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THE U.S. DOT/TSC TRAIN PERFORMANCE SIMULATOR

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Research and Special Programs Administration
Transportation Systems Center
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FINAL REPORT

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16. Abstract

A Train Performance Simulator (TPS) is a computer program which simulates the operation of a train over a railway route. It may be used for a variety of purposes to determine the effects of some operational strategy or equipment change upon schedules and energy consumption. The general characteristics of a TPS are discussed, including requirements for route and train input data and fundamentals of the mathematical models available.

The USDOT/TSC TPS is a relatively complex, but simple to use, example of a general-purpose TPS. Its features are described and the operating cycle of the program is examined. The mathematical model is discussed in detail. A wide variety of output data may be specified and many output options exist. Instructions for setting up the input data or running the TPS are not given, but samples of output are included.

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PREFACE

The purpose of this report is to acquaint interested researchers and potential users with the features of the Train Performance Simulator (TPS) in use at the Transportation Systems Center (TSC) of the U.S. Department of Transportation and to provide enough information to assess its usefulness.

The basic simulation program was developed for Missouri Pacific Railroad Company (MoPac) by R.W. Drucker while a graduate student at the University of Illinois and by staff members of the Industrial Engineering Division of MoPac. It has been extensively modified by TSC to provide for many additional features, particularly relating to electric propulsion and passenger service, as well as to provide more flexible input and output options which take advantage of the capabilities of the TSC DEC system-10 computer system and which reflect the broader needs of the Federal Railroad Administration.

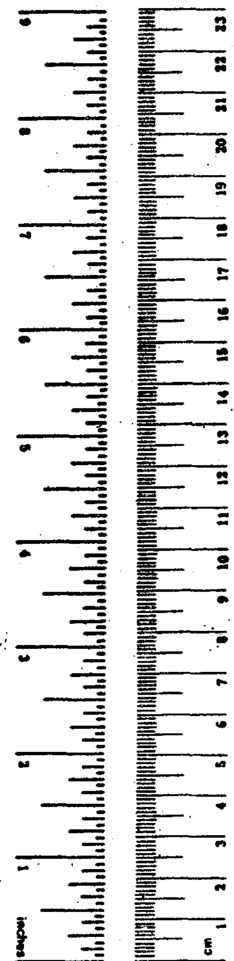
This report is based in part on the User's Manual written by MoPac, but includes much updated, expanded, and revised information applicable to the USDOT/TSC TPS.

Acquisition, validation, calibration, and utilization of this simulator have been supported by the Freight Service Division of the Office of Research and Development, Federal Railroad Administration. The Passenger Systems and Facilities Division of that office has supported the modification, documentation, and maintenance. Modification and maintenance of the TPS has been the responsibility of M. Hazel of TSC, assisted by R. Larkin, C. Teague, and H. Landon of Kentron International Limited. The author is grateful to Dr. J. Hopkins of TSC for his valuable counsel in organizing this report.

METRIC CONVERSION FACTORS

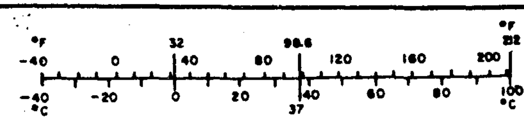
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

A Train Performance Simulator (TPS) or Train Performance Calculator (TPC) is a computer program which simulates the operation of a train over a railway route. It has become a useful tool for many of the larger railroads, most of which have developed simulators to suit their own needs and computer system capabilities. The TPS in use at the Transportation Systems Center (TSC) of the U. S. Department of Transportation was originally developed by a railroad (Missouri Pacific) for its own use. It has been adapted to the TSC DECsystem-10 computer and has been modified to expand its capabilities even further.

This introductory section discusses the general characteristics and features, and the basis for the mathematical model, for any TPC and for the USDOT/TSC TPS. Technical detail is kept to a minimum in this section as well as in Section 2, which describes the operating cycle, or iterative process. The details of the mathematical model are presented in Section 3 for the more technical reader. Section 4 discusses the computer-related and user-related features and describes the various output forms. Samples of output are provided in the Appendix.

The purpose of a Train Performance Simulator is to predict or replicate the movement of a train along a given track. The results of such a program are contained in tables or graphs that show the speed, time, distance, energy or fuel consumption, and throttle positions as the train moves along the route. Additional information about the route, such as grades, curves, mileposts, and speed limits may also be shown. A TPS may be used to:

1. Determine the scheduled operating time for a train.

2. Determine the motive power necessary to make a run in a given amount of time.

3. Determine the effect of adding (or dropping) a locomotive unit to (or from) the train.

4. Determine the effect of adding (or dropping) tonnage to (or from) the train.

5. Show the effect of a track relocation or reconstruction (which eliminates or reduces grades or curves) upon the operating speeds, motive power requirements, and energy consumption.

6. Compare the operational problems presented by various proposals for a new line.

7. Determine the effect of eliminating or introducing a speed restriction or station stop.

8. Determine tonnage ratings for a route based on a train operating over the ruling grade at a specified minimum speed.

9. Compare runs over different routes.

10. Compare results from the use of different train resistance formulas (i. e., vary the simulation model).

1.1 General Characteristics Of A TPS

1.1.1 Input Requirements - In order to simulate the running of a train the TPS needs information about the route and about the train.

1.1.1.1 Route Data - The TPS must have a description of the track over which to run the train. A set of values describing the characteristics of a point on the track constitutes one record of track data. A group of records, usually beginning at one station and ending at another (not necessarily the next), constitutes a route segment. The TPS will link together a number of such segments and run a train with or without stops from one end to the other.

The selection of points along the route to be coded is a matter of judgment. The following guidelines are recommended:

1. A record is required where speed limits change.

2. A record is required at every significant change in gradient.

3. If possible, a record should be coded for the beginning and end of every curve; but where curves occur in frequent succession, it may be desirable to code only one record at the beginning and end of several curves and enter an average value for the curvature.

4. A record is required for each significant station, junction, or inspection stop.

1.1.1.2 Train Data - When the route has been described, information about the train is needed in order to run it over the route. The length and type of cars in the train determine the aerodynamic forces acting on them. For example, short low flatcars and gondolas will offer much lower aerodynamic resistance than hi-cube boxcars and loaded TOFC cars, and the effects at higher speeds will be significant. The car weight and number of axles determine the resistance from friction in the bearings and flanges and from rolling contact. The locomotive characteristics required are the data on tractive effort capabilities, and the fuel or energy rates both idling (e. g. gallons per minute) and running (e. g. gallons per horsepower-hour).

