AN ENHANCED PARAMETRIC RAILWAY CAPACITY EVALUATION TOOL (RCET)

Yung-Cheng (Rex) Lai

Assistant Professor

Department of Civil Engineering

National Taiwan University

Room 313, Civil Engineering Building

No 1, Roosevelt Road, Sec 4

Taipei, Taiwan, 10617

Tel: +886-2-3366-4243

Fax: +886-2-2363-9990

Email: yclai@ntu.edu.tw

Christopher P.L. Barkan

Associate Professor

Director – Railroad Engineering Program

Department of Civil and Environmental Engineering

University of Illinois at Urbana-Champaign

1203 Newmark Civil Engineering Laboratory

205 N. Mathews Ave., Urbana IL, USA 61801

Tel: +1- (217) 244-6338

Fax: +1- (217) 333-1924

Email: cbarkan@illinois.edu

ABSTRACT

Many railroad lines are approaching the limits of practical capacity, and the estimated future demand is projected to increase 84% by 2035.   Therefore, identifying a good multiyear capacity expansion plan has become a particularly timely and important objective for railroads. In this research, we have developed an enhanced parametric capacity evaluation tool to assist railroad companies in capacity expansion projects.   This evaluation tool is built upon the CN parametric model by incorporating enumeration, cost estimation, and impact analysis modules. Based on the subdivision characteristics, estimated future demand, and available budget, the proposed tool will automatically generate possible expansion alternatives, compute line capacity and investment costs, and evaluate their impact.   For a particular subdivision, there are two outputs from this decision support tool: (i) a delay-volume plot depicting the delay-volume relationship for each alternative; and (ii) an impact & benefit table showing the impact of the future demand on the subdivision with different upgrading alternatives.   The decision support tool is highly beneficial for budget management of North American railroads.

Keywords: railway system, capacity planning, decision support, optimization, freight, passenger, train, transportation, cost benefit analysis

INTRODUCTION

Railways all over the world are increasingly experiencing capacity constraints.   In North America, railway freight traffic has increased nearly 30% over the past 10 years, and this demand is projected to increase another 84% by 2035 (*1*).   This would not be as important if alternative modes were able to handle the traffic but highway construction is not keeping up with the growth in demand, either.   Even if the capacity was available much rail traffic is not economically transported by truck.   Rail is also generally recognized as safer and more efficient in terms of land-use and energy efficiency.   Therefore, public officials increasingly see rail as an alternative transport mode needed to handle the increasing freight traffic that will accompany sustained economic growth (*1,2*).

Effective capacity management is the key to a railroad company's success but this is a non-trivial task.   On the one hand, capacity planners work on multiyear capacity planning projects aiming to provide enough network capacity to accommodate customers' future demand at a desired service level; on the other hand, they must try and maximize the use of assets (trackage and related infrastructure) because overcapacity may be as harmful as insufficient capacity to company performance.   The first step in capacity management is usually measuring and monitoring capacity and congestion; however, railway capacity is a loosely defined term that has numerous meanings.   In general, it can be stated as a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan (Level of Service (LOS)).   This capacity is highly dependent on a number of infrastructure and operational factors (*3, 4*), such as:

- Length of subdivision
- Siding length, spacing, and uniformity
- Intermediate signal spacing
- Percentage of single, double, or multiple track
- Peak train counts
- Average and variability in operating speed
- Heterogeneity in train types (train length, power to weight ratios)
- Dispatching priorities
- Schedule

Numerous approaches and tools have been developed to determine rail line capacity; however, unlike the highway capacity analysis domain, there is no commonly accepted standard for railway capacity measurement in North America (*5*).   Each model has its strengths and weaknesses and is generally designed for a specific type of analysis (*6*).   Railway capacity tools can be categorized into three groups: (i) theoretical (ii) simulation, and (iii) parametric.   In

general, simulation is best suited to analysis of local-level problems, as it becomes computationally intensive when applied at the network level.   Theoretical models can often be computed manually but are sometimes too simple to be valid for anything more than high-level comparisons.   Parametric capacity models fill the gap between detailed simulation and simple formulae; they focus on key elements of line capacity to quickly highlight "bottlenecks" in the system (3).   Parametric models are suitable for strategic capacity planning because they can account for the dynamic nature of line capacity, and provide system-wide capacity measurement of subdivisions in a rail network.

Two parametric railway capacity models have been developed to help capacity planners manage track assets by measuring track capacity.   Prokopy and Rubin (7) developed the first parametric model for railway line capacity.   Their model uses formulae that reflect train delay or capacity as a function of physical-plant train operations and control systems.   The formula was derived through multi-variable regression analysis of many different simulation runs using the Peat Marwick Mitchell (PMM) model.   Krueger (3) applied a similar method to develop the CN Parametric Line Capacity Model; however, his model was new with different parameters. Simulations were conducted using the in-house tool – Route Capacity Model (RCM) to develop the CN parametric model.

