A Project Selection Model for Improving Running Time on Passenger Rail Corridors

Brennan M. Caughron
bcaughr2@gmail.com

C. Tyler Dick, P.E.
ctdick@illinois.edu

Christopher P.L. Barkan
cbarkan@illinois.edu

Rail Transportation and Engineering Center (RailTEC)
University of Illinois at Urbana-Champaign
B118 Newmark Civil Engineering Lab
205 N. Mathews Ave
Urbana, IL, 61801

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. Several alternatives exist for reducing running time and increasing average passenger train speeds, including investments in track, signal, highway grade crossing, and rolling stock improvements. However, with limited resources, investments to improve performance on a corridor must be made in a cost effective manner. Often, the marginal travel time benefit of improving segments of a line from 79 to 90 or 110 mph maximum speed is less than the benefit of improvements that could be made to other segments currently restricted to lower speeds. In addition, running time benefits from upgrading adjacent track segments may compound based on the acceleration and braking performance of different rolling stock types. This paper presents a methodology for optimally selecting projects or establishing infrastructure budgets to reduce running time on a passenger rail corridor. A mixed integer program is formulated to solve this problem and the model is applied to a case study route. The model input information includes capital improvement and maintenance costs, existing route conditions, and rolling stock performance. This model can be used as part of a methodology for quickly and efficiently developing a strategic plan for improving minimum travel time on passenger rail corridors.

INTRODUCTION

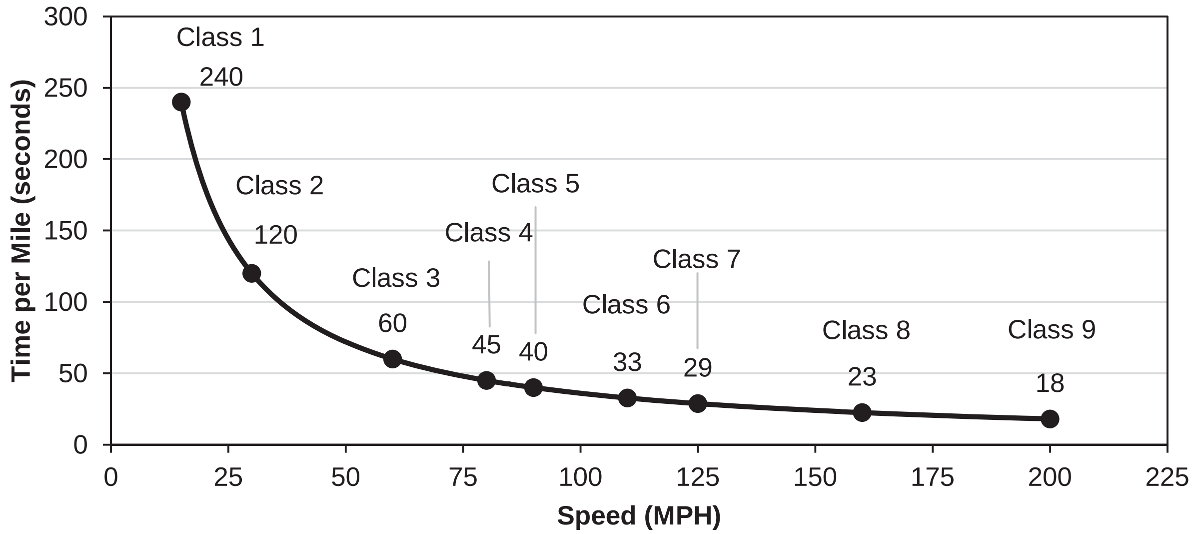
Recent proposals for expanded intercity passenger rail service in the United States have included plans for new dedicated high speed lines as well as incremental improvements to existing Amtrak service. Improvements to existing services aim to accommodate faster and more frequent passenger train operation, generally on trackage owned and operated by heavy axle load freight railways. In recent years, many studies and reports have been commissioned by state agencies and the U.S. federal government to assess the feasibility of new or improved passenger rail services (1-3). The scope of improvements considered in each of these studies varies considerably depending on the existing route conditions and the proposed rail service changes. Feasibility studies are typically too broad in scope to consider improvement projects on specific route sub-segments and instead group a set of improvements together into two or three alternative scenarios based on maximum operating speed. As part of this process, existing permanent speed restrictions are evaluated to determine the scope of improvements necessary to increase train speeds. More detailed reports may evaluate the performance benefits of segment specific improvement projects in terms of capacity, reliability, or running time (4). The methodology for selecting the most cost effective projects is not well defined and often relies on the judgment of experts involved in planning the corridor. In some cases, planning focus and attention has been placed on achieving high maximum speeds for rail services (5), when instead service may be more greatly improved and passengers better served by focusing on improvements that will increase average speeds.

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 (6). The problem is formulated as a mixed integer program that maximizes the reduction in travel time for different combinations of rolling stock and infrastructure. This model considered the performance of various trains given a set of line improvements but, given the long length of segments, did not account for any interaction affects between adjacent route segments. The subject of this paper is a considerable modification of this methodology as this research includes the interaction between different route segments as well as maintenance costs over an analysis period.

Scheduled running times of passenger trains are composed of two main time components. For a given train consist and route, there is a minimum achievable running time that assumes no delay from passengers, other rail traffic, or external factors. Passenger train schedules typically have a second element of slack time distributed in different parts of the schedule to accommodate an expected amount of delay. The amount of slack time can vary depending on the track configuration along the route, conflicting rail traffic, train performance characteristics, and expected passenger boarding and alighting times. Sogin et al. (2011) demonstrated the capacity impacts of passenger train speed differential on single track rail networks (7). Although it is important to consider route capacity impacts caused by higher-speed trains, the focus of this research is on investments that improve minimum run time and not those addressing the slack portion of the schedule that is most sensitive to rail capacity constraints and resulting train delays. For example, in order to support the operation of higher-speed passenger service, renewal of the track structure might allow an increase in track class and therefore reduce minimum running time on the route. At the same time, additional segments of double track might be added to mitigate the loss in free capacity taken up by operating faster passenger trains and consequently reduce the potential of delay from conflicting rail traffic. This research develops an optimization framework for the former types of investments in higher speeds. The latter types of investments in capacity are not considered here because they do not change the minimum achievable running time.

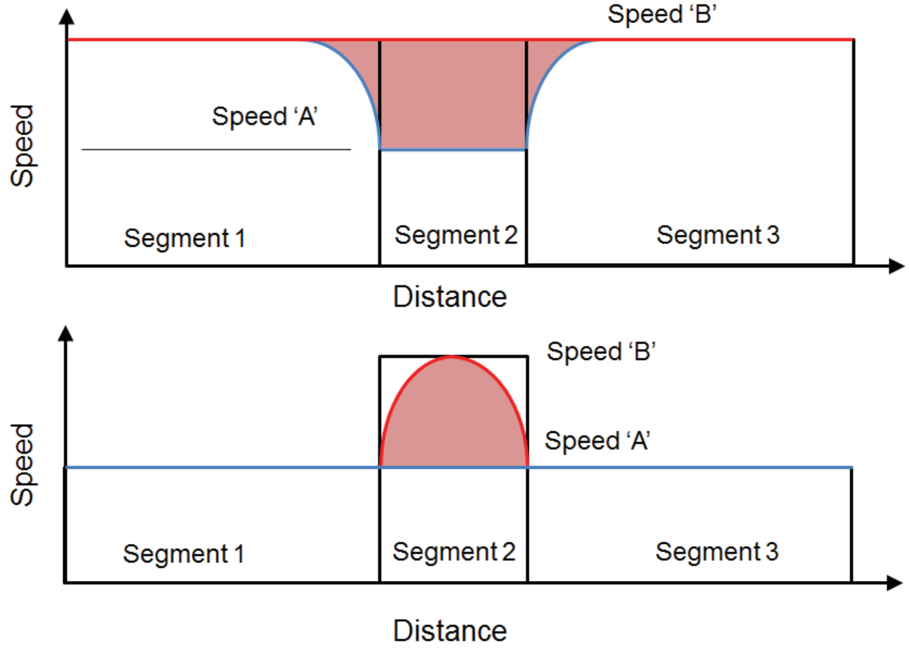
Figure 1 illustrates running times for a passenger train travelling one mile at speeds corresponding to the Federal Railroad Administration (FRA) track classes 1 through 9. For a one mile segment of track, the greatest marginal benefit in running time can be achieved by upgrading slower, rather than higher speed segments. For example, upgrading a route segment from FRA track class two to three reduces running time by one minute per mile, whereas upgrading a segment from track class five to six saves only seven seconds per mile. Acceleration and braking events between segments of different operating speeds can diminish the already marginal running time benefit provided by higher speed improvements. Given a railway line with a distribution of existing operating speeds and segment specific upgrade and maintenance costs, there exists a lowest cost set of infrastructure conditions to achieve a target running time.