1.1.1.3 Operating Scenario - When a route and a train have been described, the TPS can run a train over the route. However, a TPS usually can provide for additional variations from the normal operating conditions, such as:

1. Starting time.
2. Alterations to the route (grades, curves, etc.)
3. More or fewer stops and different stop times.
4. Temporary changes in speed limits from those specified in the track data.
5. Changes in consist (locomotives and/or cars) at stops enroute.
6. Adhesion ratio variation for bad weather (wet rail), or worst case.
7. Prevailing winds, both velocity and direction.
8. Modification of resistance characteristics to account for unusual cars or locomotives.

1.1.2 Basic Model (Algorithms) - The fundamental mathematical model for a train is based on simple Newtonian laws of motion. The forces involved are those due to train resistance, locomotive tractive effort, and braking.

1.1.2.1 Train Resistance - Train resistance is made up of a number of components:

1. Rolling friction resistance is proportional to the weight and independent of velocity.
2. Bearing friction resistance is proportional to the number of axles but independent of weight and velocity.
3. Flange friction resistance is proportional to weight and velocity.
4. Aerodynamic resistance is a function of size and shape and is proportional to the square of the velocity but independent of the weight.

The train resistance due to gradients and curvature can be added conveniently to the resistances listed above. Both are independent of velocity but proportional to weight and to the gradient or degree of curvature. The basic equation used for train resistance was formulated in the 1920's by W. J. Davis*. Expressed in pounds of force, the resistance of a single rail car is

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R = F*W + 20*g*W + .8*c*W + b*n + f*W*V + K*(V**2)
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where
- b is the bearing friction coefficient
- c is the curvature in degrees
- f is the flange friction coefficient
- F is the rolling friction coefficient
- g is the gradient in percent
- K is the air resistance coefficient
- n is the number of axles
- V is the velocity in miles per hour
- W is the car weight in tons
- * indicates multiplication
- ** indicates exponentiation

---

* W. J. Davis, Jr., "Tractive Resistance of Electric Locomotives and Cars", General Electric Review, October 1926.

It should be noted that the Davis Equation as stated here determines the resistance force of a rail car. The power required to overcome the force will be proportional to the product of that force and the velocity. Therefore, the locomotive horsepower required to pull a given aerodynamic shape at appreciable speed will be proportional to the cube of the velocity.

Davis determined values for the coefficients which were considered accurate for the rolling stock of his day. More recent tests have supported the use of alternative coefficients which are often used*.

1.1.2.2 Tractive Effort - Tractive effort is the force which a locomotive exerts at the driving wheels to move itself and its trailing consist. It is limited by the power available from the traction motors, by the velocity, and by the adhesion characteristics of the wheel-rail interface. For a given locomotive horsepower, a typical tractive effort curve is a hyperbola of the general form

$$TE = 375*E*HP/V$$

where

- E is an efficiency factor
- HP is the locomotive horsepower
- V is the velocity in miles per hour
- TE is the tractive effort in pounds

1.1.2.3 Braking - When the train needs to be slowed because of a speed restriction or station stop, brakes are applied. This results in a retarding force at the wheel-rail interface of all locomotives and cars in the train which is adhesion limited but which acts as an additional resisting force. The force applied is a function of brake system parameters, time, velocity, and weight of lading.

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* American Railway Engineering Association, "AREA Manual for Railway Engineering", Chapter 16, Part 2, 1970.

1.1.2.4 Acceleration - If the forces due to train resistance, tractive effort, and braking are in balance, the train will remain at constant velocity. However, if they are different, there will be an acceleration (or deceleration) resulting from the familiar F=m*a of Newton. The acceleration will be equal to the algebraic sum of the forces divided by the mass of the train.

1.1.3 Output - Since a TPS may be used for different purposes, the output needs to be flexible. Some users may want only a timetable listing, others may want merely the total running time. Other possibilities are instantaneous speed at every time or distance interval, average speed for the whole run, drawbar pull, acceleration, throttle notch settings, and brake application or release. Users interested in energy consumption may want incremental energy used at every time or distance interval or just the total for the run, expressed as kilowatt-hours or gallons of fuel or even as cost in dollars.

Obviously all these data cannot be displayed in a single format which will be convenient for everyone. Therefore a TPS should offer a variety of alternative outputs differing in degrees of complexity and which can be specified simply.

1.2 The USDOT/TSC TPS

A TPS can be designed with any degree of sophistication, depending upon the form and accuracy of the input data and the desired use and accuracy of results. The USDOT/TSC TPS is a relatively complex example. It incorporates all of the capabilities described above. In addition, a number of other features are included which add to its usefulness.

1.2.1 Special Features - The USDOT/TSC TPS is extremely flexible. It has built-in (default) values for almost every conceivable parameter, including the complete specification of a train. Unless otherwise specified, a freight train pulled by three GP-35's and consisting of 40 loaded cars and 29 empties, all 50 feet long, with 3684 gross trailing tons, will be run. One computer run, called a "job", can run up to 99 different trains over a route, with changes enroute to the grades, curves, stops, speed limits, and train consist.

1.2.1.1 Route Data - Track data may be read either from a previously prepared data base or from the input data. Stops, curvature, gradients, and speed limits can be changed during a train run and will be restored automatically for the next train. The train can be made to start and end its run virtually anywhere along the track.

1.2.1.2 Train Data - Conventional freight or passenger trains may have up to nine locomotives and any number of cars. Multiple-unit passenger trains may have up to 18 cars, any number of which may be unpowered. Energy sources may be fuel (diesel-electric, diesel-hydraulic, or turbine) or all-electric. Data is maintained in a TPS library data base for virtually all common locomotives, including complete specification of the tractive effort curves. Non-standard locomotives may be specified easily. The data required are:

1. Weight in tons,
2. Length in feet,
3. Rated horsepower,
4. Number of axles,
5. Running energy rate in gallons per horsepower-hour (or kilowatts per horsepower),
6. Idling energy rate in gallons per minute (or kilowatts), and
7. Transmission efficiency.

The standard tractive effort curve will be computed by the TPS unless an indicator is included with the locomotive data, which allows for non-standard tractive effort data to be specified simply as a table of tractive effort values at increments of one mile per hour.

The car length will be 50 feet and each will have four axles unless otherwise specified. Freight car consists can be specified in eight different ways:

1. Specify nothing, yielding the default consist: 40 loads, 29 empties, 3684 gross trailing tons.
2. Specify the total number of cars. The TPS will assign 58% of them as loads and 42% of them as empties with average weight of 53.4 tons.

3. Specify the number of loads and empties. The TPS will assign weights of 72.5 and 27 tons, respectively.

4. Specify number of loads and empties and gross trailing tons.

5. Specify number of loads and empties and total weight of lading. The TPS will assign a light weight of 27 tons to each car.