The three most important elements of the CN parametric model that make it particularly useful are: (i) the ability to calibrate each parameter for particular scenarios; (ii) produce a graphical delay versus volume relationship; and (iii) "What-if" ability to quantify the sensitivity to, and significance of parameters individually, and in combination.   However, it does not have the ability to create possible alternatives, estimate the construction cost, and evaluate the tradeoff between capital investment, delay and operating costs.   Thus, there is incentive to develop an enhanced parametric capacity evaluation tool that incorporates these features.   Consequently, we have developed a new decision support model, the Railway Capacity Evaluation Tool (RCET), which built upon the CN parametric model by incorporating enumeration, cost estimation, and impact analysis modules.   Based on subdivision characteristics, estimated future demand, and available budget, RCET is able to help capacity planners generate possible expansion alternatives, compute line capacity and investment costs, and evaluate their impact.

AN ENHANCED PARAMETRIC CAPACITY EVALUATION TOOL

FIGURE 1 demonstrates the decision support process using RCET.   By inputting the link properties, available budget, and estimated future demand, RCET will first enumerate possible expansion alternatives (Enumeration Module), and then compute the cost and capacity increase for each alternative (Cost & Capacity Module) followed by evaluation of the tradeoff between

capital investment and delay cost to determine if each particular capital investment is cost-effective (Impact Analysis Module).   The outputs of RCET will be a graph showing relationship between traffic volume and delay for each alternative, and an impact and benefit table containing a set of options that the capacity planner can use to guide decision making.

One of the most important components inside RCET is the CN parametric model that is located in "Cost and Capacity Computation" and used to determine the delay-volume relationship and line capacity.   In the following sections, we review the CN parametric model, and then describe the three modules in RCET.

Review of CN Parametric Model (*3*)

The CN parametric model provides a system-wide measure of subdivision capacity in a rail network and enables evaluation of the effect of improvements for various alternatives.   The model measures the capacity of a subdivision by predicting its relationship between train delay (hours per trip) and traffic volume (trains per day).   In general, the more trains that run on a subdivision in a given time period, the more delay each train experiences (*7*).   The CN model calculates this relationship using several key parameters that affect the traffic handling capability of a subdivision.   These parameters are categorized into plant, traffic, and operating parameters as follows:

Plant Parameters

• Length of Subdivision (SL)
• Meet and Pass Planning Point Spacing (MPPPS): MPPPS is the mean spacing of locations used to meet or overtake trains, namely siding spacing.   Sidings are crucial for operating bi-directional, mixed priority and different speed trains.   MPPPS for a subdivision is computed as:

$$MPPPS \; = \; \frac{Length \; of \; Subdivision}{(Number \; of \; MPPP \; + \; 1)}$$

• Meet and Pass Planning Point Uniformity (MPPPU): MPPPU is the measure of uniformity in siding spacing (MPPPS).   It is a ratio of the standard deviation versus average siding spacing:

$$MPPPU \ = \ \frac{Standard \ Deviation \ of \ MPPP \ Spacing}{MPPPS}$$

A uniformity value of zero represents a subdivision with equally distributed sidings.   In general, the higher the uniformity of siding spacing, the more the line capacity.

• Intermediate Signal Spacing Ratio (ISSR): Intermediate signals reduce the required headway between adjacent trains thereby increasing line capacity.   This parameter accounts for the ratio of signal spacing to siding spacing.   Te parametric expression for ISSR is:

$$ISSR \ = \ \frac{\left(\dfrac{Length \ of \ Subdivision}{MPPP \ + \ 1 \ + \ \# \ of \ Signals} \right)}{MPPPS} \times 100$$

• Percent Double Track (%DT): Adding a second track has a significant impact on line capacity (more than double the capacity of a single track mainline).   %DT is calculated as the ratio of double track versus the length of the subdivision:

$$\% \ DT \ = \ \frac{Miles \ of \ Double \ Track}{Length \ of \ Subdivision} \times 100$$

Note that the CN parametric model can handle %DT up to 75%; this limit was found to retain the exponential characteristics and fall within the parametric range of most of CN's subdivisions.

Traffic Parameters

• Traffic Peaking Factor (TPF): TPF represents the concentration of traffic within a short time frame (4 hours), often called bunching or peaking.   It has a significant impact on capacity, because when the traffic level is greater than the sustainable capacity, it causes lengthy system recovery time.   TPF is calculated as the ratio between the maximum number of trains dispatched in a 4-hour period versus the average number of trains within the same time duration.

$$TPF \ = \ \frac{Maximum \ Tains \ in \ 4 \ hours}{Average \ Trains \ in \ 4 \ hours}$$

• Dispatching Priority Factor (DPF): Dispatching priorities for different types of trains dictate which trains will experience delay.   Higher priority reduces transit time for higher priority trains by penalizing trains of lower priority.   Generally the greater the number of

priority classes, the less capacity is available.   DPF is quantified using a probability function that calculates the chances of a train meeting another train of a higher priority, which is calculated as:

$$DPF = \frac{1}{T}\sum_{i=2}^{N}\left(\frac{C_i}{(T-1)}\sum_{j=1}^{i-1}C_j\right)$$

Where:

    N = Number of priority classes (passenger, express, freight, and unit)
    T = Daily number of trains
    C_i = Number of ith priority class trains
    C_j = Number of jth priority class trains

