A Project Selection Model for Improving Running Time and Operating Cost Efficiency on a Passenger Rail Corridor

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Abstract

Recent proposals for expanded intercity passenger rail service in the United States have included plans for new dedicated high speed lines as well as incremental improvements to existing Amtrak service. Improvements to existing services aim to accommodate faster and more frequent passenger train operation, generally on trackage owned and operated by heavy axle load freight railways.

Although several alternatives can be applied for this upgrade, they have different benefits at different sections and adjacent sections can interact with each other. For instance, the marginal travel time benefit of improving segments of a line from 129 to 145 or 177 km/h maximum speed is less than the benefit of improvements that could be made to other segments currently restricted to lower speeds. Therefore, a cost effective investment must be made to improve performance on a corridor with limited resources.

This paper presents a methodology for optimally selecting projects or establishing budgets to reduce running time with consideration of maintenance and operating cost on a passenger rail corridor. The proposed project selection model is formulated as Genetic Algorithms (GAs). A route is divided into sections that can be independently upgraded so that the objective function could be described as minimization of running time and project cost along the route.

This model can be used as part of a methodology for quickly and efficiently developing a strategic plan for improving running time on passenger rail corridors with consideration of project cost.

Keywords

Project Selection, Running Time, Operating Cost, Genetic Algorithms

1 Introduction

Recent proposals for expanded intercity passenger rail service in the United States have included plans for new dedicated high-speed lines as well as incremental improvements to existing short-haul regional intercity Amtrak service. Improvements to existing services aim to accommodate faster and more frequent passenger train operation, generally on track owned and operated by private heavy-axle-load freight railways. Since the track and signal infrastructure is privately-owned and the passenger trains are typically supported by government agencies, investments to improve passenger service are made through public funds or, where there is mutual benefit to the freight railways, a public-private partnership. In either case, individual improvement projects must be justified based on their benefits and costs.

Running time is one of the major factors affecting the quality of passenger service. Although many upgrade alternatives may be applied to individual route segments, they each may have different time reduction effects. Therefore, it is critical to make informed decisions on improvement project selection.

Several studies have investigated topics related to running time performance improvement of intercity passenger rail corridors. Lai et al. (2012) presented a framework for using mathematical programming to identify an optimal strategy to reduce running time on a passenger rail corridor. This research did not consider the interaction between different route segments. Caughron et al. (2013) incorporated the interaction between different route segments as well as maintenance costs into the analysis of potential capital infrastructure and rolling stock improvements. However, the model did not consider effects of train operating cost, a key consideration for upgrading route segments to higher operating speeds.

According to previous work on this subject, running time reduction on a selected route is affected by many factors. Principally, running time reduction is affected by track classes and their associated maximum train operating speeds. In United States, the Federal Railroad Administration (FRA) has identified nine track classes based on track quality and the ability to operate passenger and freight trains. In this classification system, the maximum possible running speed has been defined for each track class. The time to travel one kilometre segment at different track classes is illustrated in Figure 1. From this figure, we can see that the greatest benefits in running time reduction can be achieved from track class improvements on lower speed sections, rather than higher speed ones. For example, upgrading a route section from FRA track class one to two reduces running time by more than one minute per kilometre, whereas upgrading a segment from track class five to six saves only four seconds per kilometre.

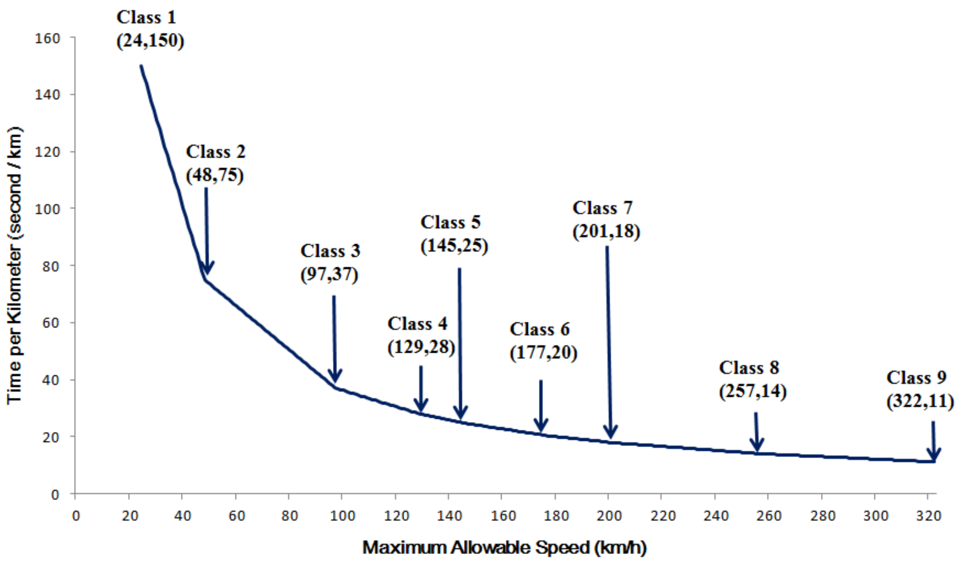

Figure 1 Running Time per Kilometre at Different FRA Track Classes

Running time reduction is also affected by the type of improvement projects and the condition of adjacent route segments. Upgrade alternatives include investments in track, signal, highway grade crossing, and rolling stock improvements. Each improvement approach has distinct benefits within different sections of the route and those improvement projects can interact with each other. For example, for section 2 with a current speed limit at speed A, consider two types of adjacent sections: Figure 2 (a) shows the case of adjacent sections 1 and 3 having higher speed restrictions (speed B) than speed A; while in Figure 2 (b), adjacent sections have the same speed restrictions as section 2. The project cost to upgrade section 2 from speed A to speed B remains the same for both cases. However, due to acceleration and deceleration effects, the incremental benefit of upgrading the intermediate segment will be greater for former case. Thus, the benefit-to-cost ratio for the project to upgrade the intermediate segment varies greatly with the boundary conditions of adjacent sections.