6. Specify total number of cars and gross trailing tons. The TPS will assign 58% as loads and 42% as empties.

7. Specify the number of loads and empties and the weights of each.

8. Specify all parameters individually for every car in the train by supplying them directly.

Passenger train consists can be specified simply. A simple code indicates whether conventional or multiple-unit. If conventional, the locomotives are specified as for a freight train and the number of cars and their weight, length, and number of axles are given. Any default resistance coefficients may be overridden. A multiple-unit train is specified as if it were all locomotives. The TPS gives them the proper tractive effort characteristics while treating them in all other respects as cars.

1.2.1.3 Model - Five train resistance equations are built into the TPS. The default equation will be Davis modified by Tuthill*, but any of the others may be specified easily. The gradient and curvature terms are identical and are omitted here. In the equations below:

L is the car length in feet
n is the number of axles
R is resistance of a single car in pounds
V is the velocity in miles per hour
W is the car weight in tons
* indicates multiplication
** indicates exponentiation

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* J. K. Tuthill, "High Speed Freight Train Resistance", University of Illinois Engineering Bulletin 376, 1948.

1. Davis, optionally modified by Tuthill above 40 mph.

   R = 1.3*W + 29*n + .045*W*V + .045*(V**2)

   Note: In the Tuthill modification the equation is replaced by a matrix of coefficients when the velocity exceeds 40 mph.

2. "Canadian National".

   R = 0.6*W + 20*n + .01*W*V + .07*(V**2)

3. Canadian National - Erie Lackawanna for TOFC/COFC.

   R = 0.6*W + 20*n + .01*W*V + .20*(V**2)

4. Totten* streamlined passenger.

   R = 1.3*W + 29*n + .045*W*V
   + [.0005+.060725*(L/100)**(.88)]*(V**2)

5. Totten non-streamlined passenger.

   R = 1.3*W + 29*n + .045*W*V
   + [.0005+.1085*(L/100)**(.7)]*(V**2)

In addition, the user may specify individual coefficients for the locomotive consist or the train consist or for each unit in each consist (i. e. make up custom resistance equations).

For accuracy on grades, the train is "blocked". The trailing consist is divided into up to 25 blocks of cars. Each block is considered as an independent mass upon which the train forces act. This is particularly significant in long trains where part of the train is going uphill while another part is going downhill. The entire length of the train is considered so that no acceleration is permitted until the caboose has left a speed-restricted zone.

A simplified explanation of the basic iterative procedure is as follows. The TPS compares the present train speed to the speed limit. If tractive effort is available in excess of the train resistance, it will be applied subject to the adhesion limit. The velocity will be incremented and the time and distance to achieve the velocity change will be calculated and incremented. The user has the ability to override the default velocity increment of 1.0 mile per hour. If the train is

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* A. I. Totten, "Resistance of Light Weight Passenger Trains", Railway Age, Vol. 103, July 17, 1937.

already at speed limit, then the distance is increased by 528 feet and the new time is calculated.

The TPS looks ahead 30 track records for speed limit reductions and calculates the distance required for braking in advance. When that point is reached, the brakes are applied. A brake pipe propagation time of one tenth second per car and the variation of brake shoe friction coefficient with speed are both taken into consideration. Once deceleration is called for, the velocity will be decremented and the time and distance to achieve the change will be calculated and incremented.

The model requires the train to attempt to accelerate to and run at the speed limit whenever possible. This could be a serious constraint were it not for the fact that the user can modify the speed limits at will anywhere along the track where there is a data record. The TPS can simulate speeds up to 200 mph. Caution is advised, however, in interpreting results of runs at over 80 mph, due to uncertainties in train resistance at the higher speeds.

1.2.1.4 Output - The user has a choice of Summary or Detail Printout. The Summary Printout contains a line only at stations along the route and includes only location, time, speed, and energy information. The Detail Printout contains a line every time the speed changes by one mile per hour or the distance is incremented by one mile. In addition to all the information from the Summary Printout, a Detail Printout gives tractive effort, drawbar pull, throttle notch, and acceleration.

Both printouts give a complete description of the train (length, weight, horsepower, resistance coefficients, etc.) at the beginning and both give a Run Summary (total time and energy and average speed) and a timetable at the end. A Throttle Position Summary and a Velocity Range Summary are available as options to both printouts. Another output option is a file of values at each iterative step which can be used later by another program to plot graphically speed, speed limit, energy, elevations, grades, or curvature against time or distance.

1.2.2 Limitations - The nature of the model creates some limitations.

1. Velocity initialization is not permitted. The train must depart the originating station at zero speed and arrive at the destination station at zero speed.

2. If wind effects are desired, the wind velocity and relative direction must be constant for the entire run.

3. The train may not be handled exactly as a real engineer might do it. For instance, in some situations a real engineer might apply brakes lightly while applying power just to keep his train "stretched". This would be difficult to model.

4. The TPS is ultimately limited by the accuracy of the train resistance model. Most models were developed many years ago, and are generally considered to be valid only below about 80 mph. Only recently has there been a renewed interest in developing accurate resistance models, primarily for use in simulations of high-speed passenger trains.

5. Tractive effort is applied in a continuous curve, not quantized by notch setting.

1.2.3 Future Modifications - The features and limitations described above apply to the TPS currently in use at TSC. Possible modifications include:

1. Discrete tractive effort values determined by throttle notch setting.

2. Ability to override the default parameters in the braking algorithm.

3. Optional addition of dynamic braking.

4. Built-in car library data base, callable by code numbers.

1.2.4 Interpretation Of Results - Comparisons of simulation results with actual performance have shown that the simulator reproduces the movement of the train with reasonable accuracy. Results should be thought of as an estimate of the minimum running time over the selected section of track for a train with the specified motive power and consist characteristics and considering the speed restrictions and stops imposed. Normal stopping times for inspections and crew changes are not usually included in the prepared track data and the TPS does not automatically include the random delays such as meets and mechanical failures incurred by freight trains. When applying the simulator to scheduling applications, additional time should be allowed for these delays, by either adding them to the TPS results or by specifying them in the input data.

2. OPERATING CYCLE OF THE TPS PROGRAM

The "run cycle" of the TPS program actually computes the movement of a train. Before this cycle may be begun, information (supplied by the user) must be read specifying:

1. The route, which tells the program which track records, if any, are to be removed from the disk and stored during the course of a job, and the order in which the records must be removed;

2. The locomotives, which tells the program how to compute the tractive effort and locomotive resistance at each speed; and

3. The train consist, which tells the program the weight and length of the train, which is necessary to compute the train resistance.