• Speed Ratio (SR): Besides DPF, speed ratio is another parameter reflecting the traffic mix over the subdivision.   The difference in speed among trains can significantly increase delay because of overtakes and/or holding trains in yard.   SR is calculated as the ratio of the fastest train speed to the slowest train speed:

$$SR = \frac{Fastest\ Train\ Speed}{Slowest\ Train\ Speed}$$

• Average Speed (AS): Average train speed plays a vital role in line capacity because the higher the train speed the lower the delay and transit time.   AS is measured as the average minimum run time of all trains in each direction, as obtained from a Train Performance Calculator (TPC).

$$AS = \frac{\sum_{i=1}^{N}n_iV_i}{\sum_{i=1}^{N}n_i}$$

Where:

    V_i = Speed of ith class
    n_i = Number of trains in i^{th} class
    N = Total number of classes

Operating Parameters

• Track Outage (TO): Track outage accounts for the planned and unplanned events that take a track out of service.   TO directly reduces the available service time of a subdivision as well as line capacity.   Capacity is sensitive to the occurrence and duration of TO.   This parameter is defined as the number of hours the subdivision is out of service:

$$TO's = \frac{Total\ Duration\ of\ Outages}{\displaystyle\sum_{i=1}^{N} \frac{1}{n_T d_i}}$$

Where:

n_T = Total number of outages per day

d_i = Duration of each outage (hrs)

• Temporary Slow Order (TSO): TSO has a negative impact on line capacity due to: (i) the time loss due to operating at slower than normal speed; and (ii) acceleration and deceleration time (V time).   It is often maintenance related and can be applied to a distance or at a single point on the line.   TSO is computed as follows:

$$TSO = V_{time} + Travel\ Time$$

$$V_{time} = \frac{(V_m K - V_{TSO})}{A} + \frac{(V_m K - V_{TSO})}{D}$$

$$Travel\ Time = \left(\frac{L}{V_{TSO}} + \frac{L}{V_m K} \right) \times 60$$

Where:

V_m = Maximum freight speed (mph)

V_{TSO} = Temporary slow order speed (mph)

K = % of time running at max speed (85%)

A = Acceleration rate (20 mph/min)

D = Deceleration rate (30mph/min)

L = Length of TSO + average train length

The relationships between "delay-volume curve" and "key parameters" were developed based on a series of regression analyses and simulation results from the RCM. The relationship between train delay and traffic volume was found to be best expressed by the following exponential equation:

$$Train\ Delay = A_o e^{B_o V}$$

Where:

A_o = Parametric Plant, Traffic, Operating Coefficient

B_o = Constant

V = Traffic Volume (trains/day)

Coefficient "A_o" depicts the relationship between train delay and the parametric values. "A_o" is a unique value for each combination of parameters defined by the plant, traffic and operating conditions of a subdivision. A different "A_o" will define a new delay vs. volume curve (FIGURE 2). This parametric model was verified by comparing its output to the RCM output of the CN network, and the results show that the accuracy was on average within 10 % (*3*).

The following three sections cover the development of the three modules (Enumeration, Cost & Capacity Computation, and Impact Analysis) in RCET.

Enumeration Module

The purpose of the enumeration module is to automatically generate conventional capacity expansion alternatives for each subdivision being evaluated. In the model described here, three common types of capacity expansion alternatives are built into this module: adding (i) passing sidings, (ii) intermediate signals, and (iii) 2nd main track but other options could be included if desired. For the single track scenario, increasing the number of sidings can reduce meet and pass delay, and shortening block length and the consequent decrease in signal spacing, can reduce the headway between trains, thereby increasing line capacity. Beyond that, according to Rollin Bredenberg (V.P. Service Design at BNSF Railway), if the combined total number of trains in both directions averages 60 trains per day with a peak of 75, double-track must be added to single-track segments (*4, 8*).

For each subdivision, the enumeration module calculates all possible combinations of expansion alternatives until it reaches the limit of minimal siding spacing or maximal number of

signals per spacing specified by the user.   For example, consider a 100-mile subdivision with CTC, nine existing sidings, and no intermediate signals.   The minimum siding spacing is set to eight miles and the maximum number of intermediate signals between sidings is two   The largest number of sidings that can be placed on this subdivision is 11 ($\approx 100/8 - 1$), and the largest number of intermediate signals that can be placed (between two sidings) is two.   TABLE 1 shows the possible alternatives for this example ordered by ascending construction cost. Since adding signals is usually less expensive than adding sidings, these are considered first (up to the limit) before adding another siding; therefore, the first and second alternatives for each signal spacing is to increase the number of intermediate signals by one and by two, respectively. Because two intermediate signals is the upper bound for the siding spacing considered in this example, the next (third) alternative is to increase the number of sidings (by one).

Cost and Capacity Evaluation Module

After the enumeration, the next step is to determine the capacity increase and construction cost of each alternative (FIGURE 1).   For each subdivision, the Cost & Capacity Evaluation Module will first compute the current line capacity based on the existing parameters.   Capacity planners usually have an idea of the current line capacity based on empirical experience.   These empirical values can be used to determine the current LOS by adjusting the acceptable delay to match the capacity values from the delay-volume relationship.   If empirical values are not available, the default setting is to use the maximum trip time of 10 hours or an acceptable delay of 2 hours to calculate the capacity (FIGURE 2) (*3*).   Users can specify their own suitable limits depending on the context in which it is used.