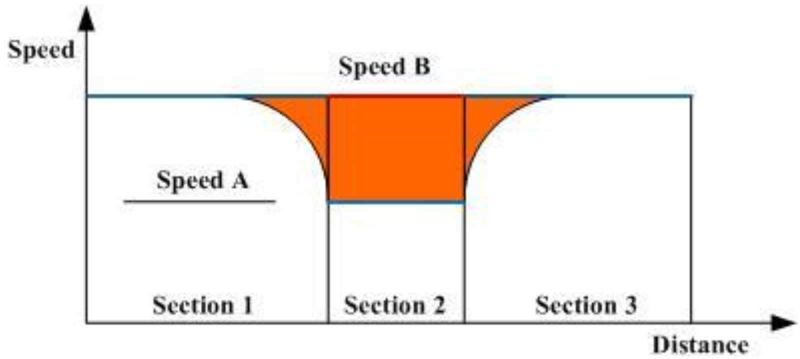

Figure 2 (a) Running Time Benefit for Speed Upgrade on Section 2

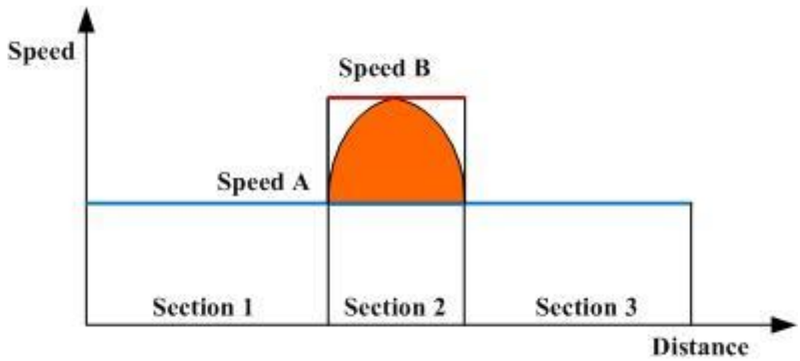

Figure 3 (b) Running Time Benefit for Speed Upgrade on Section 2

By integrating operating cost into the project selection model, the running time reduction is also affected by fuel consumption. This is critical for selecting projects to upgrade routes to “higher-speed” operation above 150 km/h since the fuel consumption is disproportionately greater for higher operating speeds. By decreasing running time and increasing average train speed, air resistance is the major component of the train resistive force. As air resistance increases quadratically during train acceleration, more fuel will be consumed for propulsion. This leads to an additional cost penalty for selecting higher-speed versus lower-speed improvements, providing additional incentive to eliminate slower segments before raising the maximum speed on the corridor. Thus for every incremental investment, the decrease in running time and energy saving will be balanced in the optimal solution.

Because of these potential interactions between different projects on a passenger rail corridor, individual improvement projects cannot be considered in isolation. Therefore, this paper develops a project selection model for selecting cost effective investments to improve performance on a passenger rail corridor with limited resources.

2 Project Selection Analysis

Three types of project selection costs are considered in this paper: capital cost, maintenance cost and operating cost.

Capital cost refers to the fixed, one-time expenses for infrastructure improvement. Increasing infrastructure quality helps to allow higher operating speed and can effectively reduce travel time. To accommodate increased operating speeds, multiple project alternatives need to be applied. For example, the signal system needs to be upgraded to provide more protective information; highway grade crossings should be improved to eliminate safety issues. Three main elements were considered when estimating capital costs on each section of the route: track structure/geometry, signal system, and number of highway grade crossings.

Track structure includes rails, ties, fastening system, ballast, and subgrade. Common improvement practices include replacing 1/3 ties with new ones, removing existing rail, spikes, plates, anchors and installing new 136 lb CWR are applied for each target track class. In addition to the U.S. federal regulations (FRA 2013), railway companies also apply stricter local standards for higher operating speed. Track geometry is mainly concerned with curvature improvement in this paper. Two upgrade methods are considered: increased super-elevation on curves and curvature reduction. In the first case, increasing the height of outer rail of a curve gives trains the possibility to operate at higher speed. The cost of super-elevation adjustment consists of the adjustment of spirals and super-elevation for the new operating speed. As the maximum super-elevation is regulated, further speed improvements can only be achieved by curvature reduction. The work consists of curve re-alignment through the curved section of the existing line within the given right-of-way. Reducing the degree of curvature degree also allows trains to operate at higher speed. Both upgrade costs for track structure and track geometry are estimated by U.S. dollars per kilometre.

The signal system is used to direct the railway traffic safely in order to avoid any collisions. Upgrade alternatives include implementations of signalling systems like Centralized Traffic Control (CTC), Automatic Train Stop (ATS) / Automatic Train Control (ATC). In United States, CTC system provides centralized control for signals and switches within a pre-defined area. ATS and ATC systems provide automatic train stop and over-speed protection, required to ensure the train safety at higher operating speeds. If such a signal system is already installed on the existing line, then the corresponding upgrade cost is less expensive than if the line is not signalled. The cost to improve the signal system is estimated by U.S. dollars per kilometre.