After the necessary information has been read, the TPS examines the train and divides it into blocks of cars to more accurately determine the forces involved, particularly important in long trains. The maximum number of blocks is 25. If the train is longer than 25 cars, no block can have less than two cars. All blocks have the same number of cars except the last block, which may have a different number if required to account for all of them. Trains with 25 or fewer cars will be blocked one car per block. Multiple-unit trains are always blocked one unit per block. The cycle proceeds in the following manner:

4. Calculates tractive effort of power consist at present speed (0 mph at start);

5. Calculates train resistance based on train weight and flange and air resistance coefficients (input) and present grade and curve track characteristics;

6. Calculates force available (tractive effort minus resistance), and

   A. If force available is positive and:

      1. Speed limit is higher than present train speed: calculates distance and time required to accelerate to a new speed higher than the present speed by the amount of the incremental velocity;

2. Speed limit is at present train speed: calculates time required to move 0.1 mile distance at present speed;

3. Speed limit is lower than present train speed: calculates distance and time required to brake to a new speed lower than the present speed by the amount of the incremental velocity;

B. If force available is zero and:

1. Speed limit is higher than or equal to the present train speed: calculates time required to move 0.1 mile distance at present speed;

2. Speed limit is lower than present train speed: calculates distance and time required to brake to a new speed lower than the present speed by the amount of the incremental velocity;

C. If force available is negative and:

1. Speed limit is higher than or at present train speed: calculates distance and time required to decelerate to a new speed lower than the present speed by the amount of the incremental velocity;

2. Speed limit is lower than present train speed: calculates distance and time required to brake to a new speed lower than the present speed by the amount of the incremental velocity;

7. Adds the distance and time determined in 6. to the totals already established (which the train has moved previously) and raises or lowers the speed by an amount equal to the iterative velocity increment unless the train has maintained a constant speed;

8. If the train, in moving the distance, has encountered a track record, which usually indicates a change in grade, curvature, or speed limit, the movement is abbreviated so that it does not miss any sudden changes reflected in the new record. The time required is reduced proportionately to the distance, but the new train speed remains in effect. The train has actually accelerated or decelerated by an amount equal to the iterative velocity increment in a fraction of the distance and time which normally would be required. Using the program default value of 1.0 mph for the velocity increment can result in significant running time variations on runs with only slightly different consist characteristics when the track being simulated has many grades and curves (causing track data records to be closely spaced) and when the train is accelerating or decelerating frequently. (This program characteristic has no effect on accuracy when the train is moving at a constant speed.)

9. If the rear of the train has passed the rear-most track record still stored in the computer, it is removed from memory and a new track record is read in ahead of the train;

10. If the new track record indicates a reduction in the speed limit or a stop at a location of the track record, the program determines the distance required to brake the train from its previous speed to the desired speed and stores this information as an "artificial speed limit" at the point where the train should begin braking, so that the train will begin braking in advance of the stop or new speed limit.

11. Returns to 4. to begin the cycle again at the new location with the new information.

Finally, the general program stores certain information at selected locations for use in printing summaries and a timetable at the end of the run, as well as the accumulated energy consumption information.

3. MATHEMATICAL DESCRIPTION OF THE TPS

This section describes in mathematical terms the basis for the calculations made by the TPS in simulating the running of a train. The train is expected to follow Newtonian laws of motion.

3.1 Notation

Following is a list of all the variables used in this section. As a general rule adjacent letters in equations are part of the name of a single variable. Variable names are always separated by a mathematical operation symbol ("=", "-", "+", "/", "*", or "**") or a space. Parentheses and square brackets act as separators also.

a	acceleration, mph/sec
A	cross-sectional area, ft**2
AL	adhesion force limit, pounds
AR	adhesion ratio
Aw	wind angle
b	bearing friction coefficient
B	braking ratio
c	curvature, degrees
C	air drag coefficient
d	distance, feet
e	Totten exponent
E	transmission efficiency factor
Eb	brake rigging efficiency factor
f	flange friction coefficient
fs	brake shoe friction coefficient
F	rolling friction coefficient
Fa	force available for acceleration, pounds
Fb	braking force, pounds
g	gradient, percent
G	gravitational acceleration, 32.2 ft/sec**2
HP	locomotive engine horsepower
HPD	de-rated locomotive horsepower
HPR	rated locomotive horsepower
k	streamline coefficient
K	air resistance coefficient
L	car length, feet
n	number of axles on a car
N	number of cars in a train
p	brake application ratio
R	resistance of a rail car, pounds
t	time, seconds
tp	brake pipe propagation time, sec/car
T	a force, pounds
TE	tractive effort, pounds

v	velocity, ft/sec
V	velocity, mph
Vair	effective air velocity, mph
VH	high-speed break, mph
VL	low-speed break, mph
Vw	wind velocity, mph
W	weight of a car, tons
Wd	weight on drivers, tons
We	empty car weight, tons
*	means multiplication
**	means exponentiation

3.2 Forces

The force available to accelerate a body is the difference between the propelling force and the force which is resisting movement. For a train the propelling force is the tractive effort provided by the locomotive. The resisting force is the train resistance, including grade, curvature, and wind resistance. Braking force will be discussed in Section 3.7.

3.3 Tractive Effort

Horsepower (or power) is the rate of doing work. Work is force multiplied by the distance through which the force acts. Horsepower is defined as

$$HP = (T*d/t)/550 \quad (1)$$

when T is in pounds, d is in feet, and t is in seconds. The term d/t is the velocity, v, in feet per second.

$$HP = T*v/550 \quad (2)$$

The TPS uses the customary units for velocity, V, in miles per hour. The force is the tractive effort, TE, also in pounds.

$$HP = TE*V/375 \quad (3)$$

Equation 3 assumes a transmission efficiency of 100%. Diesel-electric locomotives typically have a transmission efficiency of 80 to 85 percent. Including the efficiency factor, E, in Equation 3 gives

$$HP = TE*V/(375*E) \quad (4)$$

or

TE = 375*E*HP/V (5)

3.4 Train Resistance

Train resistance is made up of a number of components:

1. Rolling friction resistance is proportional to the weight and independent of velocity.

2. Bearing friction resistance is proportional to the number of axles but independent of weight and velocity.

3. Flange friction resistance is proportional to weight and velocity.

4. Aerodynamic resistance is a function of size and shape and is proportional to the square of the air velocity but independent of the weight.

The train resistance due to gradients and curvature can be added conveniently to the resistances listed above. Both are independent of velocity but proportional to weight and to the gradient or degree of curvature.

