	$4,671 per EMU	EMUs in fleet
	$16,889 per coach	Coaches in fleet
Switching Costs (GCT)	$20,623 per EMU consist	EMU consists in fleet
	$44,698 per coach consist	Coach consists in fleet
Engine Crews	$293,715 per consist	Consists in AM peak lineup

Source: Metro North Railroad, 2001.

Discount Rate Assumptions

Present value analysis (PVA) is a commonly employed technique to evaluate the economic implications of planning scenarios that involve different cash flows. The sum of the discounted cash flows is known as the "present value." Heuristically the present value can be viewed as the lump sum amount that a transit agency would need to invest today to ensure that adequate funding is available to make all the required capital expenditures for rolling stock over the planning horizon.

The purpose of the PVA is to discount the cash flows in future years based on the discount rate. Therefore, it is vital to select the discount rate based on the cost of funds to the entity considering the project. Both CDOT and Hartford, Conn.-based investment bankers were consulted to select the appropriate discount rate for the NHL Fleet Analysis. Based on the weighted average of 32 bond issues outstanding for CDOT in June 1999, a discount rate of 4.91% was derived.

A Case Study of New Haven Line Services

The NHL service is operated with 342 electric multiple-unit (EMU) cars, augmented by locomotive-hauled coaches for service on some branch lines (Connecticut Department of Transportation, 2000). The majority of the EMU fleet dates back to the early 1970's designated as M-2's, with more recent additions in 1987 and 1994. In view of the eventual obsolescence of the original EMU fleet and in consideration of continuing ridership increases, the owner of New Haven Commuter Services, CDOT, needs to examine various alternative vehicles and motive power-scenarios for fleet replacement and expansion over the next 30 years.

The mature nature of the NHL and its heavy ridership, precludes any possibility of investing in untried or experimental technology with the attendant risk of equipment failure. The size of the fleet also precludes a "one time" total replacement. Thus, the candidate equipment must be able to co-mingle with the existing fleet during an extended transition period. The fleet analysis needs to address all of these parameters, while seeking to provide a range of differentiable alternatives for consideration by the agencies that own and operate the commuter services.

Performance Simulation of Alternative Equipment

The operations analysis initially compared the run time of the existing EMU train set with a locomotive-hauled consist powered by a modified AEM-7 locomotive. Train sets were composed of single level coaches. Concerns with the availability of a supply of AEM-7 locomotives for conversion, space needed for DC equipment, and Federal Railroad Administration (FRA) compliance issues resulted in a decision to focus on a conceptual model, High Speed Electric Locomotive (HSEL), developed by Bombardier Transit Corporation. As illustrated in Figure 1A, the run times for the existing EMU equipment, proposed AEM-7, and HSEL with single level coaches are all less than the published time table, which indicates the possibility of replacing the existing EMU equipment with proposed locomotive-hauled coaches for those selected trips. When comparing the proposed equipment, train performance simulation revealed that both locomotive-hauled coaches, AEM-7, and HSEL, have longer run time than the EMU consist, and the HSEL train has a slightly shorter run time than the AEM-7 trains.