Highway grade crossings are the intersections where the rail line crosses highway at the same level, which is a common practice in North America, instead of crossing over or underneath with a bridge or tunnel. Thus grade crossing protection is needed to alert motorists to the approaching railway traffic and the presence of a railway crossing. Warning facilities such as four quadrant gates, four quadrant gate crossings with intrusion detection, and fenced right-of-way (ROW) are implemented at different speed levels according to regulatory requirements and/or the engineering policies of the railway in charge of the rail infrastructure. The cost to upgrade each grade crossing depends on the number of crossings and the section speed levels.

In order to select different infrastructure improvement projects at sections with different speed limits, infrastructure improvement alternatives have been assigned as outlined in Table 1. This is only an illustrative example applied in this paper; more alternatives may be applied in actual project situations.

Table 1: Infrastructure Improvement Alternatives

Track Class	**Max. Speed (km/h)**	**Track Structure / Geometry**	**Signal System**	**Grade Crossings**
Class 3	96	Replace 1/3 Crossties (wood) , 136RE CWR, Surfacing, Curve Shift		
Class 4	129	Replace 1/3 Crossties (wood), 136RE CWR, Surfacing, Curve Shift	CTC	
Class 5	145	Replace 1/3 Crossties (wood), 136RE CWR, Surfacing, Curve Shift	CTC / ATS or ATC	Four quad gate crossings
Class 6	177	Replace 2/3 Crossties (wood), 136RE CWR, Surfacing, Curve Shift	CTC / ATS or ATC	four quad gate crossings with intrusion detection, fenced ROW

According to Table 1, for example, to upgrade a given section from FRA track class 4 to class 5, the procedures include replacing one third of timber crossties, installing 136 RE continuous welded rail, surfacing, adjust curve super-elevation and/or curve alignment, installing Automatic Train Stop (ATS) or Automatic Train Control system and implementation of four quadrant gates at highway grade crossings. If any of these items were already present on the section, their cost would not be included in the capital cost of the project.

The maintenance cost, including regular service for track, signal system, etc., is very important to keep a certain portion of track at a particular service level (allowable operating speed) for a long period. If the maintenance task is not carried out in a timely manner, track condition will deteriorate, which affects the quality of rail service. As opposed to the one-time capital cost for infrastructure improvement, maintenance cost is an annual expenditure, and is therefore converted into net present value in order to be compatible with capital cost analysis. Different physical characteristics of sections and upgrade alternatives may give rise to different maintenance costs, which are presented in terms of a total cost per track mile in this case.

For this research, operating cost is mainly calculated based on fuel consumption of the passenger train. Fuel consumption for each train run is affected by two factors: the driving patterns and route characteristics. Driving patterns can be described as the series of throttles switches at particular moments along the route. Different combinations may have different energy performance. Higher throttle settings can generally provide higher acceleration, but consume more energy; while low throttle settings are more energy efficient. The characteristics of route such as speed limits, grades and curves also play an important role in the fuel consumption of a train. Frequent changes in speed restrictions may cause the frequent changes of train operating status between acceleration and braking, which consumes more time and energy.

3 Project Selection Model

3.1 Assumptions

A few assumptions have been made to solve this problem. We assume the train is modelled as single-mass point, so we don't consider train length when it enters and leaves speed limit area. Since the passenger train is very short and has a relatively high power-to-weight ratio, we do not include the effects of grade in our model. Thus all grades are assumed level along the route.

3.2 Mathematical Model

This paper proposes a project selection model to reduce running time with respect to a net present value capital, maintenance and operating cost budget on a passenger rail corridor. The mathematic model has been presented from (1) to (8).

$$\min \quad f = \int_0^S \frac{1}{v_s} ds \ . \tag{1}$$

$$\int_0^S c_{upgrade}\left(\bar{v}_s, \bar{v}'_s\right) ds + c_{oper} \cdot \int_0^S n_{T,s} F_T\left(v_s\right) \lambda ds \le B \ . \tag{2}$$

$$v_s = ds / dt \ . \tag{3}$$

$$M \cdot \dot{v}_s = \begin{cases} n_{T,s} F_T\left(v_s\right) - R_m\left(v_s\right) - R_G\left(s\right) - R_C\left(s\right) \\ n_{B,s} F_B\left(v_s\right) - R_m\left(v_s\right) - R_G\left(s\right) - R_C\left(s\right) \end{cases} . \tag{4}$$

$$\begin{cases} n_{T,s} \in [0,1] & (Traction) \\ n_{B,s} \in [-1,0) & (Braking) \end{cases} . \tag{5}$$

$$P_{v_s} = n_{T,s} \cdot F_T\left(v_s\right) \cdot v_s \cdot \mu \ . \tag{6}$$

$$v_0 = 0, \qquad v_S = 0 \ . \tag{7}$$

$$0 \le v_s \le \bar{v}'_s \ . \tag{8}$$

Equation (1) is the model objective function, which minimizes the travel time for a passenger rail trip along the entire route. It is described in the form of integration, where *s* is the travel distance, *S* is total length of the route, v_s is the train speed at *s*.

