Estimation of Railroad Capacity Using Parametric Methods

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This paper reviews different methodologies used for railroad capacity estimation and presents a user-friendly method to measure capacity. The objective of this paper is to use multivariate regression analysis to develop a continuous relation of the discrete parameters identified for capacity estimation. The algorithm developed in this paper can be used for managerial decision making regarding railroad capacity by various state agencies and state DOTs. This paper illustrates the relationship between the parameters and section capacities, which can be used to improve the throughput of the transportation system. The paper also illustrates the application of the model to estimate capacity of a statewide railroad network.

INTRODUCTION

A major concern for transportation planners and many decision makers is whether or not the nation's freight transportation system, especially the freight railroad system, can keep pace with the expected growth of the economy for the next 20 years. The freight rail system carries 16% of the nation's freight by tonnage, accounting for 28% of total ton-miles and 40% of intercity ton-miles (Cambridge Sytematics 2003). If there is no growth in railroad capacity by 2020, there will be a shift of about 900 million tons of freight and 31 billion truck vehicle miles of travel (VMT) to the nation's highways (Cambridge Sytematics 2003). Assessing freight railroad capacity and its flexibility to accommodate the increased demand of freight transport seems to be an urgent requirement for transportation planners. As infrastructure expansion is an expensive and long term proposition, optimizing available infrastructure resources would be an important goal for transportation planners and decision makers.

There are two methods for estimating railroad capacity: analytical and simulation. This paper reviews literature, on both techniques, for the estimation of freight railroad capacity. Analytical and simulation methods each have their advantages and shortcomings, but these methods can be integrated to give better results (Pachal and White 2004). The vast majority of literature on railroad capacity refers to the train-dispatching computer simulation model developed by Peat, Marwick, Mitchell and Co. (Prokopy and Rubin 1975). This research, undertaken by Prokopy and Rubin (1975) under a Federal Railroad Administration (FRA) grant, examines the relationship between railroad capacity and different operating parameters, such as speed, siding spacing, signal spacing, and siding capacity. The Prokopy and Rubin (1975) research was the foundation for other research in railroad capacity. The parametric capacity model in the Prokopy and Rubin (1975) study looks at capacity from a perspective different from that of theoretical capacity. In the Prokopy and Rubin (1975) study, delay is used as a primary component of capacity measurement. Computer software developed by the Canadian National Railroad for faster estimation of railroad capacity is based on the research done by Prokopy and Rubin (1975). Neither this software, developed by the Canadian National Railroad, nor its results, are available to the public.

The objective of the paper is to gain insight into the Prokopy and Rubin study. The contribution of the paper to the literature is the development of a computer algorithm to measure railroad section[1] capacity that would be available to state DOTs and other state agencies for planning and managerial decision making. This algorithm can be part of a decision support system that can be used to identify bottlenecks and measure system capacity of a railroad network. In this study multivariate regression

analyses is used to develop a continuous relationship between railroad capacity and various parameters affecting capacity.

LITERATURE REVIEW

Hyman (1998) estimates railroad capacity for two major subtypes: transit railroad capacity and freight railroad capacity. Hyman (1998) states that for freight rail, trains per day are a more appropriate measure of capacity, unlike transit capacity, which is measured in trains per hour. The Hyman (1998) report refers to the work done by Prokopy and Rubin (1975), where a simulation model was developed to estimate capacity based on different parameters associated with train movement (Hyman 1998).

In a freight corridor capacity study for the Upper Midwest, the Prokopy and Rubin (1975) method is used to estimate capacity (Srimantula 1999). In this study the parametric method, as proposed by Prokopy and Rubin (1975), serves as an effective tool for capacity estimation. The findings of this research indicate that the most important factors for determining capacity are number of tracks and operating speed. This paper also states that a double track experiences less delay than a single track.

A parametric model similar to the one used by Prokopy and Rubin (1975) is used by the Canadian National (CN) Railway to assess railroad capacity (Krueger 1999). In this CN model, similar to that in the Prokopy and Rubin (1975) model, delay is used as a measure of capacity. A Windows-based user-interface is developed in the CN model for quick and easy capacity estimation of railroad subdivisions.[2] The inputs required to run the model are divided into three categories of parameters, namely plant, traffic, and operational. The plant parameters include length of subdivision,[3] meet pass planning point spacing,[4] meet pass planning point uniformity,[5] intermediate signal spacing ratio,[6] and percentage of double track.[7] The traffic parameters consist of traffic peaking factor,[8] priority probability,[9] speed ratio,[10] and average minimum run time.[11] The operating parameters are track outages,[12] temporary slow orders,[13] train stop time, and maximum trip time threshold.[14]

White (2006) examined the suitability of delay as a measure of capacity. He is of the opinion that delay is not a suitable indicator of capacity. In his paper, White (2006) states that time is a better indicator of capacity than delay. He mentions that a blocking time[15] diagram is an efficient method of capacity estimation.

Capacity estimation research can be divided into analytical research and simulation research. Blocking time theory is an analytical approach to estimation of capacity. Blocking time has its advantages and disadvantages (Pachal and White 2004). A big advantage of the blocking time method is the detailed evaluation of a line or section and identification of the critical location of delay. In this paper, the author believes that building a blocking time model is less complex than a simulation model, but a blocking time model works only on the scheduling level and cannot evaluate running operation. Pachal and White (2004) also point out that the blocking time method can be used in conjunction with a simulation model.