Figure 1: Running Time vs. Train Speed



Several alternatives exist for reducing running time and increasing average speeds, including improvements to track structure and geometry, signaling systems, highway grade crossings, and rolling stock. These types of projects cannot be evaluated in isolation because many of them offer different benefits depending on the condition of other components on the same or adjacent segments of the route. For example, consider a project to upgrade a single segment from a low maximum speed A to a higher maximum speed B. The cost of the upgrade from speed A to speed B is the same regardless of the condition of the adjacent segments. However, as illustrated in Figure 2, due to acceleration and braking effects, the incremental benefit of upgrading the intermediate segment will be greater for the case where the adjacent segments are already at the higher maximum speed B than it is for the case where the adjacent segments remain at the lower maximum speed. Thus, the benefit-to-cost ratio for the project to upgrade the intermediate segment varies greatly with the boundary conditions of adjacent segments. Given these complications and the multiple improvement options available, a methodology is needed for determining the relative cost effectiveness of upgrading different segments of a route. To meet this need, an optimization model was developed to be used as a decision support tool that rapidly and efficiently evaluates railway improvement strategies.

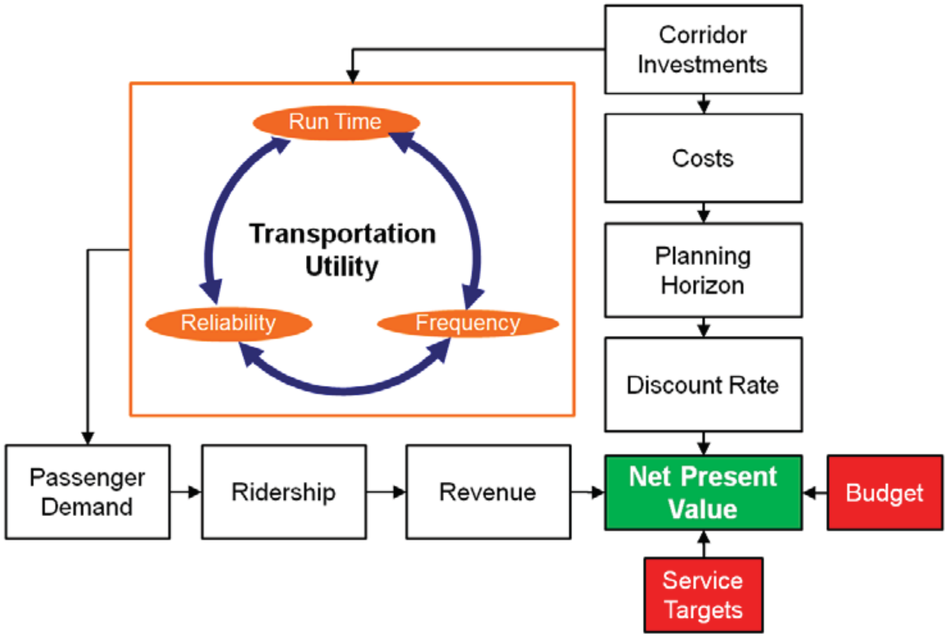
Figure 2: Change in Project Benefits Due to Speed Boundary Conditions



PROJECT SELECTION METHODOLOGY

An ultimate process for planning improvements to a rail corridor is shown in Figure 3. In this process, existing or proposed rail service is evaluated for a given budget or service target. To meet this objective, planners may select from a range of potential corridor improvements that may include alternative improvements to infrastructure and/or rolling stock. Each of these improvements may have an impact on service quality metrics including frequency, running time, and reliability. Each of these three metrics has a potential impact on ridership and revenue depending on the passenger demand along the route. In addition to an impact on revenue, each improvement scenario has a characteristic initial capital and long term operating cost. The net present value (NPV) of each scenario over a time period can be calculated using its associated revenues and costs. The improvement scenario with the highest NPV can be selected as the optimal strategy for the corridor.

Figure 3: Ultimate Rail Service Optimization



This work focuses on a subset of these steps and considers infrastructure improvements that impact the minimum running time of a passenger service. The model developed through this research and used in this paper is formulated as a mixed integer program with an objective function that minimizes the running time of train services (8). The primary decision variable is the speed condition of each track segment along the route. Model constraints ensure the feasibility of train speed profiles and account for the time necessary to accelerate or brake between adjacent route segments of different speeds (Appendix Tables 2-5). At a high level, the model computes total train running time in a manner similar to a simple train performance calculator (TPC) while constraining the track condition to combinations that have a present value cost less than a specified budgetary amount.

Using this model, planners can define the relationship between running time and minimum present value capital and maintenance cost of infrastructure. Once this relationship has been established for a given route, the results can be applied to select an appropriate running time goal, infrastructure cost budget and suite of performance improvement projects. Future expansions of this work will incorporate frequency and reliability improvements into the model framework along with a ridership and revenue model to allow for a complete net present value analysis. When fully formulated in this manner, the resulting NPV could be used to define the initial budget through a feedback loop and the optimization framework run through a series of iterations until a stable equilibrium is reached. At this point, an optimal set of improvement projects that can be funded on the basis of future revenues is identified.

CASE STUDY

A case study route was developed to demonstrate the functionality of the model. The route characteristics are based on a segment of a typical Midwest regional intercity passenger rail corridor. The portion of the rail corridor analyzed in this work is 48.1 miles long and features 15 curves, 74 highway grade crossings, and eight station locations. The maximum operating speed is 79 MPH. However, there are several segments where speed is restricted due to curves or the lack of a signal system, decreasing the running time performance of trains on the corridor. The route was divided into 49 segments of average length 0.98 miles, with each segment having a distinct set of physical and operating characteristics (Figures 4 and 5).