Expression (2) constrains the net present value of capital, maintenance and operating costs along the route to not exceed a certain budget B. The first term computes capital and maintenance cost. $c_{upgrade}(v_1,v_2)$ is the capital and maintenance cost to upgrade a unit length segment from v_1 to v_2. $\bar{v}_s$ is current speed limit and $\bar{v}'_s$ is the upgraded speed limit. The second term computes operating cost. c_{oper} is unit diesel price, $n_{T,s}$ is tractive coefficient, $F_T(v_s)$ is the tractive effort when train is at speed v_s. λ is fuel efficiency.

Motion equations (3) to (6) define train movement along the route. Equation (3) defines train acceleration. Equations (4) show that a train is experiencing tractive effort, train resistance, grade resistance and curve resistance in tractive status; while braking effort will be applied instead of tractive effort during braking process. $n_{T,s}$ and $n_{B,s}$ are applied tractive coefficient and coefficient level respectively at position s. $F_T(v_s)$ and $F_B(v_s)$ are applied attractive effort and braking effort respectively at speed of v_s. $R_m(v_s)$ is basic resistance at the speed of v_s. $R_G(s)$, $R_C(s)$ are gradient resistance and curve resistance respectively at position s. Expressions (5) gives the value range of tractive and braking coefficients. Equation (6) computes the power, where μ is transmission efficiency.

Expressions (7) and (8) constraints train speed during the trip. (7) gives the boundary condition and (8) ensures speed will not exceed new speed limit.

4 Application of Genetic Algorithms

The proposed project selection model is formulated as a Genetic Algorithm (GA).

Genetic algorithms are a global search algorithm technique based on the principle of natural selection. It mimics the evolution of biological organisms to achieve optimal solutions with a given objective function in an artificial system. In GAs, a solution to the problem is encoded into strings of digital numbers. Each string (chromosome) represents one possible solution. The collective chromosomes form a set of possible solutions, called the population. GAs perform operations like selection, crossover and mutation on chromosomes in the population with a probability based on their corresponding fitness values. Optimal solutions, in the form of high fitness individuals will eventually appear after generations of evolution.

Compared with other optimization techniques, GAs have several advantages for a large scale optimization problem. First, since it searches from a group of solutions instead of a single point, it avoids being trapped into a local stationary point. Second, it can be applied to various types of problems as the search is carried out based on the fitness function rather than derivatives. Third, probabilistic transition rules are used so that the optimum can be achieved faster with real-time adjustment.

However, traditional genetic algorithms will give rise to premature convergence if a dominant individual occurs in the population. Therefore, by introducing combinational selection method and adaptive probability, an enhanced genetic algorithm is proposed to solve the project selection model to ensure the solution's effectiveness and efficiency.

4.1 Problem Coding and Fitness Function

In this problem, a route is divided into N segments that can be independently upgraded. By discretization of the model, this problem can be solved by GAs. A chromosome has N genes and each one represents the project decision on a corresponding segment. The value of the gene indicates the target upgrade speed if the segment needs to be improved; otherwise it is the original speed limit.

As shown in (9), the fitness function is re-written from (1) and (2) as minimization of running time and net present value budget excess over all segments in the given route. In this function, V_i is the ith gene which decides the target upgrade speed (or original speed limit if no upgrades applied). T_i represents the travel time along the ith segment. This value needs to be re-calculated if the route speed limits change. $C_{upgrade}$ is the capital and maintenance cost for the improvement project from current speed limit to V_i within the ith segment. C_{oper} is the unit energy cost while E_i is the energy consumption at the ith segment. B_{const} is the given net present value budget for capital cost, maintenance cost and operating cost. To avoid solutions where the cost exceeds total budget, a large penalty α is added to the over-budget term for the optimal solution.

$$\text{Fitness Function } = 1/\left(\sum_{i=1}^{N} T_i + \alpha\left(\sum_{i=1}^{N} C_{upgrade}\left(\overline{v}_i, V_i\right) + C_{oper}\sum_{i=1}^{N} E_i - B_{const}\right)\right). \tag{9}$$

4.2 Combinational Selection

Selection is the process used to select a group of chromosomes from a population for later breeding based on their fitness values. Individuals with higher fitness values are more likely to be chosen to produce the next generation. Two main selection strategies are applied here: roulette wheel selection and rank selection.

Roulette wheel selection is a fitness-proportionate selection method and is commonly used due to its efficiency in best individual selection. The probability for a chromosome to be selected is proportional to its fitness. However, since this method can quickly eliminate the lower fitted individuals, the solution may inadvertently converge to a local optimum point.

To avoid this potential risk, rank selection is used for population selection in the early stages. Instead of using fitness value, rank selection assigns ranking numbers (from 1 to N) to each chromosome. The worst has 1 and the best has N. The selection probability is then established according to this ranking number. In this way, lower fitted chromosomes have more chances to survive.

The combination of these two methods ensures a variety of species in the early evolution stage and that multiple good solutions will emerge for breeding. As the evolution proceeds, by using roulette wheel selection, better-fitted individuals have a greater chances of selection. Therefore, the later evolution process will be accelerated.

4.3 Adaptive Crossover

Crossover is the process of taking more than one parent chromosomes and producing offspring by exchanging part of their gene information. Crossover has two key parameters: crossover probability and crossover operator. The former decides how likely an individual is to be chosen for crossover operation, while the latter decides how parents exchange information.