A paper by Leilich (1998) discusses the applicability of simulation models in capacity estimation. Leilich (1998) discusses four basic types of rail operation simulation models, namely, the route seeking models, optimization models, computer assisted dispatching models, and event-based simulation models.

DIFFERENT MEASURES OF RAILROAD CAPACITY

The railroad capacity concept can be broadly categorized as transit railroad capacity and freight railroad capacity (Hyman 1998). Railroad transit includes commuter rail line, urban rapid transit,[16] street cars, and light rail transit. Station and line haul are linear facilities,[17] and capacity of the combination will be the minimum capacity of the link or the station (Transportation Research Board 2000). Transit capacity is dependent upon the number of passengers who can be accommodated in a

car and the number of cars in a train. Capacity also depends on the acceleration and deceleration of the train. Lang and Soberman (1964) included the loading coefficient of passengers[18] in their transit rail capacity equation. Unlike transit rail capacity, which is measured in number of passengers per hour in one direction, freight rail capacity is measured in trains per day. Oftentimes, planners who have to relate the traffic forecast in tons per year to train requirement measure freight rail capacity in tons/day.

Capacity measure of transit and freight railroad can be theoretical and practical. Theoretical railroad capacity is calculated for idealized conditions, which are a) trains operated at the same speed, b) train movement is one direction only, and c) there is no significant grade which would result in variation of train speed. Under these conditions, the capacity is the number of hours of train operation divided by the time headway.[19] In this idealized situation, the maximum line throughput is the measure of the capacity of the track.

$$\text{Throughput}_{max} = \frac{24V}{L_B\,(N_S - 1) + L_t}$$

where:

L_B = Block length[20] (in miles)
L_t = Train Length (in miles)
N_S = Number of signal aspects[21]
V = Speed (in miles per hour)

The American Railway Engineering and Maintenance of Way Association (AREMA) (1998) presents capacity equations in the Manual for Railway Engineering. The AREMA equation of the theoretical capacity of a line segment is:

$$C_t = \frac{T \times N}{H_n}$$

T = Number of time units in the period for which capacity is being calculated.
N = Number of directions run on a single track.
H_n = Maximum gross headway[22] in N directions.

The idealized conditions assumed for the estimation of theoretical capacity is realistically not possible for any actual scenario. Practical capacity is a more sensible measurement of the number of trains that can actually move through a track with an acceptable amount of delay, level of service, and reliability. According to AREMA, practical rail-line capacity for freight operation can be expressed as:

$$C_p = C_t \times E$$

C_p = Practical line segment capacity
C_t = Theoretical line segment capacity
E = Dispatching efficiency for line segment

The dispatching efficiency depends on a) type of signal, b) type of traffic, c) class of line, and d) terrain. A study by Kraft (1982) states that practical capacity is 60-70% of theoretical capacity.

Krueger (1999) defines capacity 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 plan. In this definition, the specific plan could mean speed of trains, on-time performance, available track maintenance time, service reliability, and train handling power of the subdivision. In NCHRP Report 399 (Hyman

1998), line capacity is defined in terms of delay instead of maximum theoretical throughput. According to this report, capacity should not be measured by how many trains can be moved in a segment of track; instead, what is more important for capacity measurement is the movement of trains without undue delay.

REVIEW OF THE PARAMETRIC ANALYSIS METHOD

The literature review on railroad capacity estimation reveals that the parametric analysis method, which is based on the computer train dispatching simulation model developed by Prokopy and Rubin (1975), is the most comprehensive analysis of capacity. Simulation results published in Prokopy and Rubin's (1975) report enable one to estimate capacity without getting engaged in the actual simulation. Acknowledging the importance of this report, an attempt is made here to scrutinize the report piecemeal, suggest some minor changes in the estimation steps, and, finally, use the methodology in the report to develop a computer algorithm.

The parametric analysis of railroad line capacity has five main steps:

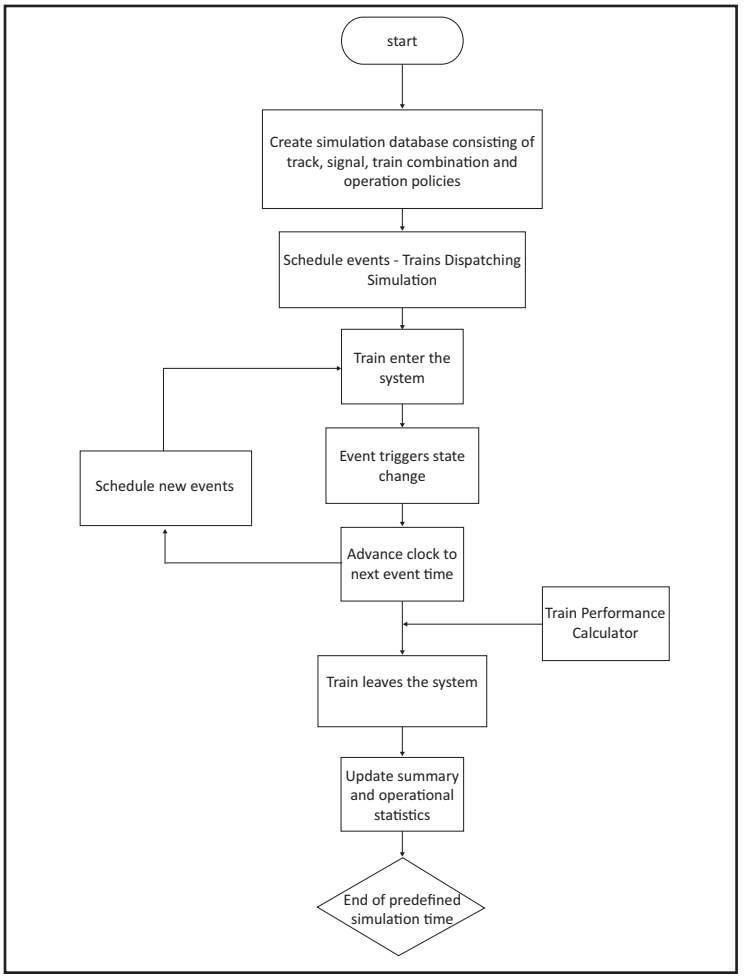
- Modification of Prokopy and Rubin's (1975) train dispatching simulation (TDS)
- Identify key parameters affecting capacity
- Procedure for parametric analysis
- Evaluation of the parameters
- Validation of the model and verification of the accuracy