Figure 4: Grade Crossings on Route

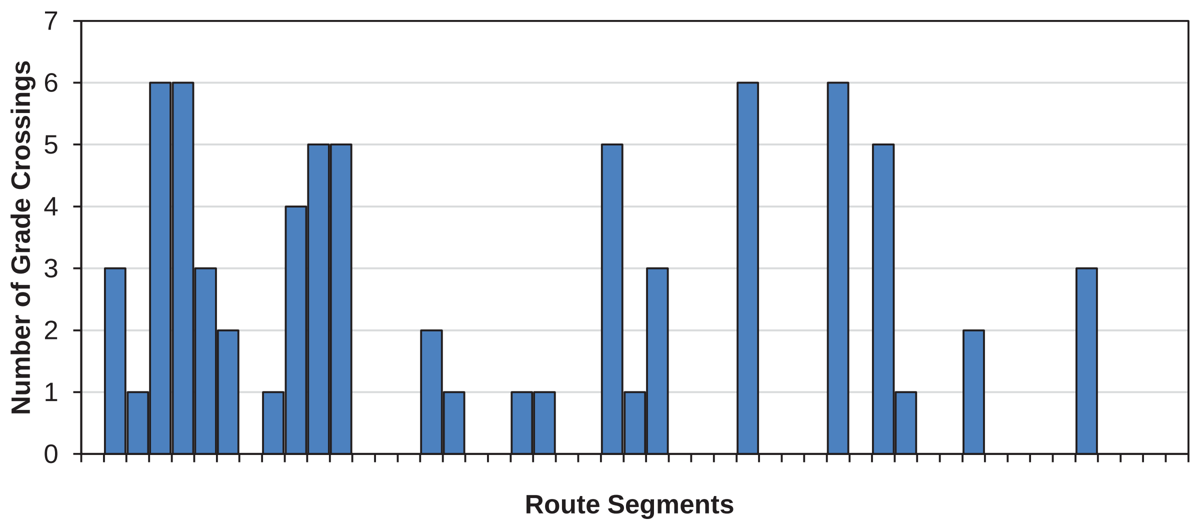
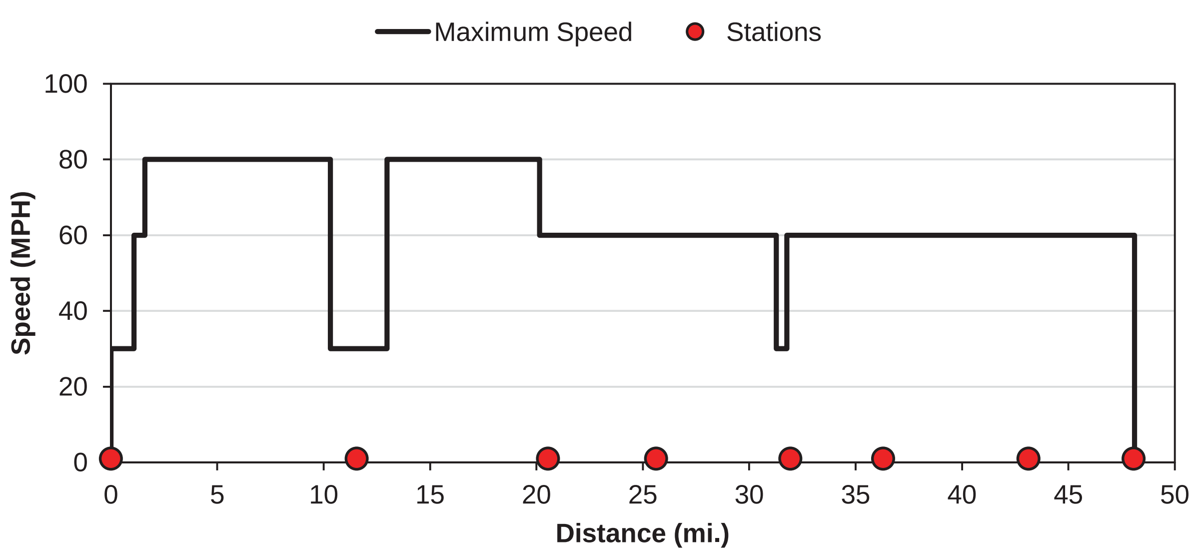


Figure 5: Route Speed and Location of Stations



Two train services were introduced on the case study route. An express service operates from endpoint to endpoint without stopping at any intermediate stations. A commuter service also operates from endpoint to endpoint but features six intermediate station stops. Figure 6 illustrates the train services and stopping patterns along the route.

Figure 6: Route Map Illustrating the Rail Service Stopping Patterns

INPUT DATA

The characteristics of the existing railway track and associated infrastructure have a major impact on capital improvement and maintenance costs. Infrastructure improvements were considered in the scope of potential projects if the improvement in question would help support higher train operating speeds. The differences in physical characteristics of each route segment means that each segment has a different relationship between capital cost, maintenance cost, and maximum operating speed. Four main elements were considered when estimating capital and maintenance costs on each segment: track structure, track geometry, signal system, and number of highway grade crossings.

Track structure refers to the system of components including rails, ties, fastening system, ballast, and subgrade. Depending on the segment, this may also include bridge structures and drainage elements like culverts. For an existing track, some or all of these components may need rehabilitation or replacement to support higher operating speeds. For example, increasing passenger train speeds from 30 to 60 MPH requires an increase in FRA track class from 2 to 3. Depending on the present segment condition, more quality cross ties in a given segment may be required in order to meet track safety regulations (9). In addition to these requirements, railway companies often have engineering policies that dictate use of premium track components for higher operating speeds, even if they are not explicitly required by federal regulations. One cost not considered in this case study was that associated with increased track center spacing. Some existing railway lines may not have adequate adjacent track separation in order to safely support higher speed passenger trains. When analyzing these scenarios, the additional costs of widening cut and fill sections, improving bridges, modifying drainage features, and potentially relocating utilities must be considered.

More sophisticated signaling and grade crossing warning systems are required for higher train operating speeds. The presence and condition of existing signaling equipment on a line has an effect on the incremental improvements and consequent costs of upgrading the corridor to support higher speeds. If a track segment in question is already equipped with cab signals or automatic train stop, the marginal cost of upgrading track speed from 80 to 90 MPH would be less than an equivalent segment that is not already so equipped. The cost of upgrading highway crossings to include features like four quadrant gates and intrusion detection to support higher passenger train speeds is also a major factor in segment-specific improvement costs. The requirements in each of these categories to support certain operating speeds are dictated by regulatory requirements and/or the engineering policies of the railway or agency in charge of the rail infrastructure.

The present-value cost for each segment is determined by the sum of the capital costs and present value maintenance costs over a time period. A spreadsheet calculator was developed to compute improvement costs specific to the characteristics of each segment. Capital costs for each segment were determined using the cost estimation methodology outlined by Quandel Consultants (2011) as a guideline (10). In order to improve operating speeds on a track segment, specific infrastructure changes were considered when upgrading to a specific track class (Table 1). These input data were used solely to illustrate this case study and are not necessarily representative of the types of improvements necessary to support higher speeds on any specific corridor. For example, some existing railway lines may have relatively new rail suitable for higher speed operations. The improvement decisions and costs used in this methodology must be tailored to the railway corridor in question based on existing conditions.

Table 1: Infrastructure Improvement Chart

Track Class	Max. Speed (MPH)	Track Structure	Signaling System	Grade crossings / miscellaneous
Class 3	60	Replace 1/3 Crossties (wood) , 136RE CWR, Surfacing		Curve shift
Class 4	80	Replace 1/3 Crossties (wood), 136RE CWR, Surfacing	CTC	Curve shift
Class 5	90	Replace 1/3 Crossties (wood), 136RE CWR, Surfacing	CTC / ATS or ATC	Curve shift, Four quad gate crossings
Class 6	110	Replace 2/3 Crossties (wood), 136RE CWR, Surfacing	CTC / ATS or ATC	Curve shift, four quad gate crossings with intrusion detection, fenced ROW

As an example, in order to improve a segment from FRA class 3 to class 5 standards, the case study segment would require one-third of the crossties to be renewed, new 136RE continuous welded rail, ballast and surfacing, a centralized traffic control (CTC) system with automatic train stop (ATS) or automatic train control (ATC) system, a potential shift in curve geometry (if required on the segment), and a four quadrant gate warning system at each highway grade crossing. For the case study route, all existing grade crossings were assumed to have flashing lights with conventional two-arm gates. It is noted that the cost of a positive train control (PTC) system was not included in this analysis as the technology is to be implemented on all passenger routes regardless of speed by the year 2015.