To ensure the efficiency of evolution, adaptive probability has been applied for crossover probability. According to adaptive probability, higher fitness individuals have lower probability for crossover. This means their good genetic information is preserved for the next generation. On the contrary, lower fitted solutions are have a higher crossover rate and are more likely to be recombined in an effort to improve them. Adaptive probability is defined in (10).

$$P_c = \begin{cases} P_{\text{c\_max}} - \left(f' - f_{avg}\right)\cdot\left(P_{\text{c\_max}} - P_{\text{c\_min}}\right)/\left(f_{\max} - f_{avg}\right) & f' > f_{avg} \\ P_{\text{c\_max}} & f' \le f_{avg} \end{cases}. \tag{10}$$

For crossover operator, traditional two-point crossover is chosen. Everything between the two points is swapped between the parent chromosomes, rendering two child chromosomes.

4.4 Adaptive Mutation

Mutation prevents the search from being trapped into a local optimum point by introducing new genes to the selected chromosome. The adaptive method is again used here to decide the mutation probability for each chromosome. Similar to the crossover parameter, the actual mutation probability varies according to the fitness of the chromosome.

4.5 Proposed Algorithm Procedure

The proposed algorithm procedure is shown in Figure Figure 3. In this procedure, an initial reference value will be calculated first as the threshold for the two selection methods in the main search loop later on. After calculation of possible target upgrade speed at each segment, initial population can be generated.

The main GAs search loop tries to find the best-fitted individuals based on randomly initialized population. Two selection methods are used to ensure population diversity during the early stage and efficient convergence during the late period. Final optimal solution will be achieved when the pre-defined generation value is reached.

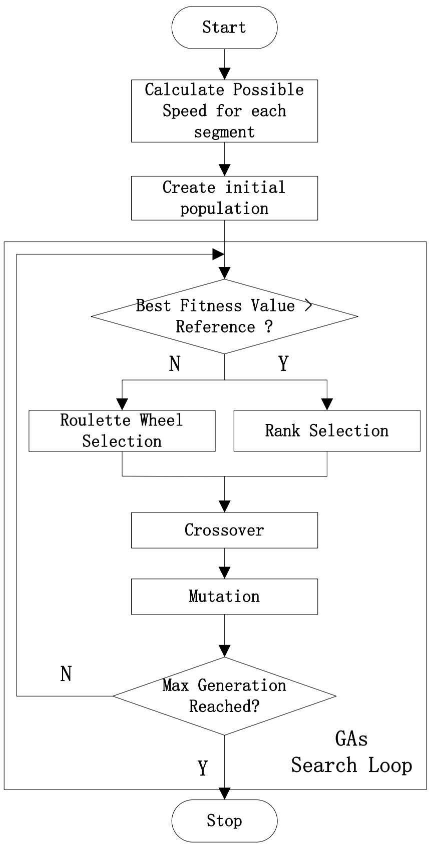

Figure 3 Procedure for Genetic Algorithms Application

5 Case Study

A case study has been carried out to demonstrate the functionality of the passenger corridor project selection model.

The simulation route is based on a typical Midwest regional intercity passenger rail line with a length of 76.83 kilometres. The route has 13 curves and 73 highway grade crossings. As shown in Figure 4, the existing maximum passenger train operating speed limit varies for different portions of the route. This is due to the limitations of curvature or the signal system. The maximum operating speed is currently 126 km/h. The route is divided into 48 segments and each of them has constant infrastructure parameters. The number of grade crossings for each segment is illustrated in Figure 5.

The train chosen for the case study is a typical Amtrak regional intercity passenger train with one 3169kW, four-axle locomotive, one locomotive without power (to serve as a lead control unit on the return trip) and six passenger cars. With maximum running speed of 177 km/h, this type of train is frequently used for operations on regional intercity passenger rail corridors in the mid-west United States.

In order to reduce the running time along the example route, different improvement alternatives have been applied at each segment based on the reference spreadsheet (Table 1). For each segment of the track, the maximum speeds of four track classes and the maximum speed of possible super-elevation and curvature re-alignments are considered as possible target upgrade speeds. However, if a certain target speed exceeds the maximum speed for curve re-alignment, it means this speed cannot be supported by current route infrastructure and should be excluded from the chromosome generation of Genetic Algorithms.

Once the project selection plan is determined, capital cost, maintenance cost and corresponding operating cost can therefore be estimated. The capital cost for upgrade alternatives follows the guideline proposed by Quandel Consultant (2011). Maintenance cost calculation is based on Zarembski et al. (2004) who carried out a maintenance analysis under different service levels for a mixed freight and passenger corridor. The operating cost can be achieved based on mechanical energy consumption for a single trip and the number of trips throughout a year. Since maintenance cost and operating cost are annual expenditure, they are converted into net present value with 10 year period and 5% discount rate.