3.4.1 Rolling And Friction Resistance - The rolling friction resistance is proportional to the weight and independent of velocity. The proportionality coefficient is F.

R(rolling) = F*W (6)

The bearing friction resistance is proportional to the number of axles but independent of weight and velocity. The proportionality coefficient is b.

R(bearing) = b*n (7)

The flange friction resistance is proportional to weight and velocity. The proportionality coefficient is f.

R(flange) = f*W*V (8)

3.4.2 Aerodynamic Resistance (Wind) - The TPS uses a simplified method for modeling the wind resistance of a moving train. Picture a train moving from west to east at a velocity V and a steady wind blowing generally east to west at velocity Vw at a small angle, Aw, to the track. The longitudinal and lateral components of the wind are

Vw(long) = Vw*cosine(Aw) (9)

Vw(lat) = Vw*sine(Aw) (10)

Although the lateral force acts along the sides of the cars of the train in a direction perpendicular to the direction of travel, it will be added to the longitudinal force for purpose of analysis and will be assumed to act upon the cross-sectional area of the train. The effective wind velocity then becomes

Vw(eff) = Vw*[sine(Aw)+cosine(Aw)] (11)

Note that, for all positive angles less than 180 degrees, the lateral component is always positive and therefore increases train resistance but when the wind angle is greater than 90 degrees (a tail wind) the longitudinal component is negative, reducing train resistance.

The wind resistance is included in the train resistance equation by using an effective air velocity instead of the train velocity.

Vair = V + Vw(eff) (12)

R(air) = K*(Vair**2) (13)

where

K = k + C*A*[(L/100)**e] (14)

which reduces to K=C*A when both k and e are zero.

3.4.3 Grade Resistance - Gradient is customarily measured in percent. For every 100 feet of horizontal distance, the vertical change is g feet, where g is the gradient. A stationary rail car held in equilibrium on a gradient will have three forces acting upon it, neglecting the friction terms which are already accounted for. The rail supporting force acts upward and normal to the rails. The drawbar force, R(grade), holding the car from rolling downhill, is parallel to the rails. The gravity force acts vertically downward and is equal to the car weight, or 2000*W pounds. The gravity force can be broken into two orthogonal components, which are equal and opposite to the other two forces for equilibrium to be maintained. The ratio of parallel force to normal force will be exactly equal to g/100, by similar triangles. Since gradient is always small, in a trigonometric sense, an approximation can be made which states that the normal component is very nearly equal to the gravity force (i. e. the rail length is very nearly 100 feet for every 100 feet of horizontal distance). Therefore, equating the sines of the smallest angles in similar triangles

R(grade)/(2000*W) = (g/100)

or

R(grade) = 20*g*W (15)

3.4.4 Curve Resistance - Curvature, c, is customarily measured in degrees of arc per 100 feet of chord. By this measuring scheme tangent track has a curvature of zero and increasing curvature means decreasing curve radius, or sharper curve. The resistance due to curvature has been found empirically* to be

R(curve) = .8*c*W (16)

3.4.5 Total Train Resistance - The total resistance of a rail car is the sum of the resistances due to rolling, bearing, and flange friction and air, gradient, and curvature.

R = F*W+b*n+f*W*V+K*(Vair**2)+20*g*W+.8*c*W (17)

----

* American Railway Engineering Association, "AREA Manual for Railway Engineering", Chapter 16, Part 2, "Train Performance", 1970, page 16-2-3.

3.5 Acceleration

In order to accelerate the train, the maximum usable tractive effort is applied. If that is greater than the train resistance, the train will accelerate.

3.5.1 Force Available

3.5.1 Force Available - The force available for acceleration is the difference between the tractive effort applied and the train resistance. The maximum tractive effort applied is limited to the tractive effort available from the locomotive and by the adhesion of the locomotive. The tractive effort available is stated by Equation 5 when HP is the maximum horsepower available. The adhesion force limit, AL, in pounds, is a function of the locomotive weight on drivers, Wd, and the adhesion ratio (or coefficient of adhesion), AR.

$$AL = 2000*AR*Wd \qquad (18)$$

The tractive effort applied will be the lesser of Equations 5 and 18 when acceleration is called for.

$$TE(appl) = \text{Smaller of } TE(max) \text{ and } AL \qquad (19)$$

The force available for acceleration is, then

$$Fa = TE(appl) - R \qquad (20)$$

3.5.2 Distance For Acceleration

3.5.2 Distance For Acceleration - The acceleration is assumed constant when iterating from one velocity to the next. The acceleration can be determined from the familiar F=m*a of Newton. Since acceleration is in mph/sec, W is in tons, and G is in ft/sec**2, some conversion factors must be introduced.

$$Fa = (2000*5280/3600)*W*a/G \qquad (21)$$

The incremental velocity when accelerating from velocity V1 to V2 is simply the product of acceleration and time.

$$V2 - V1 = a*t \qquad (22)$$

The distance travelled in that time is

$$d = (5280/3600)*[V1*t + a*(t**2)/2] \qquad (23)$$

Equations 22 and 23 may be solved for acceleration independent of time.

$$a = (5280/3600)*(V2**2 - V1**2)/(2*d) \quad (24)$$

Equation 24 may be substituted into Equation 21 to get the force in terms of distance.

$$Fa = 66.8*W*(V2**2 - V1**2)/d \quad (25)$$

Equation 25 considers velocity of translation only. The rotational acceleration of the wheels is taken into account by a five percent increase.

$$Fa = 70.14*W*(V2**2 - V1**2)/d \quad (26)$$

The distance for acceleration is determined by rearranging Equation 26.

$$d(accel) = 70.14*W*(V2**2 - V1**2)/Fa \quad (27)$$

3.5.3 Time For Acceleration - Equation 22 may be solved for acceleration and substituted into Equation 21.

$$Fa = 91.10*W*(V2 - V1)/t \quad (28)$$

This is also increased by five percent to allow for rotational acceleration of the wheels.

$$Fa = 95.65*W*(V2 - V1)/t \quad (29)$$

The time for acceleration is determined by rearranging Equation 29.

$$t(accel) = 95.65*W*(V2 - V1)/Fa \quad (30)$$

3.6 Deceleration

Deceleration will occur naturally when the resistance of the train exceeds the applied tractive effort. Deceleration also occurs when the brakes are applied, causing an additional resisting force, the characteristics of which are discussed in the next section. The equations used to determine the distance and time for natural deceleration are the same as those used for acceleration, i. e. Equation 27 and Equation 30. In these equations V2 is the new velocity, V1 is the present velocity, and Fa is the net force. Since the train is decelerating, V2-V1 is negative, but for deceleration Fa is also negative, resulting in positive distance and time. The deceleration is assumed constant during each iteration from V1 to V2.