Two potential curve geometry projects were considered for curve segments that limit train operating speed. In the first case, the curve superelevation and spiral lengths were increased to maximize the allowable train speed on the curve. This cost involves adjusting the track geometry within the footprint of the existing roadbed. For the case study route, curves were designed for passenger traffic with a maximum of 4” superelevation and 3” of cant deficiency. Spirals were designed according to AREMA recommended practice. The curve geometry and spiral design parameters may be different depending on the predominant traffic type operating on the corridor. The second project alternative involves shifting the curve so that its degree of curvature is decreased to the extent possible within the width of the right of way. In this case study, the right of way was assumed to be 100 feet wide, but this will differ on a location specific basis. For curves of short length and small initial degree of curvature, a greater reduction in degree of curve is possible than for longer and higher degree curves. Unit costs for these two types of curve projects were also based on those used by Quandel Consultants (2011). For any curved segment, there is a maximum speed benefit possible through each type of improvements. In order to constrain the model to only select feasible speeds for each curved segment, a large cost penalty is added to the present value parameter for higher curve speed conditions not possible with the two improvement scenarios.

Annual steady state maintenance costs for the different track classes were based on those used by Zarembski et al. (2004) who generated maintenance cost estimation tables for shared passenger and freight rail lines of different operating characteristics (11). For the purposes of this case study, the category of light-curvature, timber crosstie track at a traffic level less than 5 MGT per year was selected. The difference between Zarembski et al’s “high” and “low” cost estimates was used as the incremental maintenance cost allocated to the passenger service operator. These costs were converted into a present-year value using a 10-year analysis period and a 5 percent discount rate. A limitation of the maintenance cost information used here is that we assumed the same maintenance cost for track classes 1-4. The model results would be further validated by increased accuracy in maintenance cost estimation for different track classes and features (e.g. grade crossings) specific to each segment.

The passenger train consist used in the case study was based on typical Amtrak regional, intercity trainsets capable of 110 MPH operation used on short-haul, regional corridors in the Midwestern United States. The consist has one 4,250 horsepower, four-axle locomotive, six single level passenger coaches, and an additional locomotive not providing tractive force but serving as a cab car and source of head-end power for passenger amenities. Acceleration and braking time-distance calculations were performed using a simplified train performance calculator with one second speed calculation steps. The simplified train performance calculator uses the Canadian National train resistance formulas and coefficients as shown in chapter 16.2.1 of the AREMA Manual for Railway Engineering (12). Braking distances and times were computed by assuming a constant braking force throughout the range of speeds. These assumptions of passenger train performance calculation were verified by comparing the results of the train performance calculator to actual time-distance data obtained from an Amtrak track geometry car operating on regularly scheduled passenger trains. Using all this information, a combined acceleration and braking delay table was computed for use in the model. Two additional assumptions are that the passenger train is a “point mass” that can immediately begin to accelerate upon encountering a higher speed limit and second that the grades on the route are level or not significant enough to greatly change the acceleration and braking characteristics of the passenger train. These assumptions were made to simplify the initial model formulation but as discussed in the Future Work section, future development of the model will include grade and train length effects.

RESULTS

The mixed integer program and case study data were fed into Paragon Decision Technology AIMMS optimization software installed on a desktop computer with 16 GB of RAM and a 3.4 GHz quad core processor. The case study route had 26,999 decision variables and 75,902 constraints. The GUROBI 5.0 solver included with the AIMMS software was the most efficient for this problem type and was generally able to converge to an optimal solution in 1-2 minutes. Larger routes with more segments, infrastructure speed conditions, or train speeds would require more decision variables and therefore longer solution times. The model was solved for 16 separate scenarios with different budget constraints. Figures 7 and 8 reflect a representative \$45M budget scenario while Figures 9 and 10 summarize the results from all scenarios.

Figure 9 shows the \$45M optimal route configuration along with the performance of both train services along the route. The express service shown with the blue line generally meets the maximum track speed as shown in black. The commuter service, shown by the dashed red line, does not meet the maximum track speed on some segments due to train acceleration and braking characteristics as well as the short distance between intermediate stops along the route. It is clear that the segment improved to 110 MPH between mile 25 and 37 benefits the express service more so than the commuter service (Figure 7).

Figure 7: Optimal Route Configuration with \$45M Present-Value Budget

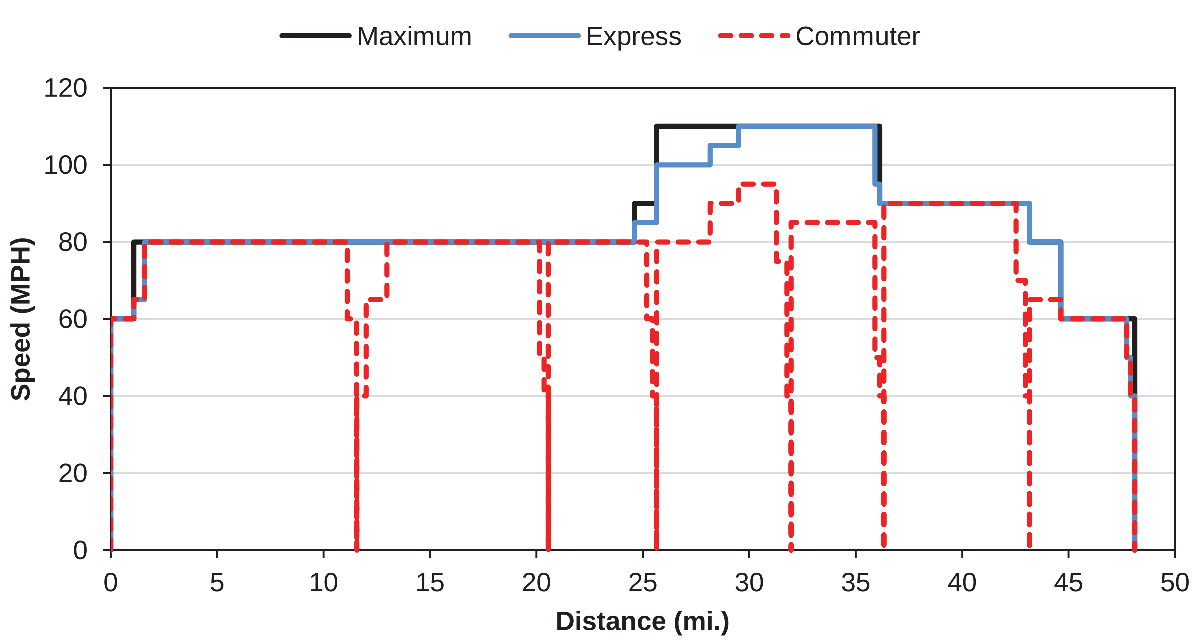
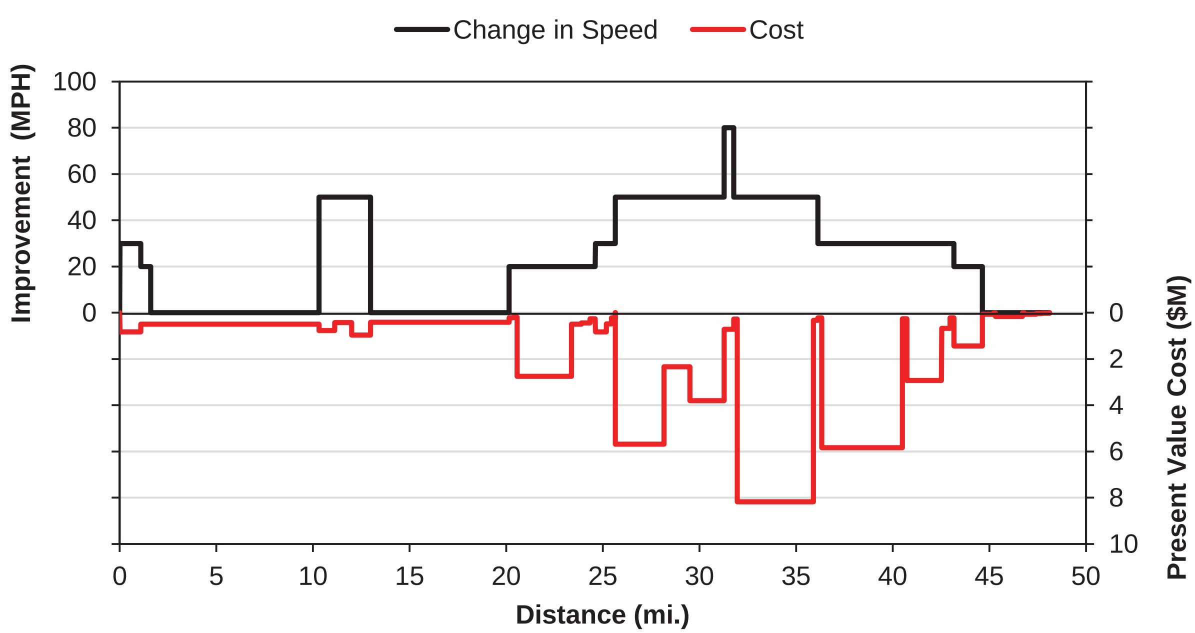