Simulation Model

In the core of the parametric analysis of rail line capacity is the computer based train dispatching simulation model. The simulation model is used here to replicate train dispatching and movement in a system, with different parameters, consisting of several hundred different combinations of track, signal, and train combinations and operation policies. In this study, an event based computer simulation model is used to create a relationship between numbers of trains dispatched and the train delay. This simulation method also analyzes the sensitivity of delay to various parameters individually and combinations of parameters simultaneously. The logic diagram of event based simulation is shown in Figure 1. In this event-based simulation, state change takes place at discrete points of time, which is prompted by events happening. These states are known as discrete change state variables. In this study, a representative line segment of 150 miles is used. The Train Dispatching Simulation (TDS) model starts with the first train entering the system at the pre-assigned time. This is the first event, which triggers a change of state in the system. The aggregate states of all elements in the model specify the state of the model as a whole. When the second train enters the system, it triggers a new event and is accompanied by change in the state of the elements in the system. In this TDS model, a time resolution of one-tenth of a minute is used, which is good enough to replicate the train movements. A train performance calculator (TPC) is used in combination with the TDS to quantify the train movement and delay. In this simulation model, statistics of train performance are gathered from the moment a train enters the system until it leaves the system. Some trains may not be dispatched at the stipulated time because of unavailability of track. In this situation they have to wait in a siding or yard. In this model there are two stages of control: micro-resource, which is the signal system control, and the macro-resource, which is the dispatcher control.

The automatic block signal[23] system, which is part of the signal system control, maintains train separation. Block signal spacing and number of signal aspects are parameters which can be set in the model to measure its effect on delay. The macro-level control in the model regulates the dispatching of trains and discharging of trains at stations. The macro-level control also prioritizes trains based on their preference of one train over another, physical characteristics, and availability of track facilities. The dispatching is controlled to ensure required spacing between two successive trains. In a multiple track facility, automatic block signal control is used to impose the required spacing between trains

Figure 1: Logic of the Simulation Model



in one or both directions. In the junction between double and single tracks, trains are kept in waiting for track availability to move from double to single track. In a section of the system where double track is available, fast trains are allowed to overtake slower trains. The condition set for overtaking is to try for no delay; the next option would be to overtake with imposition of delay on the overtaken train provided it is not a high priority train.

In this event based simulation there are three types of events: arrival event, departure event, and termination event. Arrival and departure event is the time when a train enters the system and the time the train reaches the final destination. The termination event is the end of the simulation after the completion of a predefined period of simulation. The simulation can also terminate if all scheduled trains depart the system. In this event based simulation, the parameters and the operating conditions can be set to values which are within the admissible range. Different categories of data are required to run the simulation model. Basic parameters of the model consists of start and stop time of trains and duration of simulation. Track configuration parameters include number of tracks, direction of movement on tracks, and siding and yard capacity. Train characteristics which take into account the class of train, number of locomotives and running time between stations. Signal system parameters deal with the description of blocks in the segment, number of signal aspects, and the minimum distance between trains. The dispatching schedule parameter specifies the train length, train class, train priority, and the dispatching time.

Analysis of the Simulation Result

The outcome of the simulation model is a relationship of train delay to the number of trains dispatched, sensitivity of average delay to various parameters, sensitivity of delay to combination of parameters, and model for measuring line capacity.

In this parametric method of capacity measurement, the relationship between dispatching delay per train to train volume is considered a constant value, and this relationship is considered linear in most cases. In some instances, this relationship is a square function and gives a higher measure of delay. The K value (delay slope), which is equal to the delay per train divided by the number of trains per day (delay per train/trains per day), is dependent on train speed, siding[24] spacing, siding capacity, siding length, signal block length,[25] crossover[26] spacing, and line profile.[27] The basic relationship between delay and number of trains is:

(1) $A = K_o n$

where:

A = Average delay per train
K_o = Delay slope
n = Number of trains per day

The single modification table in the Prokopy and Rubin (1975) report, as shown in Table 1, furnishes the value of K for the base case and also K values for different modification runs. K_s given in Table 1 is for the square of the slope coefficient. The column P_i is the percentage change of parameters from the base case. The second to last column is the value of f_{oi} (delay slope adjustment factor) for the test cases. The K_i of the test case is the product of the K_o value in the base case and the delay slope $(f_{oi})^{Pi}$ raised to the percentage change in parameters.