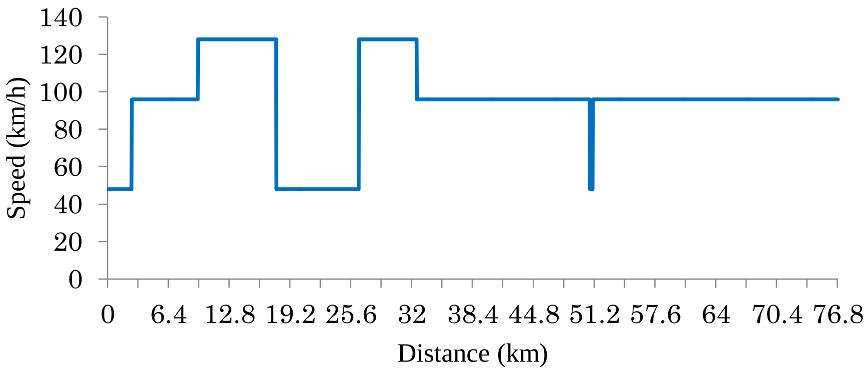

Figure 4 Route Configuration

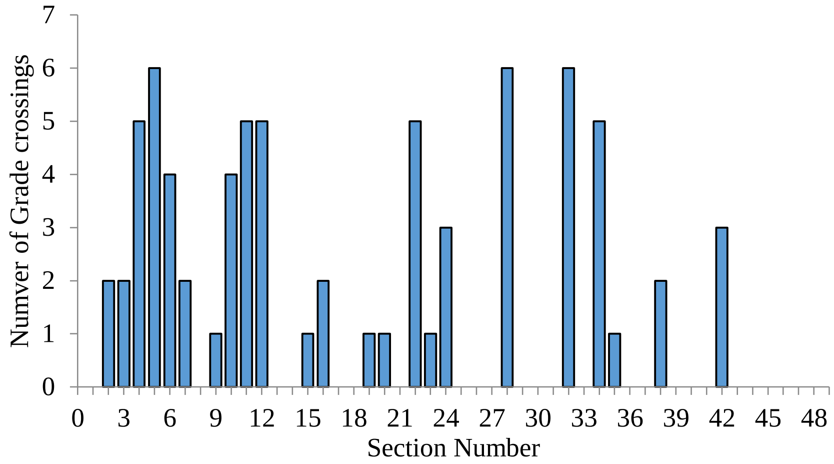

Figure 5 Number of Highway Grade Crossings at Each Segment

6 Simulation Results

In this section, we analyse the simulation results obtained for the case study route. Simulations have been carried out based on the platform developed by Visual C++ installed on a laptop with 8 GB of RAM and a 2.4 GHz i7 processor.

For the application of Genetic Algorithms, 60 chromosomes with 48 genes are generated for genetic evolution. As shown in Figure 6, optimization result can be achieved within 300 iterations, which requires less than 5 minutes for convergence.

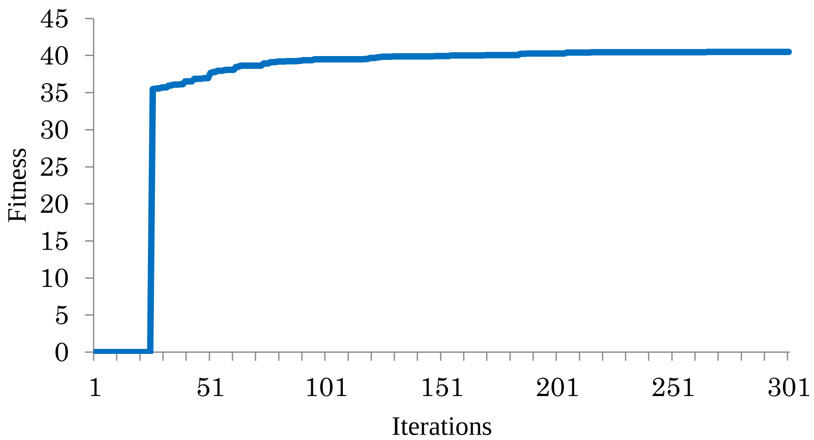

Figure 6 GAs Fitness Convergence

With a fixed budget of $60 million, Figure 7(a)-(d) shows the incremental infrastructure improvement for different traffic levels. Since the operating cost is a function of traffic level, for a fixed budget, the amount f funds available for capital upgrade projects will decrease with increasing service frequency. To illustrate this effect, four scenarios from 10 trains per day to an extreme of 100 trains per day on the same route are optimized and compared. In the figures, the dash-dot line represents the original speed limit; the bold solid line represents the new speed limit after upgrade; the dash line represents the train speed profile under the new speed limit.

With the extreme traffic of 100 trains per day, operating cost becomes the dominant part of $60M budget. To make infrastructure upgrades with the limited remaining budget, fuel consumption needs to be minimized first. Considering the higher fuel consumption rates at higher operating speed, instead of selecting higher-speed segments, the upgrade priority in this case should be raising the speed level of lower-speed segments to match that of adjacent segments, such as segment 17.7km – 26.4km shown in Figure 7 (a). By eliminating these slow sections and saving operating energy cost, more investment can be made for infrastructure improvement and the segment with highest operating speed is extended for several miles.

For the route with less daily traffic (Figure 7(b), Figure 7 (c)), more of the budget can be used for speed upgrade. Therefore, more segments have been upgraded up to 129km/h to balance the running time reduction and fuel consumption. By selecting segments that are adjacent to existing 129km/h portions for upgrade implementation, running time reduction and fuel consumption are balanced. Frequent throttle switches for transition between different speed levels are avoided, which helps to reduce time delay due to acceleration and braking. By selecting 129km/h as target upgrade speed instead of higher speed level, train operating energy can be saved.

For route with 10 trains per day, shown in Figure 7 (d), operating cost is only a minor part of the total budget. The main concern for the railway planners is to minimize running time. Finally, under this scenario, a portion of route between 54.4km - 68.6km is upgraded to 177km/h because it offers the lowest construction cost compared to other segments.