Figure 8 shows the speed improvement from the base configuration to the optimal configuration at a $45M present-value budget. The speed improvements are clustered in three distinct areas as shown by the black line. Due to the time delay incurred by braking and accelerating, the optimal pattern of upgrades for any budget case tends to exist in blocks rather than many separate individual segments. The bottom part of the figure reflects the present value cost of each segment along the route, shown by the red line. Curves that had restricted the speed of the train around mile 10-13 and 32 are selected to be re-aligned for higher speeds by the model. In addition to the curve realignment, a segment of 110 MPH infrastructure is selected. On this segment, 21 grade crossings would receive four-quadrant gates and vehicle intrusion detection. The 110 MPH segment is bracketed by two segments of 90 MPH infrastructure. On these segments, 8 grade crossings would be upgraded to four-quadrant gates.

Figure 8: Speed Improvement vs. Cost with $45M Present-Value Budget



The relationship between the running time of the two passenger services and present value cost is shown in Figure 9. The top red line shows the running time of the commuter service while the bottom black line shows the running time of the express service at different budget scenarios. As the budget constraint was increased for each model scenario, there was a corresponding decrease in the running time of both services. In lower budget scenarios, the model solution can include improvements with only the highest benefit to cost ratio. As the budget is increased, the optimal solution includes further sets of improvements that are less cost effective in reducing running time and have a lower return on investment. The running time improvement of the commuter service is more limited by the acceleration and braking performance of the rolling stock at higher budget scenarios. In these scenarios there is a greater improvement in the running time of the express service because it can take advantage of relatively longer stretches of uninterrupted, higher speed running.

Figure 9: Running Time vs. Cost Relationship for Case Study Route

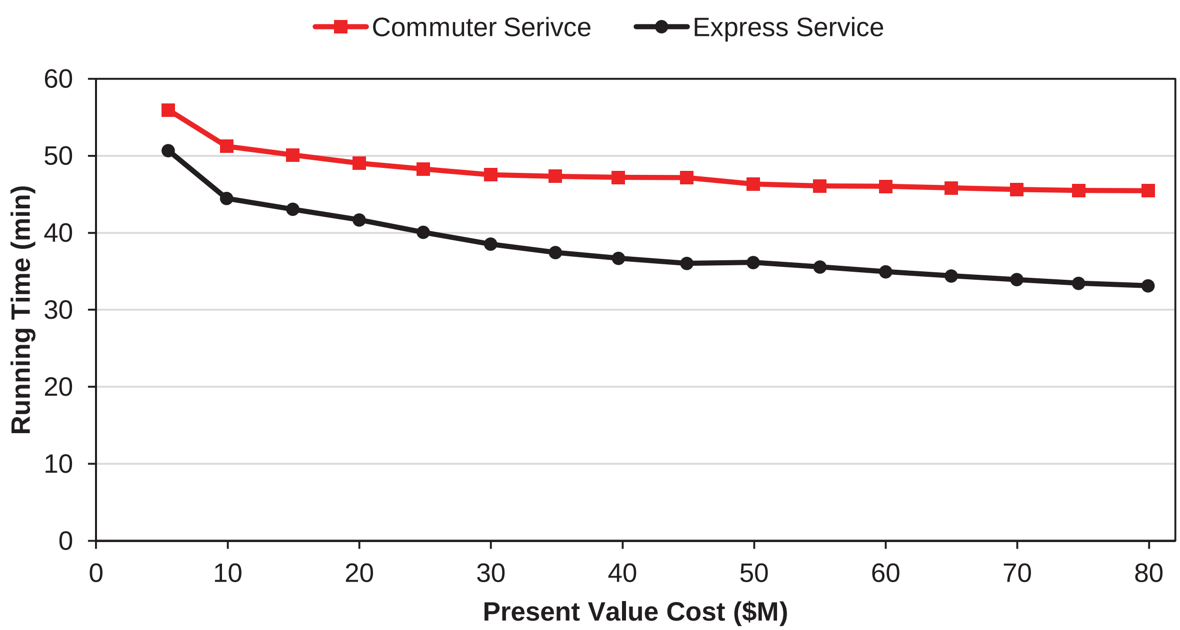
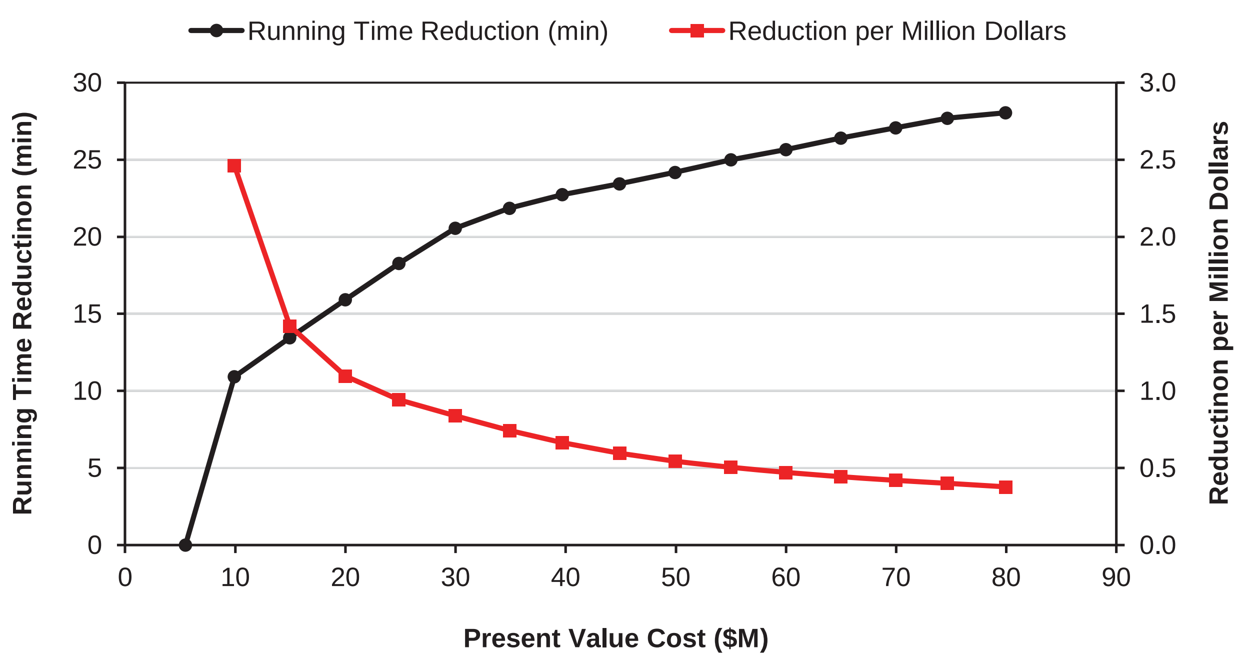


Figure 10 illustrates total running time reduction (black line) of both express and commuter services versus the present-value cost for the infrastructure configuration. The red line reflects the marginal benefit at each level of investment in minutes of running time reduction per additional million present-value dollars. As the level of investment in the existing corridor is increased, the marginal benefit decreases.