(2) $K_i = K_o (f_{oi})^{P_i}$

where:

K_i = delay slope for change in parameter i
f_{oi} = delay slope adjustment factor
P_i = Percentage change in parameter i

Table 1: An Extract of the Modified "Case Summary" of Simulation Result

Modification from Primary Base	No of tracks	Base case no.	K	k_s	Pi	f_{oi}	f_{oi}^{p}
Single track base case	1	.	.045	.001			
5-mile segment	1	1	.031	.001	-.561	1.775	.724
15-mile segments	1	1	.060	.003	+.51	1.948	1.406
21.4-mile segments	1	3	.087	.004	+.353	2.855	1.448
Uniform segments	1	1	.033	.001	+1	.789	.789
33% decrease in speeds	1	1	.064	.004	-.395	.415	1.414
40% increase in speeds	1	1	.022	.0003	+.333	.139	.518

(Prokopy and Rubin 1975)

The parameters that affected delay and in turn capacity can be classified in three broad sub-groups (Figure 2). A simulation run was done to vary the parameters; some are continuous parameters while some are discrete deviations from the base case. There are slope (K) increasing and decreasing parameters. The slope increasing parameters decrease capacity while the slope decreasing parameters increase capacity. The three broad subgroups are as follows:

- Infrastructure parameters: This includes siding spacing, distribution of siding, siding capacity, siding length, signal spacing, type of signal, portion of multiple track, crossover spacing, and subdivision length. Siding distance, which is the distance between yards or crew change points, increases delay with increase in length. Sidings, location where trains meet, overtake, or switching takes place, have a vital role in affecting capacity. The siding length should be enough to accommodate the crossing train, and an increase of siding length increases the section capacity. Increasing siding spacing and non-uniformity of distribution of sidings increase delay and decrease capacity. Signal type has a marked effect on section capacity. Automatic block signaling is an improvement over track warrant control[28], and a centralized traffic control system is an improvement over automatic block signaling. Multiple tracks significantly increase the capacity of railroad sections.
- Traffic parameters: These include speed distribution, speed limit, directional imbalance, and train priority. Increase in speed increases capacity, but non-uniformity of speed decreases capacity. Directional imbalance[29] increases track capacity, whereas train prioritization decreases capacity.
- Operational parameters: This includes both planned maintenance and unplanned disruptions. Both planned and unplanned disruptions that might cause a temporary closure of a track for a certain length of time drastically reduces capacity.

In the Prokopy and Rubin (1975) report, there are 24 simulation results for single track cases. Out of these, 10 are slope increasing cases, i.e., increased K_i value, and 14 simulation results are slope decreasing cases. In the slope increasing cases, the value of K_i is more than the K values in the base case, hence the value of f_{oi}^{pi} is more than one. In the slope increasing cases, the f_{oi} value is