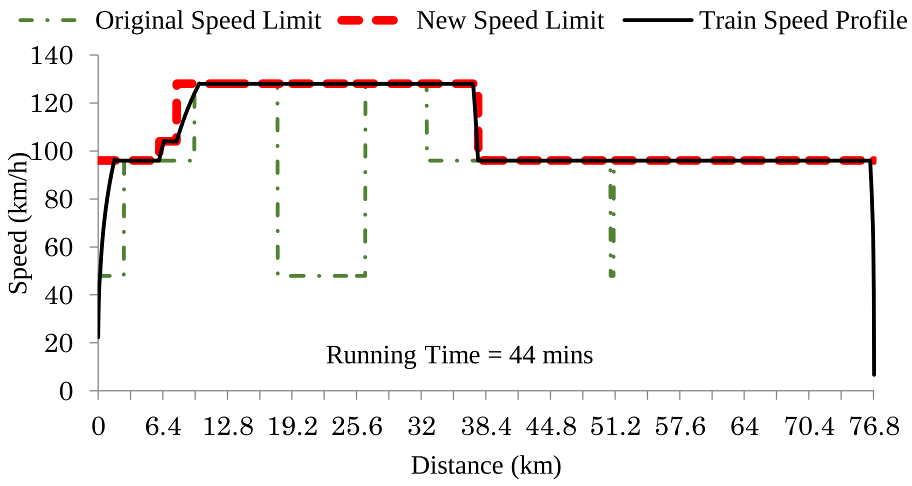

Figure 7(a) Infrastructure Improvement for 100 Trains per Day

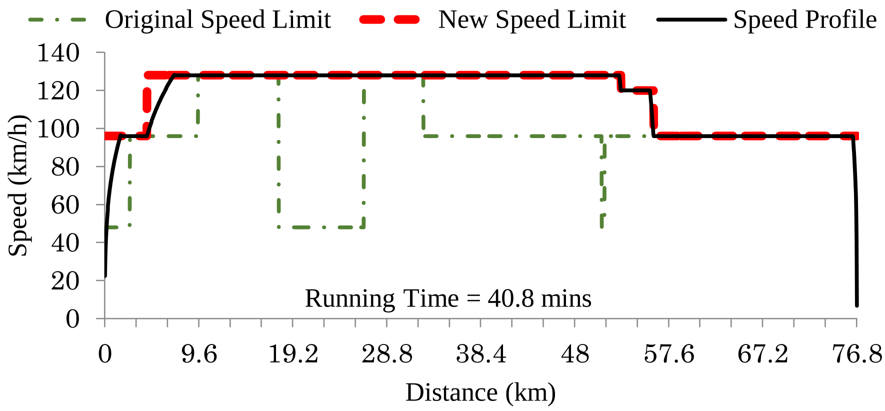

Figure 7 (b) Infrastructure Improvement for 70 Trains per Day

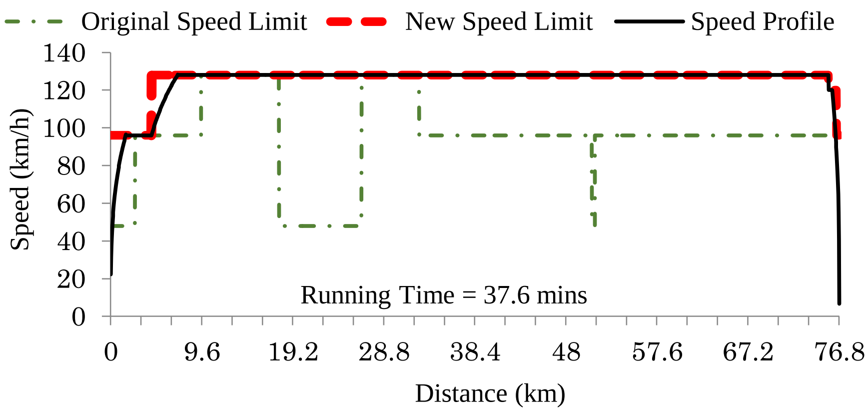

Figure 7 (c) Infrastructure Improvement for 40 Trains per Day

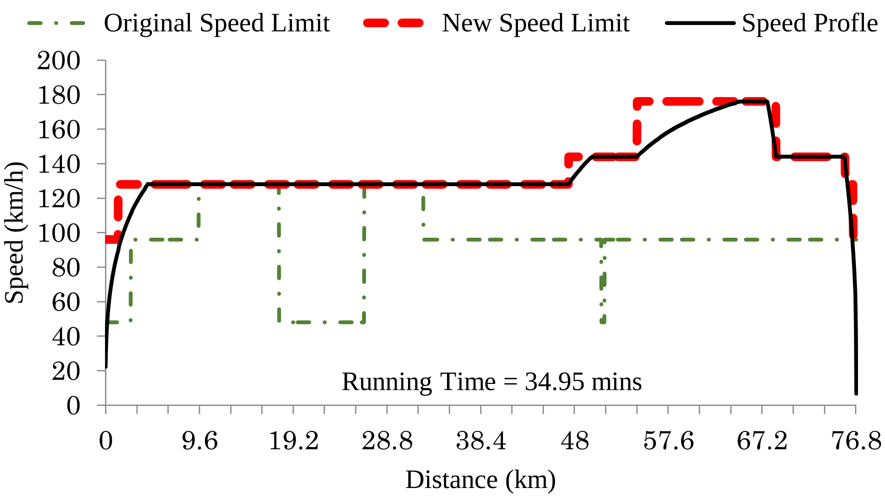

Figure 7 (d) Infrastructure Improvement for 10 Trains per Day

Keeping the service level of 40 trains per day as constant, different budgets may also have a great impact on the final passenger train running time. The relationship between available budget and running time is illustrated in Figure 8. Sixteen scenarios with different budgets amount are solved with the model for the service level of 40 trains per day. With more budgets available, railway companies are able to improve the infrastructure in order to accommodate higher operating speed. Thus the running time decreases as the budget increases. However, running time does not decrease in a linear pattern. The varying decreasing ratio exhibits diminishing returns and implies different effects for each budget level.