Figure 10: Running Time Reduction vs. Present Value Cost



These figures and analysis techniques can be used to plan a series of infrastructure improvements for an intercity corridor. For an existing corridor, appropriate cost and performance data can be collected and input into the model to determine which segments are most cost effective to upgrade. Any proposed run time improvements to the corridor can be compared to a route and train specific frontier of optimal running time improvements (Figure 12). Proposed corridor configurations that are plotted far below the optimal cost versus running time reduction frontier should be re-evaluated against other alternatives. Different rolling stock alternatives could also be evaluated using the model framework by considering different train performance characteristics and comparing the resulting cost versus running-time curves shifted by present-value equipment costs. The rolling stock alternative that offers the lowest combined infrastructure and equipment cost for a given running-time reduction should be selected for use on the corridor. Future work with this methodology could also analyze the sensitivity of results to tradeoffs in capital versus maintenance costs for premium track components such as concrete ties or premium special trackwork such as turnouts that feature moveable point frogs.

CONCLUSIONS

This paper presents an optimization model that can be used to help plan cost effective infrastructure improvements to improve running time performance of intercity passenger rail corridors. A mixed integer program is proposed that takes into account infrastructure capital costs, present-value maintenance costs, and the performance characteristics of the rolling stock operating on a route. By solving the model for a series of different budget constraints, a cost versus running time function can be established. Using this relationship, potential improvements to the corridor can be evaluated against the optimal frontier of configurations generated by the model. With suitable cost data, this model could be incorporated into passenger rail corridor planning methodology and used as a decision support tool for passenger rail service planners.

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APPENDIX

Table 2: Model Indices

Indices	Name	Description
t	trains	index of different train services
n	segments	index of route segments
s	train speeds	index for train speed
c	infrastructure speed conditions	index for track speed condition

Table 3: Model Variables

Variables	Name	Description
$v_{n,s,t}$	train speed	speed of train ‘t’ on segment ‘n’ (0,1)
$x_{n,c}$	track speed condition	condition of track on segment ‘n’ (0,1)
$z_{n,c,c^*,t}$	acceleration link variable	link variable used to indicate change in speed between segments ‘n’ (0,1)
$a_{n,t}$	segment acceleration distance	acceleration distance of train ‘t’ on segment ‘n’ (real number > 0)
$b_{n,t}$	segment braking distance	braking distance of train ‘t’ to segment ‘n’ (real number > 0)

Table 4: Model Parameters

Parameters	Name	Description
$\theta_{n,t}$	train service importance factor	weight factor for different train services (real number > 0)
l_n	segment length	length of segment (real number >0)
δ_s	running time	running time at speed 's' per length (real number > 0)
$\tau_{s,s^*,t}$	acceleration braking delay time	acceleration and braking delay time from speed 's' to speed 's*' for train type 't' (real number > 0)
$p_{n,c}$	present value cost	present value capital construction and maintenance cost for condition 'c' on segment 'n' (real number > 0)
B	present value budget	budget of present value capital construction and maintenance costs (real number > 0)
σ_s	speed parameter (s)	speed parameter at speed condition 's' (real number > 0)
ν_c	speed parameter (c)	speed parameter at segment condition 'c' (real number > 0)
$h_{n,t}$	train service pattern	parameter which can set a maximum speed for train 't' on segment 'n' (real number > 0)
$\beta_{s,t}$	standard braking distance	cumulative braking distance from speed 's' for train type 't' (real number > 0)
$\alpha_{s,t}$	standard acceleration distance	cumulative acceleration distance to speed 's' for train type 't' (real number > 0)

Table 5: Model Equations

Equation	Number
$\sum_{n=1}^{N}\sum_{s=0}^{S}\sum_{t=1}^{T}\theta_{n,t}l_n\delta_s v_{n,s,t}+\sum_{n=2}^{N}\sum_{s=0}^{S}\sum_{s^*=0}^{S}\sum_{t=1}^{T}\theta_{n,t}\tau_{s,s^*,t}z_{n,s,s^*,t}$	1
$\sum_{n=1}^{N}\sum_{c=0}^{C}p_{n,c}x_{n,c}\leq B$	2
$\sum_{s=0}^{S}\sigma_s v_{n,s,t}\leq\sum_{c=0}^{C}\nu_c\, x_{n,c}$	3
$z_{n,s,s^*,t}\leq v_{n,s^*,t}\ \ \forall\, n,s,s^*,t$	4
$z_{n,s,s^*,t}\leq v_{n-1,s,t}\ \forall\, n,s,s^*,t$	5
$z_{n,s,s^*,t}+1\geq v_{n,s^*,t}+v_{n-1,s,t}\ \forall\, n,s,s^*,t$	6
$l_n-a_{n,t}-b_{n+1,t}\geq 0\quad\forall\, n,t$	7
$b_{n,t}\geq\sum_{s=0}^{S}\left(\beta_{s,t}v_{n-1,s,t}-\beta_{s,t}v_{n,s,t}\right)\quad\forall\, 2\leq n\leq N,t$	8
$a_{n,t}\geq\sum_{s=0}^{S}\left(\alpha_{s,t}v_{n,s,t}-\alpha_{s,t}\, v_{n-1,s,t}\right)\forall\, 2\leq n\leq N,t$	9
$\sum_{s=0}^{S}\sigma_s v_{n,s,t}\leq h_{n,t}\quad\forall\, n,t$	10
$\sum_{s=0}^{S}v_{n,s,t}=1\ \ \forall\, n,t$	11
$\sum_{c=0}^{C}x_{n,c}=1\quad\forall\, n$	12

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Rail Corridor Project Selection Model

AREMA Interchange - 2013

Brennan M. Caughron

Rail Transportation and Engineering Center (RailTEC)

University of Illinois at Urbana-Champaign

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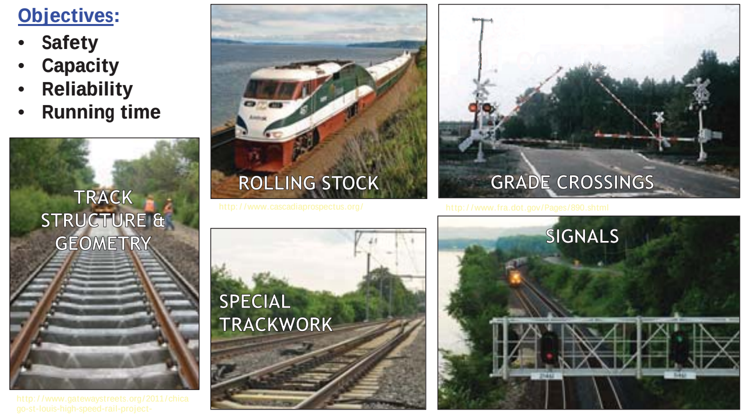
Railway Interchange/2013 AREMA/RSI/REMSA/RSSI