Figure 2: Factors Affecting Capacity of Railroad Section

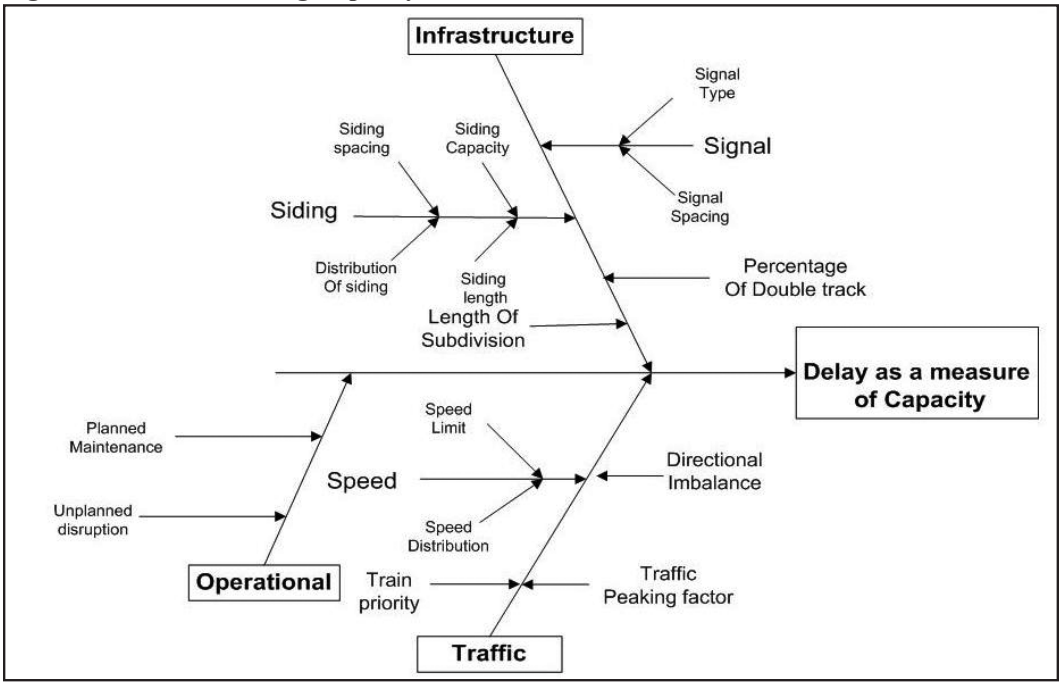


Figure 3: Visual Basic User Interface

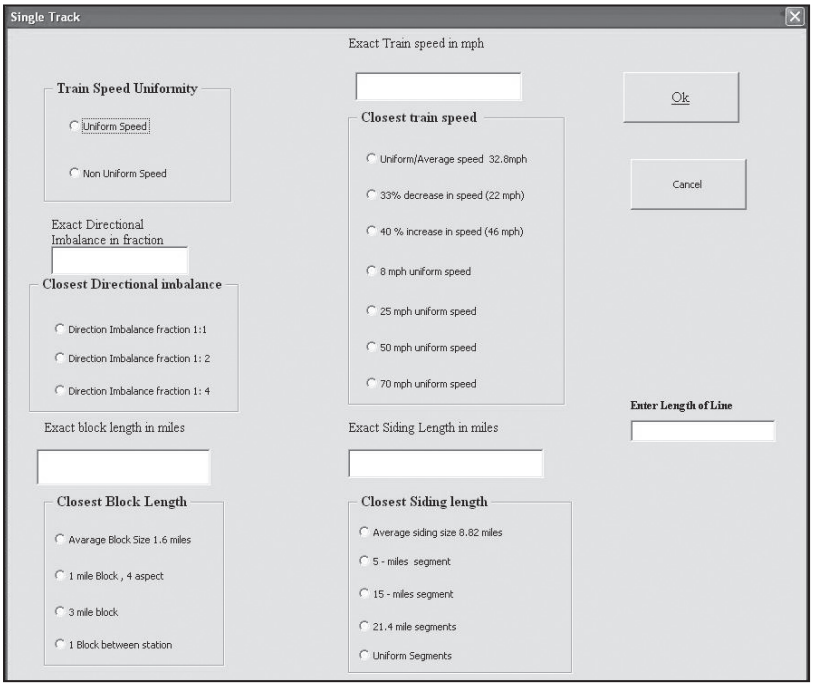


Figure 4: Flow Chart for Capacity Estimation

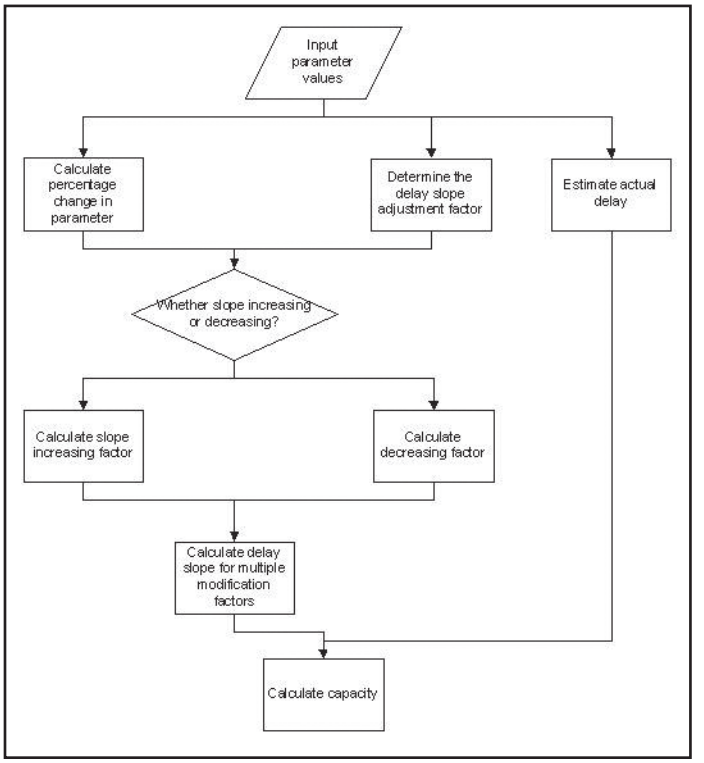
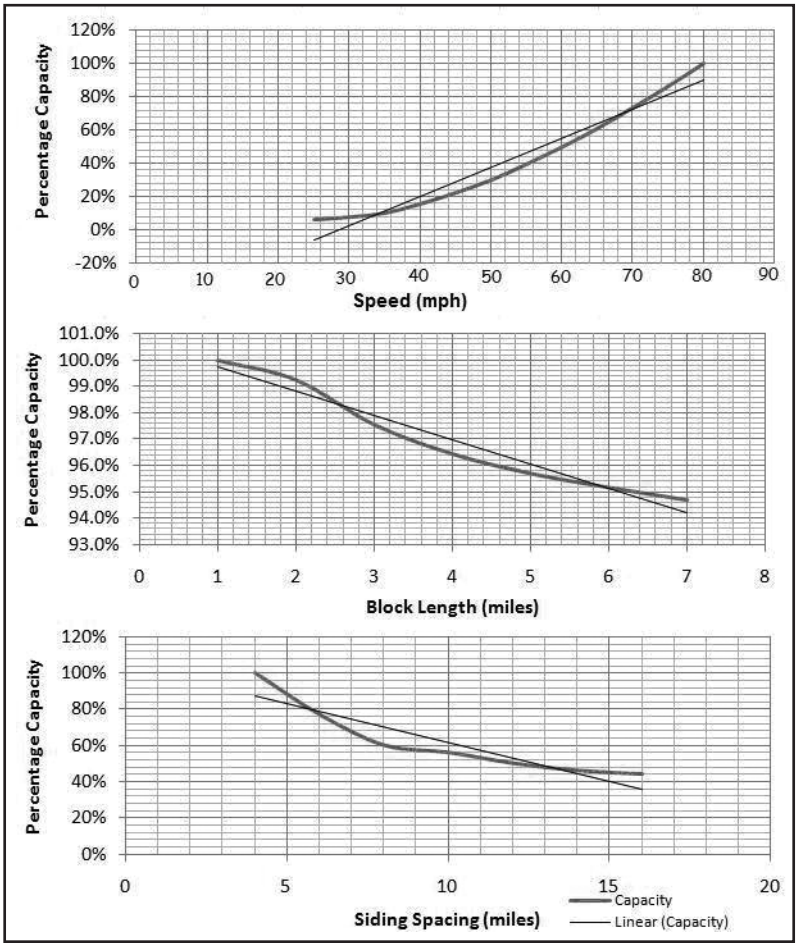


