Enhanced Parametric Railway Capacity Evaluation Tool

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Many railroad lines are approaching the limits of practical capacity, and 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. An enhanced parametric capacity evaluation tool has been developed to assist railroad companies in capacity expansion projects. This evaluation tool is built on the Canadian National Railway Company 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: a plot that depicts the delay–volume relationship for each alternative and an impact and benefit table that shows 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.

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 growth in demand would not be as significant 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 were available, much rail traffic cannot be 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 it is not a 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 to 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, known as 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; and
- 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: theoretical, simulation, and parametric. In general, simulation is best suited to analysis of local problems because 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 formulas; 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 systemwide 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 formulas that reflect train delay or capacity as a function of physical plant train operations and control systems, which were derived through multivariable regression analysis of many different simulation runs using the Peat Marwick Mitchell model. Krueger (*3*) applied a similar method to develop the Canadian National Railway Company (CN) parametric line capacity model; however, his model was new with different parameters. Simulations were conducted using an in-house tool, the route capacity model (RCM), to develop the CN parametric model.

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The three most important elements of the CN parametric model that make it particularly useful are (*a*) the ability to calibrate each parameter for particular scenarios; (*b*) the ability to produce a graphical delay versus volume relationship; and (*c*) a 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 trade-offs among capital investment, delay, and operating costs. Thus, there is incentive to develop an enhanced parametric capacity evaluation tool that incorporates these features. Consequently, the authors 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. On the basis of 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.

ENHANCED PARAMETRIC CAPACITY EVALUATION TOOL

Figure 1 shows 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 and capacity evaluation module), followed by evaluation of the trade-off 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 of RCET is the CN parametric model, which is located in the cost and capacity evaluation module and is used to determine the delay–volume relationship and line capacity. In the following sections, the CN parametric model is reviewed, and then the three RCET modules are described.

Review of CN Parametric Model

The CN parametric model (*3*) provides a systemwide 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.

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 bidirectional, mixed priority, and different speed trains. MPPPS for a subdivision is computed as

$$\text{MPPPS} = \frac{\text{SL}}{(\text{number of MPPP} + 1)}$$

- 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:

$$\text{MPPPU} = \frac{\text{SD of MPPPS}}{\text{MPPPS}}$$

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. The parametric expression for ISSR is

$$\text{ISSR} = \frac{\left(\dfrac{\text{SL}}{\text{MPPP} + 1 + \text{no. of signals}}\right)}{\text{MPPPS}} \times 100$$

- 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 SL:

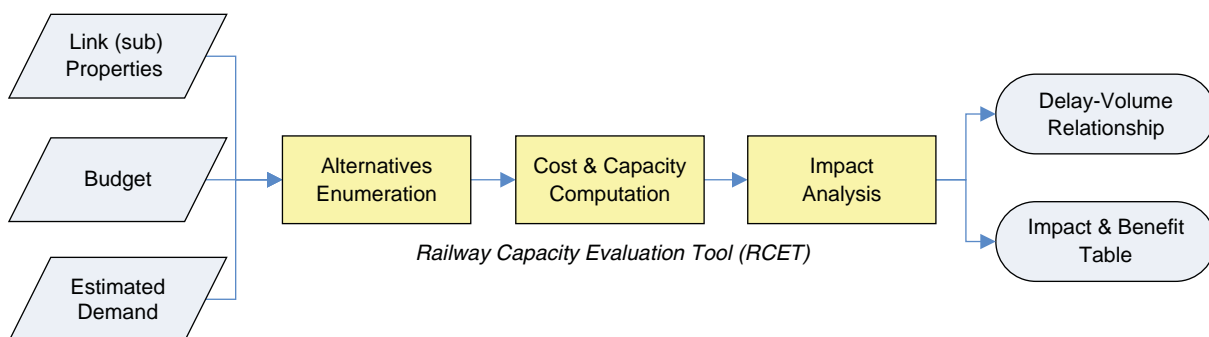$$\% \text{DT} = \frac{\text{miles of double track}}{\text{SL}} \times 100$$

FIGURE 1   Decision support process using RCET.

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 h), 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-h period versus the average number of trains within the same time duration.

$$TPF = \frac{\text{maximum trains in 4 h}}{\text{average trains in 4 h}}$$

• 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, and
- C_j = number of jth priority class trains.

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

$$SR = \frac{\text{faster train speed}}{\text{slowest train speed}}$$

• 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.

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

where

- V_i = speed of ith class,
- n_i = number of trains in ith class, and
- 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:

$$TO = \frac{\text{total duration of outages}}{\sum_{t=1}^{N}\frac{1}{n_Td_i}}$$

where n_T is the total number of outages per day and d_i is the duration of each outage (h).