Outline

- Background
- Project selection model formulation
- Case study
- Future work

Corridor Improvements

Objectives:
- **Safety**
- **Capacity**
- **Reliability**
- **Running time**



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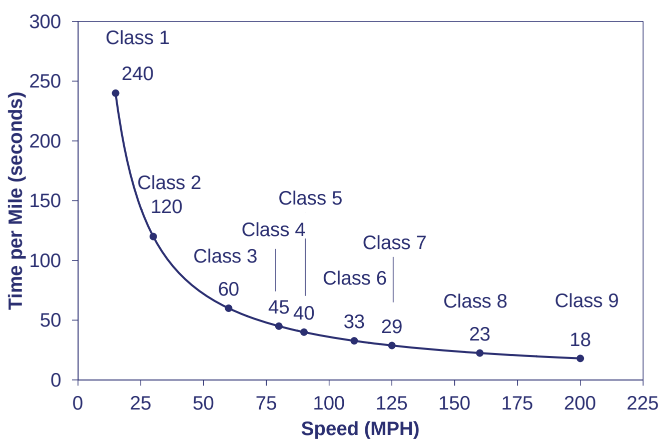
"Go Fast by Not Going Slow…"



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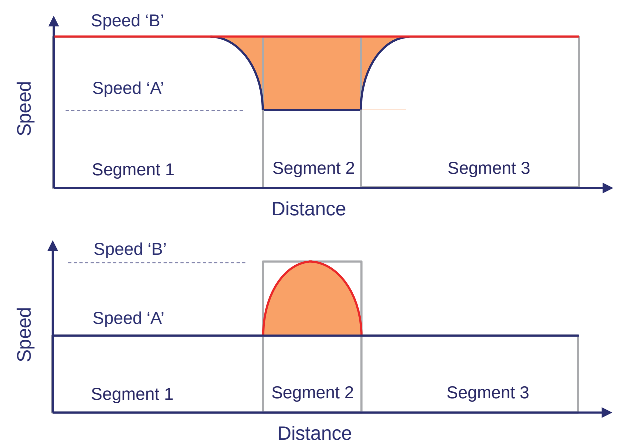
Project Benefits Depend on Boundary Conditions



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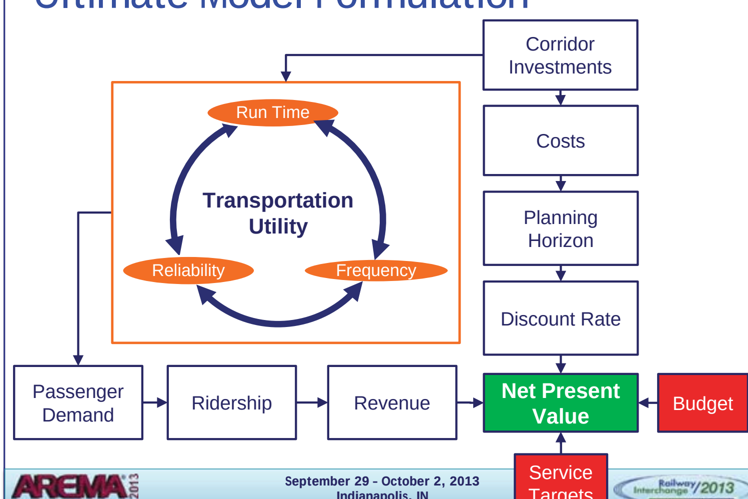
Ultimate Model Formulation



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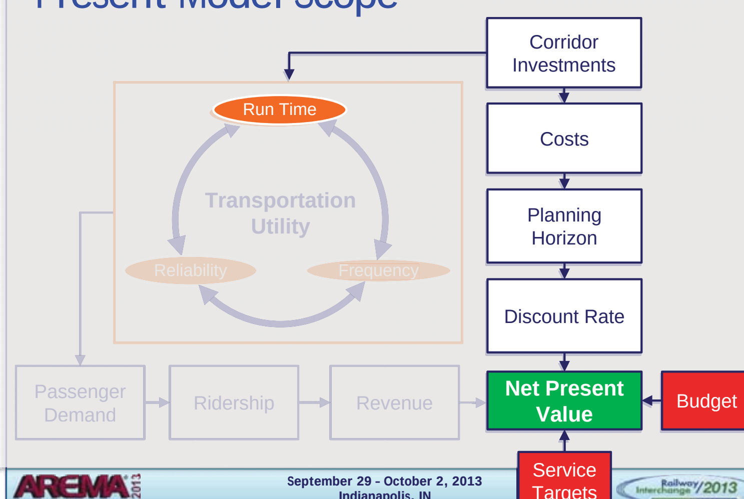
Present Model Scope



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Opportunities to Reduce Running Time

- Improvements can be made to address schedule minimum run time and schedule reliability
- Improvement projects have different impacts on both schedule components

Schedule minimum run time

- Infrastructure
  - Track structure
  - Track geometry
  - Signals
  - Grade crossings
- Rolling stock
  - Acceleration
  - Top speed
  - Curving performance

Schedule reliability (uncertainty)

- Single vs. double track
- Siding length and spacing
- Capacity utilization
  - Existing capacity
  - Other rail traffic
- Station dwell
- Passenger delays

Model Objective Function

Minimize Total Running Time:

$$\sum_{n=1}^{N}\sum_{s=0}^{S}\sum_{t=1}^{T}\theta_{n,t}\, l_n \delta_s v_{n,s,s^*,t} + \sum_{n=2}^{N}\sum_{s=0}^{S}\sum_{s^*=0}^{S}\sum_{t=1}^{T}\theta_{n,t}\tau_{s,s^*,t} z_{n,s,s^*,t}$$

- ABD link variable (1,0)
- Acceleration/Braking Delay
- Segments
- Speeds
- Trains
- Segment train speed (1,0)
- Unit running time at speed 's'
- Segment length
- Segment specific train time weight factor

Model Constraints

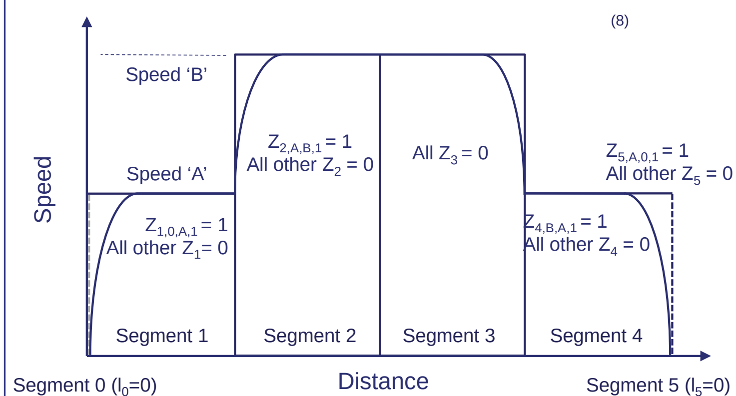
	Budget constraint	(1)
	Train speed < infrastructure speed	(2)
	Station stopping constraint	(3)
	One operating speed per service on each segment	(4)
	One track maximum speed on each segment	(5)

Speed Profile Constraints (1)

(6)

(7)

(8)

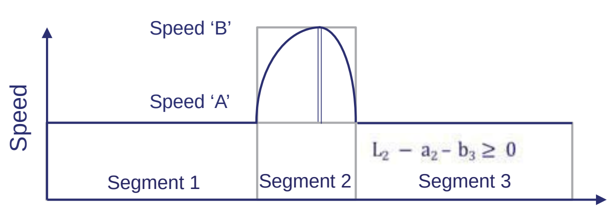


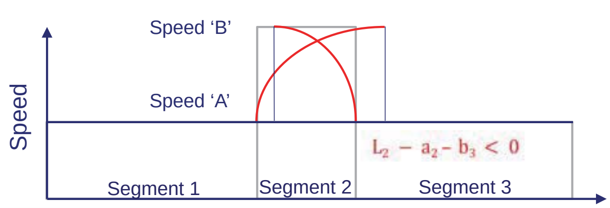
Speed Profile Constraints (2)

(9)

(10)

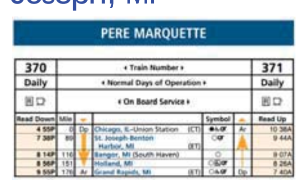
(11)