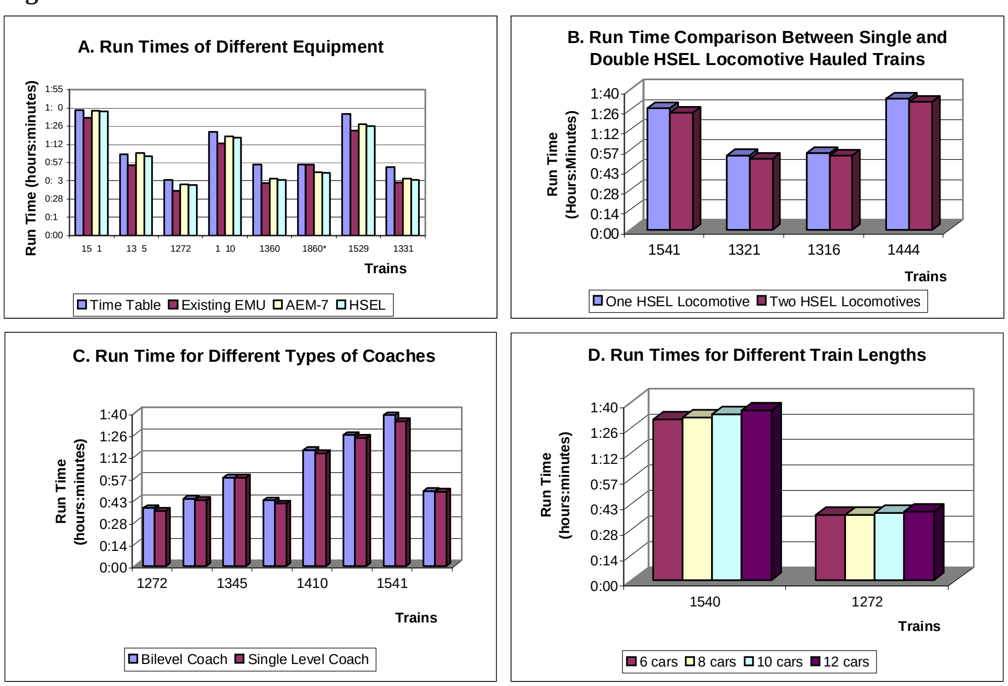
In the process of implementing the operations analysis, concerns were raised over the possibility of a train equipped with only a single locomotive becoming stranded in the area of the GCT complex, where interlockings have lengthy gaps in the third rail. To address this concern, the operations analysis subsequently utilized a pull-pull configuration with a locomotive positioned at each end of the train. The "pull-pull" configuration is a train operating with the locomotive at the front of the train in each direction while the "push-pull" configuration is a passenger train that operates with a locomotive on one end and an engineer's remote control cab in the last car. The locomotive would pull the trains in one direction, and when returning, the locomotive would push the train in the trailing car with the engineer controlling it from the cab in the leading car. As demonstrated in Figure 1B, the run time differences between a single locomotive and two locomotives, one on each end of the train, are relatively small, about 5% in most cases, even though locomotive cost doubles when two locomotives are used in the "pull-pull" configuration.

A recent trend in the commuter rail industry is the utilization of bi-level or double deck cars, which is one of the effective practices to accommodate increasing ridership. To evaluate the potential feasibility of bi-level coaches along the NHL, the operations analysis was expanded to encompass both single level and bi-level equipment. Since an engineering specification of NHL bi-level coach is beyond the scope of this study, a "typical" Northeast Corridor bi-level standard in terms of basic specifications was utilized. As presented in Figure 1C, the run times for bi-level coaches are generally longer than the single level coaches with the same number of cars.

To avoid significant run time deterioration when the train length is increased to accommodate increasing ridership, a number of simulations were performed based on different train lengths. Figure 1D depicts run times corresponding to different train consists of 6, 8, 10, and 12 cars. According to the simulation results, the run time increases slightly when the train length increases from 6 cars to 8, 10, and 12 cars respectively. The platform length at GCT confined the train length to a maximum of 10 coaches plus one locomotive in either end. Therefore, the maximum train length is limited to 12 cars in this analysis.

There does not appear to be an opportunity to equip the local trains with locomotive-propelled train sets, based on the operations analysis, without accepting some schedule degradation. However, utilizing the top speed of the HSEL, the express services, with average distance between intermediate stations exceeding four miles, allow the locomotive-hauled train sets to negate much of the EMU's run time advantage. There appears to be an opportunity to equip these

Figure 1: Train Performance Simulation Results



and similar express trains with locomotive powered train sets. As presented in Figure 1A, although the locomotive hauled train sets are still slower than the EMU's, an analysis of run times between stations indicates that there is sufficient time to adhere to the published time table without adjustments. This adaptation would require some reduction in so-called "pad" or built-in recovery time.

In reviewing the results of the train performance simulation, the research team reconciled the need to develop equipment scenarios that did not degrade the existing published schedule times or jeopardize on-time performance, with the need to explore economically viable options that could achieve significant cost savings. This will ensure that the fleet planning for the NHL acknowledges not only operational requirements, but also passenger needs, as reflected in ridership growth and service flexibility, and the fiscal capabilities of Connecticut.

Operating Scenarios

As ridership grows and the current NHL fleet ages, a substantial number of new passenger vehicles will be required. The LCC approach performs economic analyses to identify the most economic way to acquire the needed equipment without a deterioration in service quality. The economic analyses focus on the 30-year LCC for various future mixes of EMUs and locomotive-drawn push-pull and pull-pull coaches. The approximate proportions of the mix range from 100% EMUs, for the Status Quo scenario, to 85%, 25% and 15% of EMUs for high, low, and minimum EMU utilization scenarios, respectively. When applying three different EMU proportions, ranging from high to minimum, to both single- and bi-level coaches, the alternatives double. When both push-pull and pull-pull configurations are considered, the alternatives double again. Therefore, a total of 13 different scenarios have been analyzed including the base case, Status Quo. We present four scenarios in Table 3 to illustrate the application of the proposed approach: Status Quo plus three EMU levels: high, low, and minimum with pull-pull configuration and bi-level coaches.