• Temporary slow order (TSO). TSO has a negative impact on line capacity because of the time loss from operating at slower than normal speed, and 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:

$$TSO = V_{\text{time}} + \text{travel time}$$

$$V_{\text{time}} = \frac{(V_mK - V_{\text{TSO}})}{A} + \frac{(V_mK - V_{\text{TSO}})}{D}$$

$$\text{travel time} = \left(\frac{L}{V_{\text{TSO}}} + \frac{L}{V_mK}\right) \times 60$$

where

- V_m = maximum freight speed (mph),
- V_{TSO} = TSO speed (mph),
- K = % of time running at max speed (85%),
- A = acceleration rate (20 mph/min),
- D = deceleration rate (30 mph/min), and
- L = length of TSO + average train length.

The relationships between the delay–volume curve and key parameters were developed on the basis of 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:

$$\text{train delay} = A_oe^{B_oV}$$

where

- A_o = parametric plant, traffic, operating coefficient,
- B_o = constant, and
- 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 versus volume curve (Figure 2). This parametric model was verified by comparing its output with 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 and capacity evaluation, and impact analysis) in RCET.
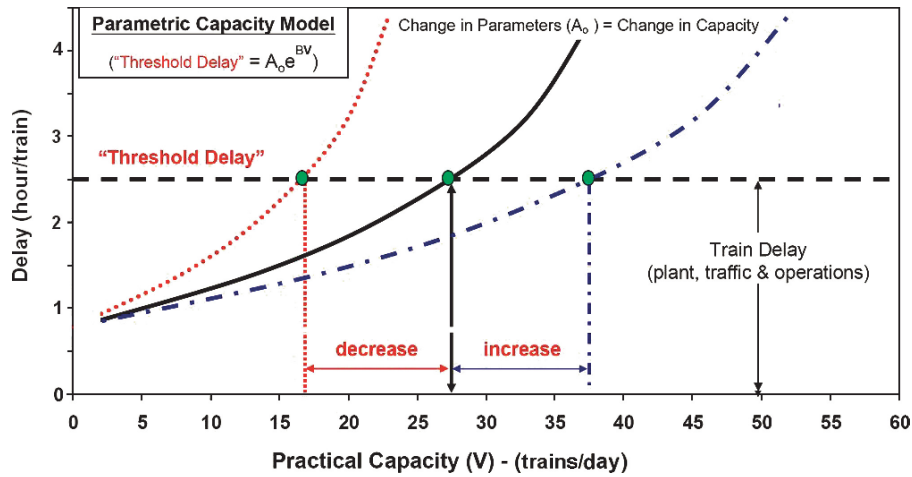
FIGURE 2   Delay–volume curve from CN parametric model (*3*).

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 passing sidings, intermediate signals, or a second 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, Vice President of Service Design at Burlington Northern Santa Fe 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 minimum siding spacing or maximum number of signals per spacing specified by the user. For example, consider a 100-mi subdivision with centralized traffic control (CTC), nine existing sidings, and no intermediate signals. The minimum siding spacing is set to 8 mi 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 alternative 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 and capacity evaluation module will first compute the current line capacity on the basis of 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 h or an acceptable delay of 2 h to calculate the capacity (Figure 2) (*3*). Users can specify their own suitable limits, depending on the context.

After obtaining the base case (current condition), the cost and capacity evaluation module will then compute the capacity increase of each alternative by changing the plant parameters (e.g., MPPPS and ISSR), assuming the traffic and operating parameters remain the same. The CN parametric model cannot handle subdivisions with %DT more than 75%; consequently, the authors assigned a capacity of 80 trains per day for a double-track segment, according to typical 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.

TABLE 1   Possible Capacity Expansion Alternatives for Hypothetical 100-mi Subdivision

Alternative	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	

Three required basic unit costs are adding a new siding, a new intermediate signal, and a second 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-ft 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 second 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 could remove inadequate alternatives or add additional ones according to their experience and judgment.

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

Step 1. Obtain the following input data from existing track condition or users: existing number of sidings and signals, limit of siding spacing (DL), and limit of signal spacing (GL).

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. Because 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). The delay cost can then be computed 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: unproductive locomotive cost, idling fuel cost, rail car and equipment cost, and 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 services, and the like.

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), the authors 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 method commonly used for multiyear capacity planning projects (10–14). Finally, the alternatives were ranked on the basis of the benefit as defined by annual delay cost divided by the annual net investment cost. Benefit is similar to