After obtaining the base case (current condition), Cost & Capacity Evaluation Module will then compute the capacity increase of each alternative by changing the plant parameters (e.g. MPPPS & ISR), assuming the traffic and operating parameters remain the same.   The CN parametric model cannot handle subdivisions with %DT more than 75%; consequently, we assigned a capacity of 80 trains per day for a double-track segment according to typical railroad industry freight-railroad practice (*4,8*).

The unit construction cost of each type of expansion option is needed to compute the cost of expansion alternatives.   Users can specify these values in advance or use the default cost estimates.   Three required basic unit costs are: the costs of (i) adding a new siding, (ii) adding a new intermediate signal, and (iii) adding a 2nd main track.   The default cost estimates are based on recent information provided by railroads and engineering consulting companies.   These values serve as the general average case considering the need for new tracks, signals, and bridges, but do not include the cost of land acquisition or environment permitting.   For a new

12,000-foot passing siding, a cost of $4,870,000 for track work and civil infrastructure was assumed.   For territory with an existing CTC signal system, the cost of signalizing a newly constructed siding within this territory would be $300,000 for each end of the siding or $600,000 total.   Therefore, the first required unit cost, adding a signalized passing siding, is $5,470,000. Within existing CTC territory, the cost of a new intermediate signal point (i.e. one signal in each direction) is approximately $100,000 (second required unit cost).   And, the third required unit cost, that of adding the 2nd main track, is $2,250,000 per mile.

TABLE 2 lists the alternatives for the subdivision.   Capacity planners would review these alternatives during the decision process, and they can remove inadequate alternatives or add additional ones based on their experience and judgment.

Both the enumeration module and the cost and capacity evaluation module can be combined and summarized into the following analytical steps:

Step 1: Obtain the following input data from existing track condition or users:

> <u>*Existing Number of Sidings and Signals*</u>
> <u>*Limit of Siding Spacing (DL)*</u>
> <u>*Limit of Signal Spacing (GL)*</u>

Step 2: Use two loops to enumerate possible expansion alternatives and evaluate their impact:

> *Loop 1 (add additional sidings from zero to DL)*
> > *Loop 2 (add additional signals from zero to GL)*
> > > *Adjust CN parameters according to change(s) in sidings and signals*
> > > *Develop the new Delay-Volume Curve for the expansion alternative*
> > > *Compute the additional capacity and cost from the alternative*
> > *End of Loop 2*
> *End of Loop 1*

Step 3: Create the Expansion Alternatives Table (TABLE 2)

Step 4:   Overlap the delay-volume curves for possible expansion alternative (FIGURE 3)

Impact Analysis Module

Based on TABLE 2, it is intuitive for capacity planners to select the alternative providing just enough capacity because this option requires the least expenditure to meet the future demand if LOS is to remain the same.   However, this selection may not be the best option.   Since capacity is defined by a particular service level, it is possible to run more trains per day if LOS is reduced.   For example, in FIGURE 4a, the solid exponential curve represents the general delay-volume relationship for the existing infrastructure, whereas the dashed curve depicts the

delay-volume relationship with upgraded infrastructure.   With the same LOS, the upgraded infrastructure can provide more capacity than the existing track.   However, it is also possible to gain additional capacity by reducing the LOS (increasing delay) (FIGURE 4b).   Line capacity is increased by increasing delay along the delay-volume curve of the existing infrastructure. Consequently, an impact analysis is essential to find the best option to upgrade the infrastructure.

The impact analysis module evaluates whether the capital investment is cost-effective by comparing the "delay cost" to the "capital investment".   The "delay cost" depends on the impact of adding additional demand to the existing track layout without upgrading the infrastructure.   According to the new demand for each link, the increase in delay can be determined using the delay-volume curve (FIGURE 4b).   We can then compute the delay cost as the product of total delay hours, and unit delay cost per hour.   From an operational point of view, the unit delay cost can be calculated by summing four components: (i) unproductive locomotive cost; (ii) idling fuel cost; (iii) car/equipment cost; and (iv) crew cost.   A recent estimate of delay cost for one Class 1 railroad is approximately $261 per train-hour (*9*).   This estimation is conservative because a more comprehensive delay calculation would include downstream costs of missed connections, loss of future revenue, extra costs from missing just in time (JIT) services, etc.

The "capital investment" of each alternative is the output of the cost estimation module. To compare delay cost and capital investment in the same duration base (year), we further defined an attribute, annual net investment, as the total construction cost of the alternative (TABLE 2) divided by the infrastructure life (~20 years).   It is based on the life cycle cost analysis (LCCA) method commonly used for multiyear capacity planning projects (*10,11,12,13,14*).   Finally, we rank the alternatives based on the benefit as defined by annual delay cost divided by the annual net investment cost.   Benefit is similar to the idea of return on investment representing how much delay cost can be reduced per unit investment in the infrastructure.   A benefit value less than 1 means the investment is not cost effective because the return on investment is negative.   The output of the Impact Analysis Module is a table showing the construction cost, delay cost, and benefit for each link subject to capacity expansion. This expansion benefit table can be provided to capacity planners for use in decision-making.