The high EMU configuration recognizes that CDOT may wish to avoid any purchases of EMUs for at least 10 years. This would allow CDOT to evaluate the actual performance of the pull-pull configuration before placing more equipment orders, and will also defer the expense of purchasing any EMUs. Applying these criteria to the projected future equipment requirements for the NHL, it was determined that a purchase of 61 bi-level coaches and 20 locomotives would allow CDOT to forestall any EMU purchases for at least 10 years. The Low EMU configuration aims to result in a fleet where 25% of the peak period consists are EMUs and 75% are provided with pull-pull train sets. The Minimum EMU scenario avoids any further purchases of EMUs, but maintains the existing vehicles for the balance of their useful life. The scenario is simply a prolonged transition from the Status Quo to a coach and locomotive fleet accomplished by replacing the current EMU fleet with coaches and locomotives as the EMUs are retired.

The Status Quo scenario, from which all alternative scenarios are derived, sets the standard for all comparisons. The following procedure describes how the fleet requirement has been developed for the Status Quo scenario; similar procedures have been applied to all other scenarios. The Status Quo (100% EMU) acquisition/ replacement would satisfy growing customer demand as the current fleet of equipment ages, undergoes periodic renewals, and equipment is retired as units reach the end of their useful life.

The analysis forecasts the number of passengers traveling during the morning peak will increase by approximately 55% over the next 30 years. During the same time period, all but 10% of the existing EMU fleet will reach retirement age. If the demand for new and replacement passenger vehicles is 100% satisfied with EMU cars, a total of 490 new EMUs will be necessary to serve the growth in demand, replace retiring vehicles and maintain a minimum spare ratio. As defined by the Federal Transit Administration (FTA), spare ratio can be derived by dividing the number of spare vehicles by the number of vehicles required during the peak period. The total fleet of EMUs on the NHL will need to grow from 342 units today to 523 units in 2030.

Table 3 summarizes the current forecast peak requirements and fleet sizes for each of the four scenarios in 2030. The forecasts were based on a 12-car maximum for EMU trains and a 10-car maximum with pull-pull operation for locomotive hauled train sets. According to Table 3, total EMUs fall from 523 in the Status Quo scenario to 33 in the minimum EMU scenario. In contrast, new coaches and new locomotives increase from zero in the Status Quo scenario to 350 and 102 respectively in the minimum EMU scenario.

In addition to accommodating growth in morning peak ridership, this fleet requirement estimate also incorporated other factors, such as upcoming life cycle milestones for the existing fleet, vehicle spare ratios, and lead time and minimum order sizes for acquisition of new passenger vehicles. Those factors are not included here, but can be referenced from other related publications (KKO and Associates, 2001).

Cost Estimates

This section presents forecasts of total LCCs including both capital and operating expense for the Status Quo fleet configuration and alternative fleet configuration scenarios. Applying similar approaches, the study team has derived the total LCC for all 13 scenarios, as shown in Table 4.

Over the 30-year planning horizon, the Status Quo configuration is forecast to cost $5.67 billion ($2.96 billion present value) in rolling stock capital and relevant operating cost outlays. Utilizing the discount rate presented earlier, the present values of the analyzed alternatives have also been derived, which range from $2.56 billion for push-pull bi-level coaches with minimum EMU scenario to $3.06 billion for pull-pull single level coaches with minimum EMU. In general, the pull-pull configuration with single level coaches is expected to yield a slightly higher total LCC than the other scenarios. The push-pull bi-level configurations are all expected to yield lower LCCs.

Studies of push-pull scenarios indicate that substantial further savings with push-pull would be achieved for all coach scenarios, relative to the Status Quo, in the areas of locomotive acquisition and renewal, locomotive maintenance, and facilities and support. Additional modest savings would be realized in engine crew expense, switching costs, and propulsion energy.

With pull-pull propulsion, the single level coach scenarios all yield higher LCC forecasts compared with the Status Quo scenario. The single level coach scenarios are all forecast to yield lower capital costs than the Status Quo scenario, but savings in capital costs are more than offset by higher operating costs especially in the area of propulsion energy and switching.