3.7 Braking

When the train needs to decelerate because of a speed restriction or stop, the brakes are applied at a location previously calculated by the TPS. That location is determined before the train reaches it by applying the equations below and iterating backwards from the speed restriction or stop (see also Step 10 of Section 2). For deceleration after that location, iteration proceeds forward as for natural deceleration except that the braking force is applied while the tractive effort is set to zero. A full service application is simulated with appropriate propagation delays.

3.7.1 Braking Force - The force, Fb, developed by the braking system to stop the train is a function of a number of braking system parameters.

$$Fb = 2000*p*B*We*Eb*fs \qquad (31)$$

The product (Eb*fs) is usually considered as a single quantity which is dependent upon the velocity. The TPS uses the following simplified relationship.

$$(Eb*fs) = 0.12 \qquad \text{for } V > 40 \text{ mph} \qquad (32)$$

$$(Eb*fs) = 0.25 - V/300 \qquad \text{for } V < 40 \text{ mph} \qquad (33)$$

The application ratio, p, is the ratio of actual brake cylinder air pressure to brake cylinder pressure for full service application and is fixed by the TPS at a value of 0.75. The braking ratio, B, is calculated according to an algorithm but generally falls in the range of 0.20 to 0.60 for freight cars, 0.65 for locomotives, and 1.50 for passenger cars.

3.7.2 Braking Distance - When braking, the tractive effort being applied is zero and the only forces acting on the train are the braking force, Fb, and the train resistance, R, both of which are negative. The quantity -(Fb+R) can be substituted for Fa in Equation 27 to get the braking distance.

$$d = 70.14*W*(V1**2 - V2**2)/(Fb + R) \qquad (34)$$

where Fb is determined by Equation 31 and R is determined by Equation 17. When braking is applied, the output indicates that the throttle is in notch 0 and the tractive effort column contains the braking force Fb, which is a negative value, instead.

The distance the train would travel, assuming no deceleration, before the last car senses a brake application is

$$d = (5280/3600)*tp*N*V \quad (35)$$

where tp is the brake pipe propagation rate in seconds per car. The TPS uses a propagation rate of 0.10 seconds per car. For a current velocity of V1, Equation 35 reduces to

$$d(prop) = 1.467*tp*N*V1 \quad (36)$$

The TPS uses the following approximation for braking distance, which is intended to allow for brake pipe propagation time and brake application rate.

$$d(brk) = 1.3*[70.14*W*(V1**2 - V2**2)/(Fb+R) + d(prop)] \quad (37)$$

The distance d(prop) is evaluated by Equation 36 only for the first iteration immediately after the brakes are applied. After the first iteration and for all subsequent iterations until the brakes are released d(prop)=0.

3.7.3 Braking Time - The quantity -(Fb+R) can be substituted for Fa in Equation 30 to get the braking time.

$$t = 95.65*W(V1 - V2)/(Fb+R) \quad (38)$$

The time, assuming no deceleration, before the last car senses a brake application is

$$t(prop) = tp*N \quad (39)$$

The TPS uses the following approximation for braking time, which is intended to allow for brake pipe propagation time and brake application rate.

$$t(brk) = 1.3*[86.00*W*(V1-V2)/(Fb+R) + t(prop)] \quad (40)$$

The time t(prop) is evaluated by Equation 39 only for the first iteration immediately after the brakes are applied. After the first iteration and for all subsequent iterations until the brakes are released t(prop)=0.

4. USING THE TPS PROGRAM

This section describes briefly how the TPS is run on the TSC DECsystem-10. It is assumed that the user is familiar with the common DECsystem-10 Monitor commands, and procedures for logging in and out of the system. Some knowledge of Fortran format specifications will be helpful but is not necessary.

4.1 The Computer Environment

The TPS program is written in FORTRAN and is compiled under DECsystem-10 Fortran-10 and loaded with LINK-10. It resides in the TPS Administrator's disk area. The executable core image file occupies 130 disk blocks and when copied into core requires 35K words of storage.

4.1.1 Temporary Files - Certain processed data required by the TPS is stored in temporary files in the user's disk area (DSK:) while the TPS is running. Because these temporary files have fixed names, the TPS should not be run by more than one user logged in under the same project-programmer number. These files are deleted automatically by the TPS when they are no longer needed and are therefore normally invisible to the user.

4.1.2 Track Data Core Storage - Modified versions of the TPS exist which do not store track data on the user's disk but instead store it in core. This decreases execution time significantly in exchange for a larger use of core. These versions are limited in the number of track data records they can store and use additional core as follows:

PROGRAM NAME	MAXIMUM RECORDS	ADDITIONAL CORE USED
TPSA	200	5K
TPSB	1000	24K
TPSC	2000	48K
TPSD	unlimited	none

4.1.3 CPU Time - CPU time for running a TPS job can vary from a few seconds for a simple job with just one train run over a very short route with no changes enroute to one minute or more for more complicated jobs with a dozen runs and a few changes enroute. It is sometimes advisable, therefore, to run the TPS under Batch Control for the more involved cases. CPU costs for a TPS job typically range between $1.00 and $70.00 depending upon the number of trains and the number of records of track data encountered.

4.2 Stored TPS Library Data Base

The TPS from time to time makes use of data stored in disk files maintained by the TPS Administrator. These files constitute a TPS Library data base and are updated as new data become available. All are written in ASCII so their contents may be examined on a line printer.

4.2.1 Stored Route Segments - The TPS Library data base includes a set of random access disk files of stored track data which currently contains data for a number of U. S. railroad main lines and branch lines. Other routes are being added as they become both available and useful to the TSC community. Many track data files may be maintained for special purposes by either a TPS user or by the TPS Administrator.

4.2.2 Standard Through Routes - Train routes are usually made up from a number of route segments. To make the coding easier for some commonly used routes, a random access disk file contains pointers to the proper segments in the track data files. Standard Through Routes are specified simply by a single numeric code.

4.2.3 Standard Locomotives - Data for a number of common locomotives are maintained by the TPS Administrator in a random access disk file. This file contains all the data needed by the TPS to characterize completely each locomotive including pointers to the tractive effort data. Standard locomotives are specified simply by single numeric codes.

4.2.4 Tractive Effort Data - Tractive effort data for Standard Locomotives which follow the typical hyperbolic curve are calculated by the TPS using an appropriate algorithm. Some locomotives, however, do not have "typical" tractive effort curves. In this case pointers direct the TPS to read tractive effort values in increments of one mile per hour from another random access disk file in the TPS Administrator's disk area. Custom Locomotives may also use data from this file or the complete set of tractive effort values may be included in the TPS input data.