Following is a summary of the analytical steps in the impact analysis module:

Step 1: Obtain <u>*Capital Investment*</u> *and delay-volume relationship for each alternative from Cost & Capacity Evaluation Module.*

Step 2: Based on the estimated future demand (<u>*Number of Trains*</u>), determine the <u>*Average Delay*</u> for each alternative using the delay-volume relationship.

Step 3: Compute the Following Attributes for each alternative:

<u>*Total Delay*</u> = the product of <u>*Average Delay*</u> and <u>*Number of Trains*</u>

>   *Reduced Delay* = *the difference between its* Total Delay *and the* Total Delay *of*
>   *alternative 1 (do-nothing scenario)*
>   Annual Delay Saving = *the product of* Reduced Delay *and 365 (days per year)*
>   Annual Net Investment = Capital Investment *divided by 20 (infrastructure life)*
>   *Benefit* = Annual Delay Saving *divided by* Annual Net Investment.

    Step 4:   *Generate the impact & benefit table by ranking alternatives by their* Benefit.

EMPIRICAL APPLICATION

To demonstrate the potential use of the capacity evaluation tool, the same subdivision described above (100-mile, 9 sidings, no intermediate signals) was analyzed and presented here. TABLE 3 summarizes the subdivision's key parameters computed based on its track and traffic characteristics.   For this application, the subdivision's current capacity is about 30 trains per day, and the estimated future demand is 37 trains per day, so the question is how to increase capacity by 7 trains per day.

According to the input data in TABLE 3, RCET generates possible expansion alternatives by adding sidings or intermediate signals with their increases in capacity and construction cost (TABLE 2).   With the same LOS, Alternative 6 is the best option because it is able to accommodate 7 more trains per day with the least construction cost.   However, it is also possible to gain additional capacity by reducing the LOS (increasing delay) (FIGURE 4b).   In order to identify the true optimal solution, we conducted an impact analysis of possible alternatives (Alternatives 1 ~ 9).   The double track option (alternative 10) is ignored here due to the large difference between demand and supply.

Delay-Volume Plot

The first output of RCET is the delay-volume plot representing the impact on capacity for each alternative (FIGURE 3).   Since each alternative represents a specific infrastructure setting, it can be depicted by a unique delay-volume relationship.

The delay-volume plot helps users determine the additional capacity provided by each alternative with a specific LOS (=acceptable delay).   It also demonstrates what the capacity will be if the threshold for acceptable LOS is increased or decreased.   For example, the capacity of alternative 1 is 30 trains per day with a 2-hour average delay, 17 trains per day with 1-hour delay, and 38 trains per day with 3-hour average delay.   Among the different alternatives, the larger the difference between two alternatives, the greater the difference in capacity performance will be.   For instance, there is a substantial difference between Alternative 1 and any of the other

alternatives; whereas, the difference in capacity between alternatives 2 and 4 is negligible.

Impact and Benefit Table

The second output of RCET is the impact and benefit table (TABLE 4) created from the impact analysis module. For each alternative, average delay is obtained according to its delay-volume relationship. Alternative 1 is the base case scenario representing the current track layout; therefore, the reduced delay of each alternative is computed as the difference between its total delay and that of alternative 1. The annual delay savings is the product of reduced delay and number of days per year. Finally, alternatives are ranked by their benefit, which is calculated by dividing annual delay savings by annual net investment.

Table 4 provides assistance to capacity planners, in their final decision making based on available budget. In this example, alternative 2 provides the greatest benefit because it offers substantial delay reduction with relatively lower expense compared to other alternatives. However, alternative 2 still may not be acceptable because the average delay is 25% below the desired LOS. The differences in both benefit and average delay in alternatives 5 or 6 are relatively small; so, the decision maker may choose alternative 5 to reduce capital expenditures.

DISCUSSION – NETWORK ANALYSIS

An example of using RCET to conduct alternatives generation, cost and capacity computation, and impact analysis of a studied subdivision is presented above. RCET can efficiently process a subdivision within seconds so this application can be expanded to the network level if necessary. For each subdivision in the studied network, the new capacity evaluation tool will produce a delay-volume plot and an impact and benefit table. Capacity planners can use these to evaluate possible alternatives and identify the best option at the subdivision level.

After completing this process for all subdivisions, planners need to conduct traffic assignment again because the network traffic pattern (i.e. route selections of trains) after the capacity expansion may differ from the original plan. Routing the traffic will assess the fluidity of the proposed system. A possible routing technique would be a multicommodity flow network model (*15*) that can be formulated as:

Minimize Transportation Cost + Maintenance of Way Cost
Subject to:
    Capacity Constraint for Each Subdivision

Flow Conservation Constraint for Each Node in the Network

The objective function in the optimization model is to minimize the expenditures required to route traffic between various origins and destinations.   It is subject to line capacity constraints such that the total traffic on a subdivision must be less than or equal to its designed capacity. The flow conservation constraint guarantees that the final routing plan fulfills the estimated future demand.

The goal of a multiyear capacity planning project should be to accommodate the estimated future demand while minimizing net present value of the capital expenditure plus operating costs due to transportation, maintenance of way, and delay costs.   Since this procedure is a two-level process, it may take multiple iterations to reach the system optimum.