Figure 5: Railroad Capacity Versus Continuous Parameters (Obtained from the User Interface)



greater than one in all cases except three, in which the P_i value is less than zero. In the slope decreasing cases, the value of f_{oi}^{pi} is less than one and the f_{oi} value is less than one in all cases other than two in which the P_i value is less than zero.

Two methods are used to calculate the effect of changes of multiple parameters. One of the methods is the elasticity method, where exponent of f_{oi} to the degree P_i are summed over i, where i is all the multiple change parameters. This compound factor is multiplied by the base case delay slope to get the multiple modification changed slope. In the second method of estimating changed slope for multi parameters, the change in parameter values are treated as fractions and the fractions are normalized by taking the P^{th} root of the fraction. The combined effect of parameter changes are computed by normalizing the slope increasing and the slope decreasing factors separately.

USER INTERFACE AND REGRESSION MODEL

The algorithm used in the Prokopy and Rubin (1975) model, along with the details of the research, is not available to the public. In the present project, a computer algorithm and user friendly Visual Basic interface is developed to measure the subdivision capacities of a railroad network (Figure 3). The source code of this Windows program is the Parametric Analysis model with the necessary changes incorporated into it. This program is convenient for measuring railroad capacity, and it can

be programmed to read data directly from GIS data bases and assign the estimated capacities as attributes to the railroad links.

In this user interface, the five parameters that the user can change are speed uniformity, average speed, directional imbalance, block length, length of the distance between sidings, and the length of the line segment.[30] There are two entries to be made for each parameter: the specific value of the parameter and the value of the parameter closest to the test cases. The algorithm used for running the interface is presented in Figure 4. Using this interface, railroad section capacity is estimated for different parameter values, and a plot of capacity versus some of the continuous parameters is shown in Figure 5.

To develop a continuous relationship between capacity and the parameters, a number of multivariate regression analyses are formulated and the goodness of fit examined. The one that gives the best result is:

$$(3)\quad \begin{aligned} Cap = {} & \beta_0 + \beta_1(Uni) + \beta_2(Speed) + \beta_3(speed^2) + \beta_4(D1) + \beta_5(D2) + \beta_6(D3) \\ & + \beta_7(D4) + \beta_8(Block) + \beta_9(Siding) + \beta_{10}(Length) + \beta_{11}(Length^2) + \in \end{aligned}$$

The variables in the equation are:

Cap = Calculated capacity
Uni = Indicator variable, if uniform speed then UNI = 1, or UNI = 0
Speed = The average speed
D1, D2, D3, D4 = Indicator variables
if directionality factor[31] 1 then D1 = 1 or 0
if directionality factor 2 then D2 = 1 or 0
if directionality factor 3 then D3 = 1 or 0
if directionality factor 4 then D4 = 1 or 0
Block = Block length
Siding = Siding spacing
Length = Length of the segment

The result of the model seems to be a good fit with high F (493.55) and R-squared (0.8199) values as shown in Table 2. The t values for all the parameters are considerably more than the $t_{\alpha/2,n-k-1}$ value. The high variance inflation[32] for Speed and Length is because of the presence of the squared term. The Speed term has an estimated parameter that is negative; this suggests that with the increase in speed, capacity will increase at a reducing rate. This pattern can be explained by the curve of delay slope versus speed plotted in the Prokopy and Rubin (1975) report. The relation between delay slope and speed is linear, but a squared function could be introduced to give a higher value of delay. As the delay and capacity are inversely related, the relationship between capacity and speed is linear, and with the introduction of a negative squared term, results in a conservative (lower) estimate of capacity.