To study the cost effectiveness of different budget investments, we develop Figure 9 that shows the running time reduction and reduction per million dollars at different budget levels. We consider the ratio of running time reduction and the amount of time reduction per million dollars of budget as the measure of cost effectiveness. By investing more money for infrastructure, maintenance and train operation, running time can be reduced, but cost effectiveness decreases. This is because upgrade alternatives with higher benefit – cost ratio must be taken first when available budget is limited. With increasing budget, more improvements can be implemented, but those upgrades are either too expensive (more investment required for higher track class) or less effective in time reduction (poor acceleration characteristics at higher speed). The return on investment therefore decreases for higher budget scenarios.

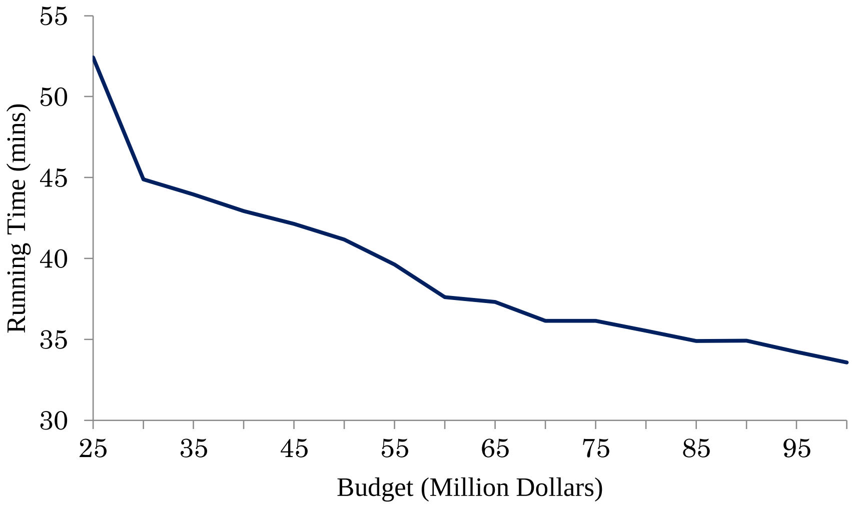

Figure 8 Running Time Performances

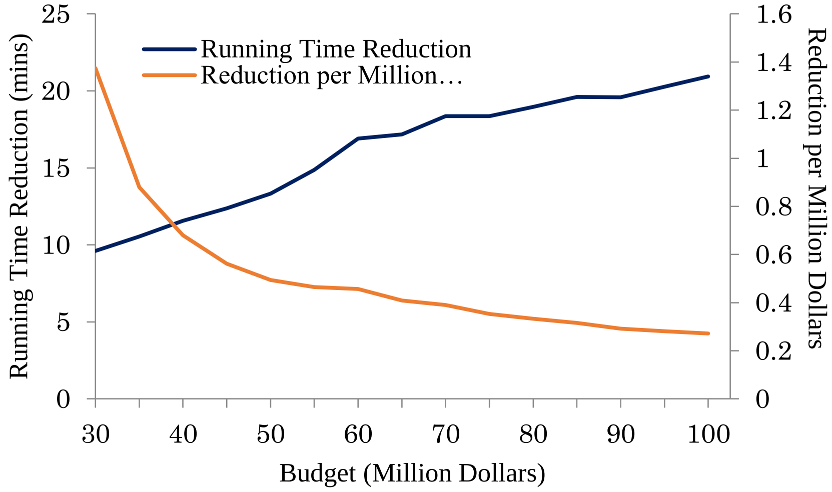

Figure 9 Cost Effectiveness for Budgets

7 Conclusions

This paper presents a methodology for optimally selecting projects or establishing budgets to reduce running time with consideration of capital, maintenance and operating cost on a passenger rail corridor. Genetic Algorithms have been proposed to solve this problem.

The simulation results show that solutions can be achieved by Genetic Algorithms within a short period of time. With a fixed amount of budget, this model can provide different upgrade options based on the estimated daily traffic level, and identify the most cost effective segments for infrastructure improvements. To study the impact of budget on running time performances, the incremental time reduction and reduction per million dollars of budget have been calculated at different budget levels. This type of analysis can help practitioners estimate the appropriate budget to achieve a desired return of investment.

With suitable cost data for a particular corridor of interest, this model can be incorporated into passenger rail corridor planning methodologies and used as a decision support tool for passenger rail service planners. Although the natural application of the model is to a single passenger rail corridor, through careful definition of segments within the Genetic Algorithms, the model can be used to select a suite of improvement projects on different routes to achieve an overall reduction in travel time across multiple train services operating on a network.

Future work with this methodology could analyse the sensitivity of results to different grade levels along the route, since grades have important effects on running time and fuel consumption. It is also interesting to study the upgrade decisions based on higher speed passenger train services, because improved rolling stocks can provide greater time reduction, but it requires more capital cost to upgrade to higher track classes at the same time. Upgrades of rolling stock give more options for project selection model. Last but not least, timetable needs to be considered for operating cost analysis in the future work as well. Current operating cost estimation is mainly based on the assumption of traffic volume. However, with consideration of more operating information (e.g. headways, operating speed, etc.) provided by timetable, the operating cost estimation would be more accurate. Therefore, the project selection model could be applicable accordingly.

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