The bi-level pull-pull coach scenarios all yield lower LCC forecasts compared with the Status Quo scenario. The savings are greatest in the capital cost expenditures, but savings in operating costs would also be expected. The operating cost reduction is greatest in the areas of vehicle maintenance, facilities and support, and engine crews. The operating cost savings are partially offset by increases in propulsion and transportation support (switching) costs.

If treating the higher cost of pull-pull configuration as an “insurance premium” for operating reliability, this analysis concludes that the most economic scenario for NHL will be bi-level coaches with low EMU in the total fleet. Comparing to the Status Quo alternative, the present value of the recommended scenario, pull-pull bi-level coaches with low EMU scenario, is 5% less, a savings of $138 million in present value dollars.

Table 3: 2030 Fleet Forecasts by Scenario

Vehicle Types	Status Quo	High EMU[1]	Low EMU[2]	Minimum EMU[3]
Peak passenger vehicles required	443	425	362	344
Total passenger vehicles in fleet	523	496	406	383
Peak consists	52	52	46	46
EMU consists	52	44	13	3
Pull-pull consists	0	8	33	43
Existing EMUs	33	33	33	33
New EMUs	490	402	100	0
Total EMUs	523	435	133	33
New coaches	0	61	273	350
New locomotives	0	20	79	102
Total vehicles in fleet	523	516	485	485

1. 85% of fleet is EMU.
2. 25% of fleet is EMU.
3. 15% of fleet is EMU.

Table 4: Forecast of Total Lifecycle Costs over 30 Year Planning Horizon

Locomotive Configuration	Scenarios	Portion of EMU Utilization	Non-Discounted Estimates (millions)	Present Value (millions)	Difference in Present Value from Status Quo (millions)	Difference (%) When compared to the Status Quo scenario
NA	**Status Quo**	**All EMU**	**$5,670**	**$2,957**		
Push-Pull (One Locomotive)	Single Level Coaches	High EMU (85%)	$5,611	$2,934	$ (23)	-1%
		Low EMU (25%)	$5,230	$2,796	$ (161)	-5%
		Minimum EMU (15%)	$5,088	$2,739	$ (218)	-7%
	Bi-level Level Coaches	High EMU (85%)	$5,520	$2,901	$ (56)	-2%
		Low EMU (25%)	$4,926	$2,618	$ (339)	-11%
		Minimum EMU (15%)	$4,777	$2,563	$ (394)	-13%
Pull-Pull (Two Locomotives)	Single Level Coaches	High EMU (85%)	$5,709	$2,979	$ 22	1%
		Low EMU (25%)	$5,838	$3,053	$ 96	3%
		Minimum EMU (15%)	$5,859	$3,062	$ 105	4%
	Bi-level Level Coaches	High EMU (85%)	$5,619	$2,946	$ (11)	0%
		Low EMU (25%)	$5,383	$2,819	$ (138)	-5%
		Minimum EMU (15%)	$5,353	$2,817	$ (140)	-5%

Note: The Push-Pull scenario is not viable even though the LCC are relatively low. The interlocking configuration at GCT with its extended gap between third rail sections could result in locomotive hauled trains, even with four power pick-up shoes, to become stranded.

CONCLUSION

As mentioned in the beginning of the paper, railroad or transit operators generally do not change vehicle types for purely operational considerations. In the case of New Haven Line Service, it is natural to adopt the next generation of EMU cars, such as M-8 driven by power consumption, maintenance considerations, spares inventory, and familiarity with the existing equipment. However, after examining various fleet configurations, it was discovered that extending the existing EMU fleet, the Status Quo scenario, is most expensive in terms of LCC.

Comparing all available options, including single versus bi-level coaches, push-pull versus pull-pull, one versus two locomotives, and various train lengths, the transit agency is able to strike a balance between LCC and service quality provided by incorporating various amounts of EMU cars in the total fleet. Generally, the higher the portion of EMU cars in the fleet, the higher the LCC would be even though the EMU cars do provide better performance in terms of running time. When compared to the single-level coaches, the bi-level coaches will cost less in terms of LCCs to accommodate the same amount of passenger seats. Again, the dwelling time for bi-level coaches may be slightly increased due to the maneuver time from the upper level of the train. Similarly, two locomotives will bring better performance in terms of running time but result in much higher costs.

This study would suggest that over the next 30 years, the New Haven Line service should be systematically converted from the present 100% utilization of EMU fleet to a predominantly pull-pull (two locomotives) bi-level coach fleet.

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