Table 2: Regression Result

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	447719	44772	493.55	<.0001
Error	1084	98334	90.714		
Corrected Total	1094	546054			
Root MSE		9.524	**R-Square**	0.8199	
Dependent Mean		31.24	**Adj R-Sq**	0.8183	
Coeff Var		30.484			

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	59.590	3.957	15.06	<.0001	0
Uni	1	-11.304	0.580	-19.48	<.0001	1.015
speed2	1	-0.031	0.001	-24.79	<.0001	33.766
Speed	1	3.467	0.113	30.55	<.0001	34.623
D2	1	-3.658	0.807	-4.53	<.0001	1.553
D3	1	-6.794	0.820	-8.28	<.0001	1.531
D4	1	-11.451	0.839	-13.64	<.0001	1.524
Block	1	-1.831	0.437	-4.19	<.0001	1.002
Siding	1	-1.796	0.047	-37.96	<.0001	1.016
Length	1	-0.625	0.043	-14.38	<.0001	54.894
length2	1	0.0009	0.0001	6.91	<.0001	54.261

APPLICATION OF THE PARAMETRIC CAPACITY MODEL

The user interface developed in this project is used to measure the capacity of the railroad network for the state of North Dakota. The user interface requires length of segment, number of tracks, speed and its uniformity, block length, siding spacing, and directional imbalance to implement the parametric capacity model. To run the model, data can be fed directly into the user interface or data can be read from a spreadsheet or database file. Before the model is implemented, a GIS database of the railroad network in the state is developed. The prime sources of data are the Bureau of Transportation Statistics' 1:100,000 scale network ("Rail100K") and 1:2,000,000 scale network ("Rail2m") (Bureau of Transportation Statistics 2005), the Federal Railroad Administration's Crossing Inventory database (Federal Railroad Administration 2007), railroad timetables of major railroad companies operating in the state, and the railroad map of North Dakota prepared by the North Dakota Public Service Commission.

Five major railroad companies (two of these are Class I) operate in North Dakota: the BNSF Railway, Soo Line Railroad (which is owned by the Canadian Pacific Railroad), Dakota Missouri Valley & Western, Northern Plains Railroad, and the Red River Valley & Western Railroad (Figure 6). Inputs from the railroad data base are used to run the parametric capacity model, and the subdivision capacities are estimated (Table 3). The track utilization factor, which is the ratio of observed trains per day and practical capacity are estimated to identify possible bottleneck areas.