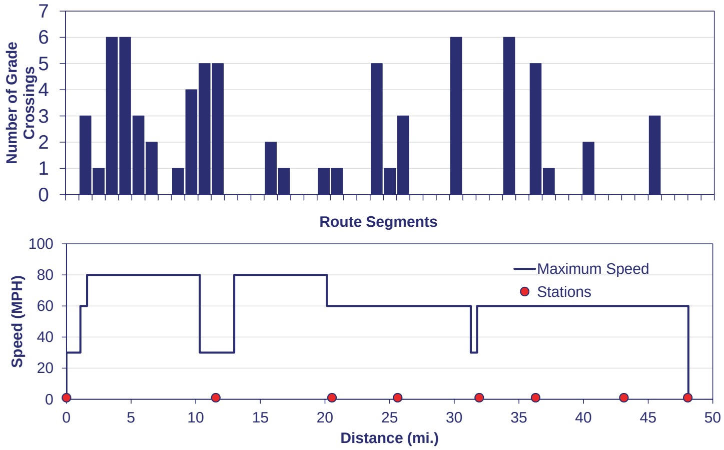


Case Study – Porter, IN to St. Joseph, MI

- One round trip frequency per day
- Route length of 176 mi
- 79 MPH maximum speed
- 44 MPH average speed (good case for improvement)
- Annual ridership 106,662 (FY '11)
- Selected segment from Porter to St. Joseph for current PSM case study
- Added hypothetical commuter rail service to demonstrate functionality of model



Route Characteristics



Upgrade Treatments

Track Class	Maximum Train Speed (MPH)	Track Structure	Signal System	Grade crossings / Misc.
Class 3	60	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing		Curve shift
Class 4	80	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC	Curve shift
Class 5	90	Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC/AT S/ATC	Curve shift, Four quad gate crossings
Class 6	110	Replace 2/3 Cross Ties (wood), 136RE CWR, Surfacing	CTC/AT S/ATC	Curve shift, four quad gate crossings with intrusion detection, fenced ROW

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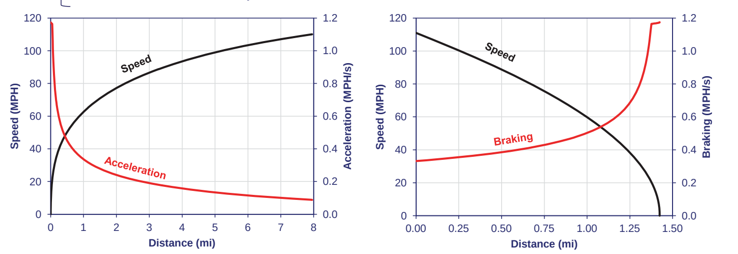
Case Study Input Parameters

Inputs
- Capital costs from Quandel Consultants (2011)
- Maintenance costs from Zarembski et al (2002)
- Discount rate 5%, 10 year period
- Equal train running time weights (alpha 1 = alpha 2)
- Identical train consists for each service (1 loco, 6 coach, 1 NPCU*)
- Acceleration and braking performance from simplified TPC

Solution
- Mixed Integer Program (MIP) with GUROBI 5.0 solver
- 1-2 minutes to optimal solution for each scenario



* NPCU = Non-Powered Cab Unit

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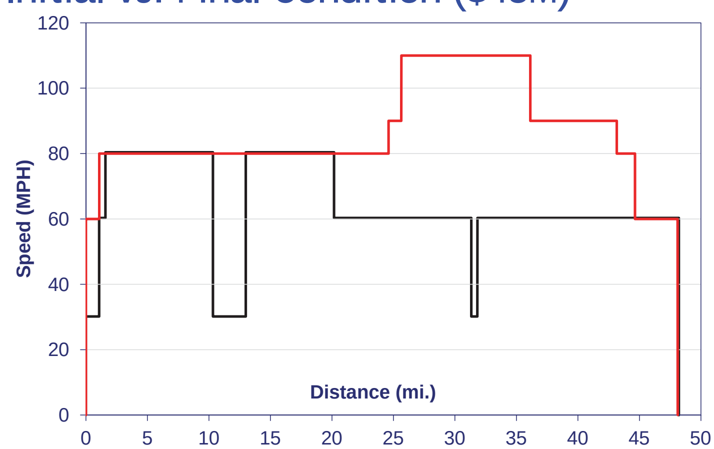
Initial vs. Final Condition ($45M)



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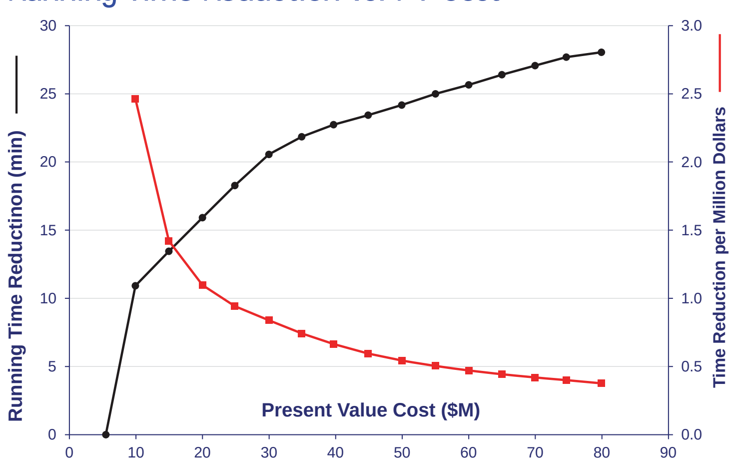
Running Time Reduction vs. PV Cost



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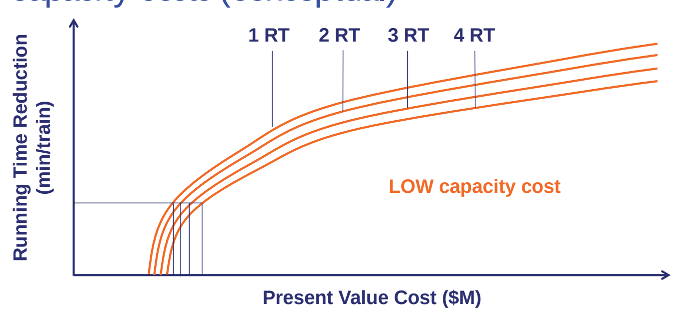
Capacity Costs (Conceptual)



- Capital costs for improved passenger service often include capacity expansion projects
- Total cost of run time and capacity upgrades may be higher for greater number of train frequencies
- Total cost vs. running time relationship highly dependent on track configuration and rail traffic levels (present and future)

RT: round trip

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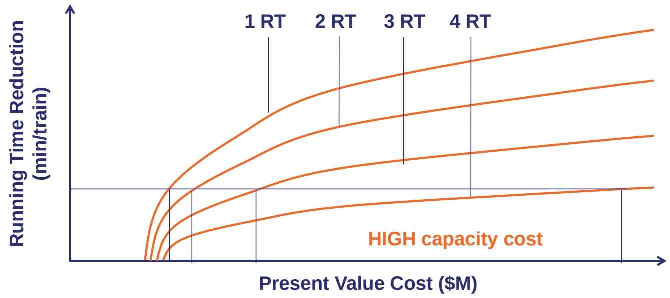
Capacity Costs (Conceptual)



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RT: round trip

Potential Freight Application

- Model framework can be adapted to analyze freight corridors
- Time sensitive freight traffic
  - Auto parts
  - Intermodal
  - Perishable commodities
- Need to incorporate grades into acceleration and braking delay constraints
- Evaluate shared passenger and freight corridors and determine what upgrades are mutually beneficial

Questions or comments?

C. Tyler Dick, P.E.
Senior Research Engineer
Rail Transportation and Engineering Center (RailTEC)
University of Illinois at Urbana-Champaign
E-mail: ctdick2@illinois.edu

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