CONCLUSION AND FUTURE WORK

Many railroad lines are approaching the limits of their practical capacity; therefore, identifying optimal multiyear capacity expansion plans have become a particularly timely and important objective for railroads.   The CN parametric model used in this analysis accounts for the dynamic nature of capacity and provides a system-wide measure of subdivisions in a rail network.   However, a limitation of the current version is that it is designed for a single track network.   It does not take into account multiple-track scenarios (e.g. crossovers), and/or other different operational practices (e.g. directional running).   In addition to identifying areas of limited or excess capacity, capacity tools serve as the baseline evaluation instrument for many other complicated optimization models, such as railway scheduling optimization tools for solving train, crew, and locomotive scheduling problems.   The better the user can assign the right capacity value, the better the optimal plan can be created from those tools.

The railway parametric capacity evaluation tool (RCET) described here can assist capacity planners to develop such plans.   RCET accounts for network characteristics, estimated future demand, and available budget, and automatically generates candidate expansion alternatives, computes their line capacity benefits and investment costs, and compares their impact.   This decision support tool can be used to maximize the capacity benefits that North American railroads will derive from their investment.

Besides use in the private sector, this capacity evaluation tool can also be useful to public agencies helping them set regional or national transportation priorities and investment plans. Therefore, we plan to develop a standard, comprehensive railway parametric capacity model. Such a model could assist public and private financing of rail capacity investment by determining the magnitude, cost, and type of capacity improvements needed for the desired

service(s).

ACKNOWLEDGMENTS

REFERENCES

1.   American Association of State Highway and Transportation Officials (AASHTO) *Transportation - Invest in Our Future: America's Freight Challenge*, AASHTO, Washington, DC, 2007.

2.   Transportation Research Board (TRB)   Research to Enhance Rail Network Performance: A Workshop [online].   [Accessed March 3, 2009].   Available from World Wide Web: <http://trb.org/conferences/railworkshop/>

3.   Krueger, H.   Parametric Modeling in Rail Capacity Planning, *Proceedings of Winter Simulation Conference*, Phoenix, AZ, 1999.

4.   Vantuono, W. C.   Capacity is Where You Find It: How BNSF Balances Infrastructure and Operations, *Railway Age*, Feb-01, 2005.

5.   Abril, M., Barber F., Ingolotti L., Salido M.A., Tormos P., and Lova A.   An Assessment of Railway Capacity, *Transportation Research Part E*, Vol. 44, Issue 5, 774-806, 2008.

6.   Martland C.D., and Hutt G.   *Analysis of Potential Approaches to Interline Capacity Flow Management*, RaiLinc, Cary, NC, 2005

7.   Prokopy, J. C., and Rubin, R.B.   *Parametric Analysis of Railway Line Capacity*, DOT-FR-5014-2, Federal Railroad Association, U.S. Department of Transportation, Washington, DC, 1975.

8.   Association of American Railroads (AAR)   *National Rail Freight Infrastructure Capacity and Investment Study*, AAR, Washington, DC, 2007.

9.   Lai, Y.C.   *Increasing Railway Efficiency and Capacity through Improved Operations, Control and Planning*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, 2008.

10. Zoeteman, A., and Esveld, C.   Evaluating Track Structures: Life Cycle Cost Analysis as a Structured Approach, *Proceedings of World Congress on Railway Research*, Tokyo, Japan, 1999.

11. Viet, P.   Track Maintenance based on Life-Cycle Cost Calculations, *Innovations for a Cost Effective Railway Track*, 6–13, 2002.

12. Lee, D.B., Jr.   Fundamentals of Life-Cycle Cost Analysis, *Transportation Research*

Record, Vol 1812, 203–210, 2002.

13. Ozbay, K., Jawad, D., Parker, H., and Hussein, S.   Life Cycle Cost Analysis: State-of-the-Practice vs. State-of-the-Art, *Transportation Research Record*, Vol 1864, 62-70, 2004.

14. Ling, D.J., Roy, R., Shehab, E., Jaiswal, J., and Stretch, J.   Modelling the Cost of Railway Asset Renewal Projects using Pairwise Comparisons, *Journal of Rail and Rapid Transit*, Vol. 220, 331–346, 2006.

15. Ahuja, R.K., Magnanti, T.L., and Orlin, J.B.   *Network Flows: Theory, Algorithms, and Applications*, Prentice Hall, New Jersey, 1993.