Figure 6: GIS Model of the Railroad Network of North Dakota

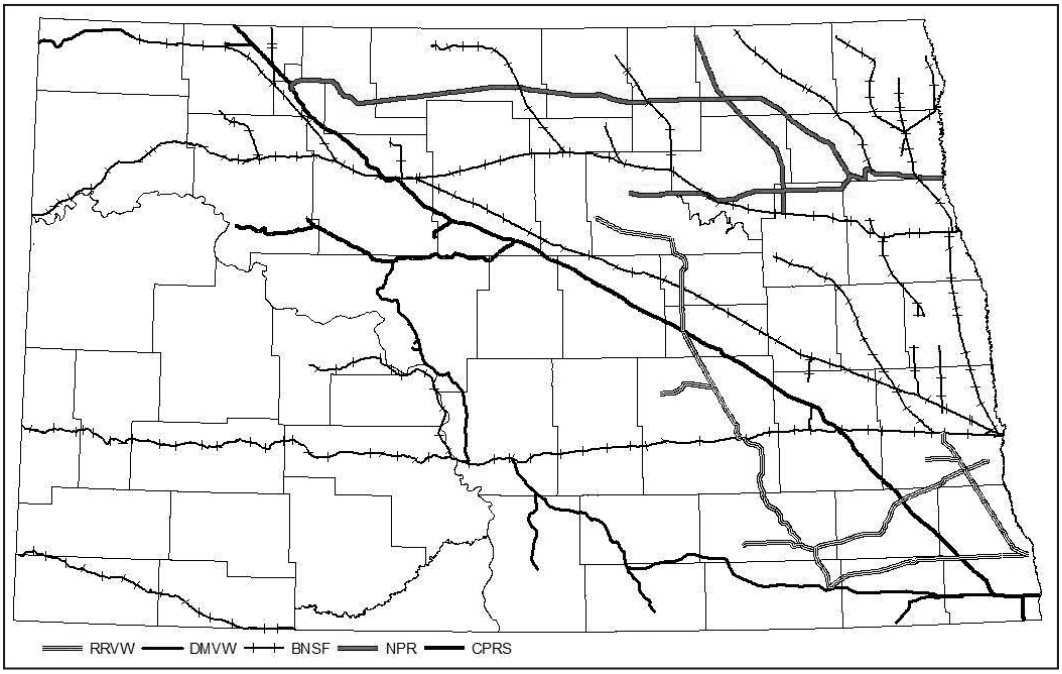


Table 3: Parametric Capacity Model Estimation Results

Railroad Company/ Subdivision	Subdiv. Length (Miles)	No of Track	Maximum Speed (MPH)	Signal Type	Block Length (Miles)	Siding Spacing (Miles)	Theoretical Capacity (Trains/Day)	Practical Capacity (Trains/Day)	Observed Trains/ Day	Track Utilization Factor
BNSF										
Devils Lake	195	1	50	CTC	1.1	14	86	42	5	0.12
K O	255	1	60	CTC	1.1	15	96	22	28	1.27
Jamestown	177	1	60	ABS	0.8	18	81	42	20	0.48
Prosper	44	1	40	ABS	0.8	22	44	35	18	0.51
Dickinson	205	1	45	ABS	1.9	11	100	23	20	0.87
Glasgow	133	1	60	CTC	1.4	7	217	87	28	0.32
Hettinger	153	1	40	ABS	3.7	19	50	28	5	0.18
Hillsboro	74	1	60	ABS	1.1	15	97	99	11	0.11
CPR										
Harvey-Portal	153	1	40	MAN	7.3	7	132	32	4	0.13
New Town	111	1	35	MAN	10.1	10	83	36	2	0.06
Carrington	139	1	40	MAN	7.3	7	131	35	4	0.11
Elbow Lake	67	1	40	MAN	3.4	3	287	75	4	0.05
DMVW										
Dakota	136	1	10	MAN	9.1	9	26	10	2	0.20
Napoleon	50	1	10	MAN	12.5	13	19	10	1	0.11
NPR										
Bisbee	217	1	25	MAN	9.4	9	64	6	2	0.33
Devils Lake	118	1	25	MAN	4.7	5	127	47	2	0.04
RRVW										
Third	76	1	25	MAN	6.9	7	87	36	2	0.06
Sixth	46	1	25	MAN	7.7	8	78	54	<1	

CONCLUSION

A true assessment of existing capacity is essential to improve utilization of existing tracks and to identify areas of bottleneck in the railroad network. Capacity assessment is also required to prioritize infrastructure (track, signal, and siding) development in capacity expansion projects. The capacity estimation method discussed here can be used to estimate section capacity, which in turn can be used to assess transportation system capacity by state agencies and state DOTs that may not have access to proprietary software for capacity estimation. The algorithm developed here for capacity estimation is presently used in a freight corridor assessment project. The user interface developed in this project provides a reasonably good estimation of the practical capacity.

In a capacity expansion project, other modules that are important are traffic forecasting modules, traffic assessment modules, and cost-benefit modules. To estimate present and future traffic flow in the network, the forecasted traffic is assigned on the railroad network, and the track utilization factor is estimated from the estimated train movement and practical capacity of the track section. System capacity can be estimated from the section capacity (Morlok and Riddle 2000), and this system capacity is a measure of throughput of a transportation system, especially when one is assessing a corridor capacity. In the future, the capacity estimation interfaces can be developed into a GIS based decision-support system that can be used by decision makers to identify locations of bottlenecks in a GIS transportation network. This will require the development of a robust GIS railroad network. The model discussed in this paper is a stride to delve into the complex issues of railroad capacity. There has to be continued research and development in this field of capacity estimation to keep railroad transportation competitive and attractive to shippers and carriers.

Endnotes

1. Section – Distance between last stop signal of a station and first stop signal of the next station.

2. Subdivision – A named section of railroad trackage.

3. Length of subdivision – Distance in miles between the beginning and end limits of the subdivision.

4. Meet pass planning point spacing – Average spacing of locations used to meet or overtake trains. Such locations are essential for the bi-directional, mixed priority, and trains operating at varying speed.

5. Meet pass planning point uniformity – The measure of uniformity or consistency in spacing of meet pass planning points.

6. Intermediate signal spacing ratio – Relates the ratio of signal spacing to the siding spacing. Intermediate signals increase capacity by reducing the required spacing between following trains.

7. Percentage of double track -–Ratio of railroad tracks in both directions to total length of the section expressed in percentage.

8. Traffic peaking factor – Ratio of maximum number of trains dispatched in certain period of time to average number of trains dispatched in the same time period.

9. Priority probability – Probability function that identifies the chance of a train meeting another train of higher priority.

10. Speed ratio – Ratio between high and low speed.

11. Average minimum run time – Mean time required by a train to travel from one end to the other of a railroad section.

12. Track outages – Planned and unplanned events that take track out of service.

13. Temporary slow orders – Temporary imposition of speed restriction lower than the normal speed limit.

14. Maximum trip time threshold – Upper time limit to travel the total section length.

15. Blocking time – The total time a section of track is exclusively allotted to a train.

16. Urban rapid transit – Passenger railway in an urban area with high capacity and frequency.

17. Linear facilities – Services which are in the same line.

18. Loading coefficient of passengers – Proportion of passenger space utilized in a passenger train.

19. Time headway – Time taken by a trailing train to cover the distance from its tip to the tip of the train in front of it.

20. Block length – Length of track of defined limits, the use of which is governed by signals.

21. Signal aspects – Appearance of a signal conveying an indication that is viewed from the direction of an approaching train.

22. Gross headway – Sum of gap and detector clearance time. Gap is rear bumper passage time of leader and front bumper passage time of the follower.

23. Automatic block signal (ABS) – In ABS system the signals are controlled by trains instead of by station operator. This allows shorter block lengths.

24. Siding – A short section of railroad track connected by switches with a main track.

25. Signal block length – Length of a block which is governed by signals.

26. Crossover – A pair of switches that connects two parallel rail tracks, allowing a train on one track to cross over to the other.

27. Line profile – Cross sectional shape of the rail line.

28. Track warrant control – A verbal authorization system used to authorize trains to occupy main tracks.

29. Directional imbalance – Disparity of trains dispatched in one direction to those dispatched in the other direction over the course of a day.

30. Segment – Part of rail track between the beginning and end limits of the subdivision.

31. Directionality factor – Ratio of train dispatched in one direction to those dispatched in the other direction over the course of a day.

32. Variance inflation – Quantifies the severity of multicollinearity in an ordinary least squares regression analysis.

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