4.3 Input Data File

Before the TPS can run any trains, an Input Data File must be created in the user's disk area which specifies the kind of output desired, the route to be travelled, the number of runs to be made over the route, the train consist for each run, and various other parameters of the job. The name of the Input Data File is selected by the user, and becomes the name of the TPS job and is identified on all printouts.

4.4 Output Data

The TPS output is written onto three files on the user's disk (DSK:). The file name of all output files is the same as the name of the Input Data File (also the TPS job name). File name extensions will differ depending upon the type of output file. The output files are described in the next three sections. Samples of output are shown in Appendix A.

4.4.1 Printout File - Is always written, even though it may be null. It is the principal output file and contains:

1. Track data listing (if enabled);
2. Summary Printout or Detail Printout (unless disabled);
3. Tonnage Rating Report (if enabled);
4. Run Summaries (unless Printout is disabled);
5. Throttle Position Summaries (if enabled);

6. Velocity Range Summaries (if enabled); and

7. TPS error messages, if any.

4.4.2 Table File - Is always written. It contains:

1. Copy of Input Data File with column headings;

2. Run Summaries;

3. CPU time and cost reports; and

4. Acceleration tables (if Plot Data is enabled).

4.4.3 Plot Data File - Is written only if enabled. This file is designed to be used as input to a separate plotting program to provide graphical TPS output.

4.4.4 Run Summaries - Run Summaries (total time and distance, average speed, and total energy used) are always written in both the Table file and at the controlling terminal. They will also be written in the Printout file if either a Summary or Detail Printout is specified.

4.4.5 Error Messages - Error messages generated by the TPS during execution are sent to both the Printout file and to the controlling terminal or Batch Control log file.

4.4.6 Printing Of Output - All output contains upper/lower case text. Two general kinds of printout are available. A Detail Printout requires the full 132 column capability of the line printers but a Summary Printout will fit on paper 8.5 inches wide. The Table file requires wide paper (the default).

4.5 Running The TPS

Once an Input Data File has been established, the TPS can be run using a simple monitor command which will copy the TPS into the user's core area and begin execution. The TPS will respond with an introduction possibly followed by an update notice and then it will request the user to enter the full name (including extension) of the Input Data File, terminated by a carriage return. No other TPS input is required. The TPS completes the job and exits to the Monitor.

Once at Monitor level, the user can issue commands to print the output data or log out of the system.

4.6 The TPS User's Manual

A comprehensive user's manual for the USDOT/TSC TPS is maintained by the TPS Administrator and is revised from time to time as the need arises. It is available to anyone who has a serious interest in using the TPS. It contains the detailed step-by-step procedure for creating an Input Data File and explains how to specify all of the various optional features.

APPENDIX

SAMPLE TPS OUTPUT

SAMPLE TPS OUTPUT

SAMPLE RUN SUMMARY

TPSD 4G(160) 19-May-78 Job EBTR Train 3EBC Run 1 Page 5

RUN SUMMARY

Run 1: Freight train 3EBC Sequence No. 2

From Hobart Yard to Barstow via A, T, & Santa Fe

Using Canadian National resistance equation

Power consist beginning at Hobart Yard
4 Diesel units: SD45 SD45 SD45 SD45

Train consist beginning at Hobart Yard
34 cars including 19 loads and 15 empties.

```
Elapsed time running: 02:33:03    Average running speed  57.20 mph.
             stopped: 00:01:00    Total miles: 145.90
                      --------
             total:   02:34:03    Average overall speed  56.83 mph.


Fuel: gallons consumed running: 1203.41
      Gallons consumed idling:     0.40
                                -------
      Total gallons consumed:   1203.81

      Cost at  39.00 cents per gallon: $  469.49
```

SAMPLE TPS OUTPUT

SAMPLE TIMETABLE

Job: PSSBNY   Train P001   27-Jul-76   Run 1   Page 4

Simulated run: Modern passenger train P001

From Buffalo   to New York   via Penn Central

Using Totten equation for streamlined cars

TIMETABLE

STATION	CLOCK TIME HRS:MIN	HRS:MIN	ELAPSED TIME HRS:MIN	HRS:MIN	PASSING SPEED	MINUTES STOPPED
Buffalo		LV 10: 0		LV 0: 0	0	
Lancaster		LV 10:16		LV 0:16	50	
Corfu		LV 10:32		LV 0:32	50	
Batavia		LV 10:47		LV 0:47	50	
Churchville		LV 11: 4		LV 1: 4	50	
Chili Jct.		LV 11:11		LV 1:11	50	
Rochester	AR 11:26	LV 11:29	AR 1:26	LV 1:29		3
E. Rochester		LV 11:40		LV 1:40	50	
Fairport		LV 11:44		LV 1:44	50	
Macedon		LV 11:55		LV 1:55	50	
Newark		LV 12: 6		LV 2: 6	50	
Lyons		LV 12:12		LV 2:12	50	
N. Weedsport		LV 12:28		LV 2:28	50	
Warners		LV 12:56		LV 2:56	50	
Syracuse	AR 13:14	LV 13:17	AR 3:14	LV 3:17		3
Canastota		LV 13:54		LV 3:54	50	
Rome		LV 13:60		LV 3:60	50	
Utica	AR 14:17	LV 14:20	AR 4:17	LV 4:20		3
Herkimer		LV 14:44		LV 4:44	50	
Little Falls		LV 14:47		LV 4:47	50	
Fonda		LV 15:11		LV 5:11	50	
Amsterdam	AR 15:25	LV 15:27	AR 5:25	LV 5:27		2
Hoffmans		LV 15:44		LV 5:44	30	
Rotterdam Jc		LV 15:50		LV 5:50	30	
S. Scheny.		LV 16: 0		LV 6: 0	45	
Carman		LV 16: 9		LV 6: 9	30	
Karner		LV 16:14		LV 6:14	60	
W. Albany		LV 16:19		LV 6:19	50	
Albany	AR 16:21	LV 16:41	AR 6:21	LV 6:41		20
Rensselaer		LV 16:47		LV 6:47	25	
Schodack Ldg		LV 17: 1		LV 7: 1	60	
Stuyvesant		LV 17: 6		LV 7: 6	50	
Newton Hook		LV 17:10		LV 7:10	50	
Hudson		LV 17:19		LV 7:19	43	
Rhinecliff		LV 17:57		LV 7:57	50	
Poughkeepsie	AR 18:14	LV 18:19	AR 8:14	LV 8:19		5
CrotonHarmon		LV 19:13		LV 9:13	35	
MO		LV 19:47		LV 9:47	35	
New York	AR 19:53		AR 9:53			
STATION	CLOCK TIME HRS:MIN	HRS:MIN	ELAPSED TIME HRS:MIN	HRS:MIN	PASSING SPEED	MINUTES STOPPED