LIST OF TABLES

LIST OF FIGURES

TABLE 1 Possible Capacity Expansion Alternatives for a Hypothetical 100-mile Subdivision

Alternatives	Sidings	Signals/Spacing
1	+ 0	+ 0
2	+ 0	+ 1
3	+ 0	+ 2
4	+ 1	+ 0
5	+ 1	+ 1
6	+ 1	+ 2
7	+ 2	+ 0
8	+ 2	+ 1
9	+ 2	+ 2
10	Adding 2nd Main Track	

TABLE 2 Expansion Alternatives with Construction Cost and Capacity Increase

Alternatives	Sidings	Signals/Spacing	Capacity (trains/day)	Cost (k)	Cost/Train
1	+ 0	+ 0	+ 0	$0	$0
2	+ 0	+ 1	+ 3	$1,000	$333
3	+ 0	+ 2	+ 4	$2,000	$500
4	+ 1	+ 0	+ 3	$5,470	$1,823
5	+ 1	+ 1	+ 6	$6,570	$1,095
6	+ 1	+ 2	+ 7	$7,670	$1,096
7	+ 2	+ 0	+ 6	$10,940	$1,823
8	+ 2	+ 1	+ 9	$12,140	$1,349
9	+ 2	+ 2	+ 10	$13,340	$1,334
10	Adding 2nd Main Track		+ 50	$204,750	$4,095

TABLE 3   Key Parameters of the Selected Subdivision

SL	MPPPS	MPPPU	ISS	%DT	TPF	DPF	SR	AS	TO	TSO
100 miles	20	0.3	1	0.04	1.62	0.344	1.44	30 mph	0	0

TABLE 4   The Impact & Benefit Table from Upgrading Infrastructure

	Average Delay (hours/train/day)	Total Delay (hours/day)	Reduced Delay (hours/day)	Annual Delay Savings ($/year)	Annual Net Investment ($/year)	Benefit
Alt 1	2.8	104	0	0	0	N/A
Alt 2	2.5	93	11	1,057,442	50,000	21.1
Alt 3	2.3	85	19	1,762,403	100,000	17.6
Alt 5	2.1	78	26	2,467,364	328,500	7.5
Alt 6	2*	74	30	2,819,844	383,500	7.4
Alt 9	1.7	63	41	3,877,286	667,000	5.8
Alt 8	1.8	67	37	3,524,805	607,000	5.8
Alt 4	2.4	89	15	1,409,922	273,500	5.2
Alt 7	2.1	78	26	2,467,364	547,000	4.5

* Current LOS = Acceptable Delay = 2 (hours/train/day)
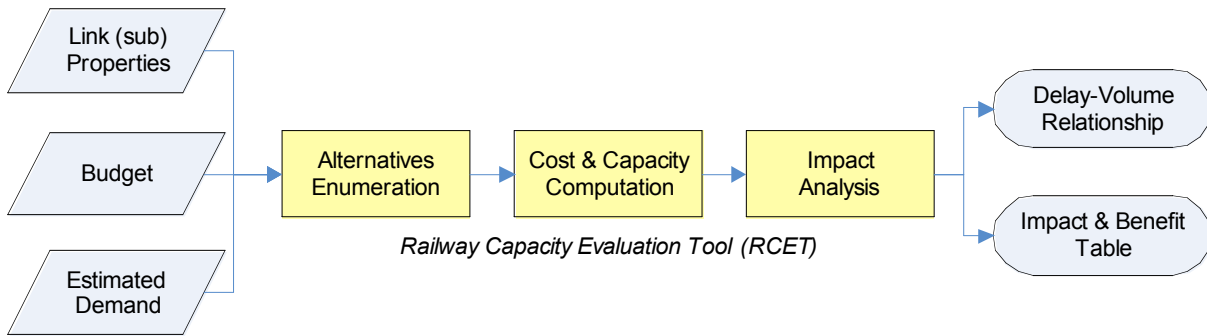
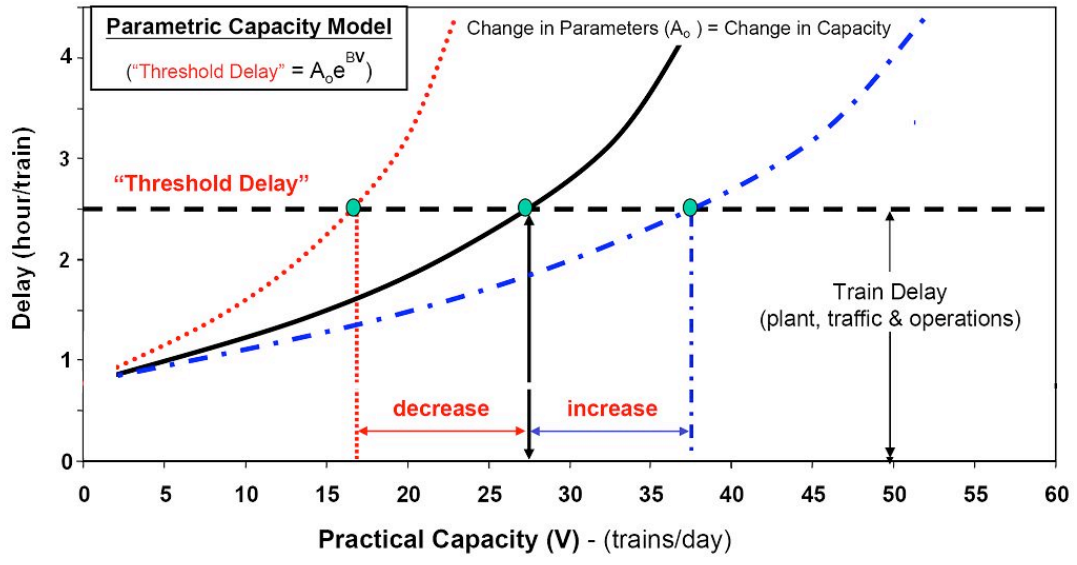**FIGURE 1   Decision support process using the Railway Capacity Evaluation Tool (RCET)**