TABLE 2   Expansion Alternatives with Construction Cost and Capacity Increase

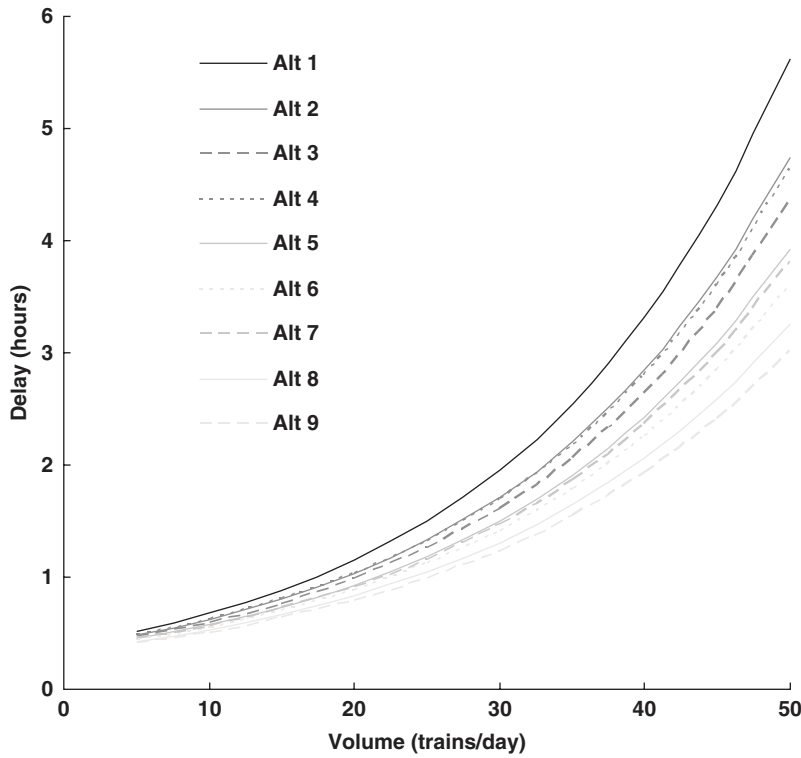| Alternative	Sidings	Signals–Spacing	Capacity (trains/day)	Cost ($)	Cost/Train ($)
1	+0	+0	+0	0	0
2	+0	+1	+3	1,000,000	333,000
3	+0	+2	+4	2,000,000	500,000
4	+1	+0	+3	5,470,000	1,823,000
5	+1	+1	+6	6,570,000	1,095,000
6	+1	+2	+7	7,670,000	1,096,000
7	+2	+0	+6	10,940,000	1,823,000
8	+2	+1	+9	12,140,000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

FIGURE 3   Delay–volume plot from RCET.

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 one 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 capital investment and delay–volume relationship for each alternative from cost and capacity evaluation module.

Step 2. Based on the estimated future demand (number of trains), determine the average delay for each alternative using the delay–volume relationship.

Step 3. Compute the following attributes for each alternative:
   –Total delay = the product of average delay and number of trains,
   –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), and
   –Benefit = annual delay saving divided by annual net investment.
Step 4. Generate the impact and 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 mi, nine sidings, no intermediate signals) was analyzed. The list below summarizes the subdivision's key parameters computed based on its track and traffic characteristics:

- SL: 100 mi,
- MPPPS: 20,
- MPPPU: 0.3,
- ISSR: 1,
- %DT: 0.04,
- TPF: 1.62,
- DPF: 0.344,
- SR: 1.44,
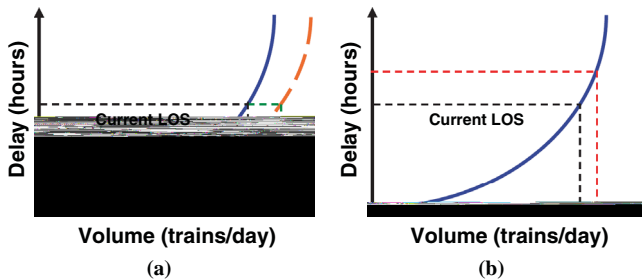- AS: 30 mph,
- TO: 0, and
- TSO: 0.

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 seven trains per day.

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

According to the input data listed above, 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 seven 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). To identify the true optimal solution, an impact analysis was conducted of possible alternatives (Alternatives 1–9). The double track option (Alternative 10) is ignored here because of 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-h average delay, 17 trains per day with 1-h delay, and 38 trains per day with 3-h 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 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 3) 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 3 provides assistance to capacity planners in 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 with the 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 and 6 are relatively small, so the decision maker may choose Alternative 5 to reduce capital expenditures.

DISCUSSION OF NETWORK ANALYSIS

An example of using RCET to generate alternatives, compute cost and capacity, and analyze impact of a studied subdivision is presented in this paper. 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, which capacity planners can use 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 follows: minimize transportation cost + maintenance of way cost, subject to capacity constraint for each subdivision and 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. Because this procedure is a two-level process, it may take multiple iterations to reach the system optimum.

TABLE 3   Impact and Benefit Table from Upgrading Infrastructure

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

[a]Current LOS = acceptable delay.
[b]N/A = not applicable.

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 systemwide 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) 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.

RCET can assist capacity planners in developing such plans. RCET accounts for network characteristics, estimated future demand, and available budget, and automatically generates 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, the authors 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 services.

ACKNOWLEDGMENTS

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