FIGURE 2   Delay-volume curve from CN parametric model (*3*)

FIGURE 3   Delay-volume plot from RCET

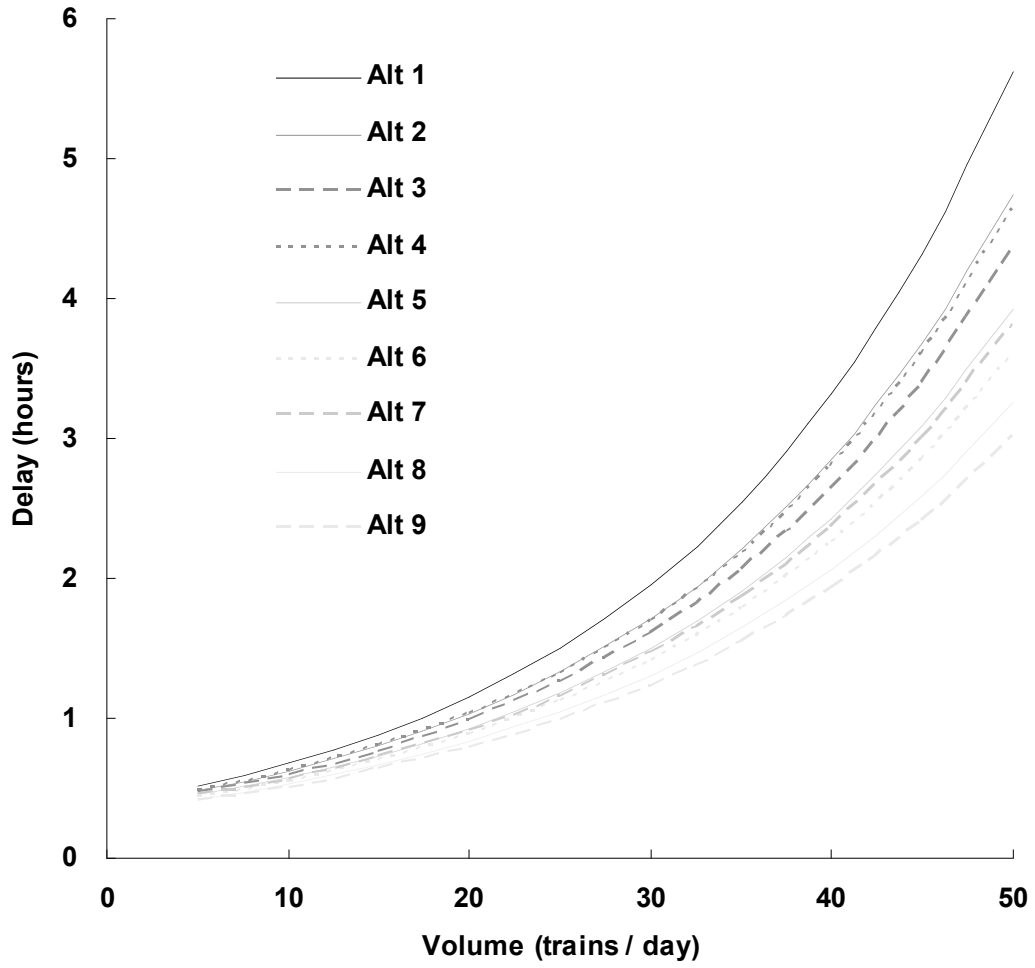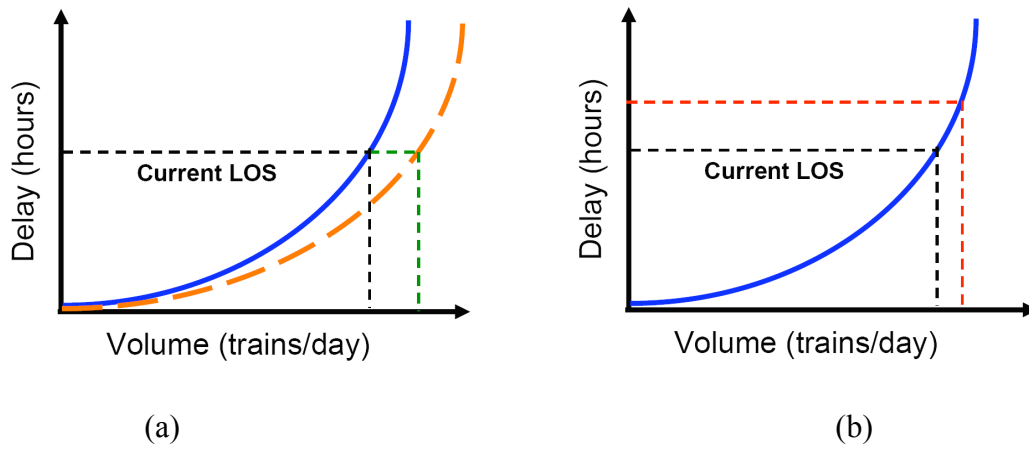(a)   (b)

FIGURE 4   Increase volume by (a) upgrading infrastructure (b) lowering LOS