SAMPLE TPS OUTPUT

SAMPLE THROTTLE SUMMARY

TPSD 4G(160) 19-May-78 Job EBTR Train 3EBC Run 1 Page 7

ELAPSED TIME IN EACH THROTTLE POSITION

Run number 1 Train 3EBC

From Hobart Yard to Barstow via A, T, & Santa Fe

Locomotive consist SD45 SD45 SD45 SD45

THROTTLE POSITION	% OF RATED H.P. AVAILABLE	ELAPSED TIME	% OF TOTAL TIME	FUEL USED
BRAKE	0.	0 hr 16.08 min	10.44%	6.43 gal
1	0.- 5.	0 hr 0.00 min	0.00%	0.00 gal
2	5.- 12.	0 hr 2.43 min	1.58%	2.68 gal
3	12.- 31.	0 hr 35.23 min	22.87%	78.99 gal
4	31.- 46.	0 hr 15.31 min	9.94%	85.96 gal
5	46.- 59.	0 hr 0.66 min	0.43%	4.50 gal
6	59.- 74.	0 hr 4.69 min	3.04%	38.09 gal
7	74.- 89.	0 hr 17.97 min	11.67%	197.63 gal
8	89.-100.	1 hr 0.66 min	39.38%	789.12 gal
IDLE	0.	0 hr 1.00 min	0.65%	0.40 gal
TOTAL		2 hr 34.03 min	100.00%	1203.81 gal

SAMPLE TPS OUTPUT

SAMPLE VELOCITY SUMMARY

TPSD 4G(160) 19-May-78 Job EBTR Train 3EBC Run 1 Page 8

ELAPSED TIME IN EACH VELOCITY RANGE

Run number 1 Train 3EBC

From Hobart Yard to Barstow via A, T, & Santa Fe

Locomotive consist SD45 SD45 SD45 SD45

VELOCITY RANGE	ELAPSED TIME	% OF TOTAL TIME	FUEL USED
0 - 10 mph	0 hr 1.51 min	0.98%	2.06 gal
11 - 20 mph	0 hr 0.64 min	0.42%	4.77 gal
21 - 30 mph	0 hr 14.46 min	9.39%	182.87 gal
31 - 40 mph	0 hr 28.07 min	18.22%	361.99 gal
41 - 50 mph	0 hr 3.98 min	2.58%	46.59 gal
51 - 60 mph	0 hr 5.75 min	3.73%	69.78 gal
61 - 70 mph	1 hr 39.62 min	64.68%	535.75 gal
TOTAL	2 hr 34.03 min	100.00%	1203.81 gal

SAMPLE TPS OUTPUT

SAMPLE SUMMARY PRINTOUT

Job: PSSBNY   Train P001   27-Jul-76 Run 1 Page 2

	STATION	MILE POST	ELAPSED MILES	ELAPSED TIME	MPH ACT	MPH LIM	CLOCK TIME	FUEL (GAL)
LV	Buffalo	437.1	0.00	0: 0.00	0.0	30.0	10:00:00	0.00
LV	Lancaster	429.1	8.00	0:15.58	50.0	50.0	10:15:35	21.04
LV	Corfu	415.2	21.92	0:32.29	50.0	50.0	10:32:17	50.99
LV	Batavia	403.1	34.00	0:46.78	50.0	50.0	10:46:47	66.75
LV	Churchville	388.4	48.70	1: 4.42	50.0	50.0	11:04:25	75.16
LV	Chili Jct.	382.6	54.53	1:11.41	50.0	50.0	11:11:25	80.90
AR	Rochester	371.1	66.00	1:25.86	0.0	45.0	11:25:51	93.33
LV	Rochester	371.1	66.00	1:28.86	0.0	45.0	11:28:51	93.33
LV	E. Rochester	362.8	74.38	1:39.81	50.0	50.0	11:39:48	106.24
LV	Fairport	359.4	77.70	1:43.79	50.0	50.0	11:43:48	114.77
LV	Macedon	350.2	86.96	1:54.91	50.0	50.0	11:54:55	126.30
LV	Newark	341.0	96.15	2: 5.94	50.0	50.0	12:05:56	136.94
LV	Lyons	336.0	101.15	2:11.94	50.0	50.0	12:11:56	143.63
LV	N. Weedsport	323.1	114.00	2:27.84	50.0	50.0	12:27:50	161.09
LV	Warners	300.0	137.11	2:56.39	50.0	50.0	12:56:23	196.44
AR	Syracuse	285.7	151.41	3:14.36	0.0	30.0	13:14:22	213.66
LV	Syracuse	285.7	151.41	3:17.36	0.0	30.0	13:17:22	213.66
LV	Canastota	256.4	180.73	3:54.03	50.0	50.0	13:54:02	259.90
LV	Rome	251.6	185.56	3:59.82	50.0	50.0	13:59:49	265.80
AR	Utica	237.4	199.73	4:16.92	0.0	50.0	14:16:55	281.77
LV	Utica	237.4	199.73	4:19.92	0.0	50.0	14:19:55	281.77
LV	Herkimer	218.1	219.05	4:43.79	50.0	50.0	14:43:47	311.58
LV	Little Falls	215.2	221.94	4:47.25	50.0	50.0	14:47:15	314.80
LV	Fonda	195.8	241.33	5:10.52	50.0	50.0	15:10:31	336.55
AR	Amsterdam	184.2	252.98	5:24.70	0.0	50.0	15:24:42	351.97
LV	Amsterdam	184.2	252.98	5:26.70	0.0	50.0	15:26:42	351.97
LV	Hoffmans	170.0	267.11	5:44.43	30.0	30.0	15:44:26	373.86
LV	Rotterdam Jc	159.6	269.92	5:50.05	30.0	45.0	15:50:03	376.89
LV	S. Scheny.	152.4	277.15	6: 0.05	45.0	45.0	16:00:03	391.80
LV	Carman	156.5	281.78	6: 8.75	30.0	60.0	16:08:45	396.17
LV	Karner	152.0	286.23	6:14.01	60.0	60.0	16:14:01	406.40
LV	W. Albany	146.7	291.53	6:19.31	50.0	50.0	16:19:19	409.49
AR	Albany	145.5	292.73	6:20.85	0.0	50.0	16:20:51	410.00
LV	Albany	145.5	292.73	6:40.85	0.0	50.0	16:40:51	410.00
LV	Rensselaer	142.5	295.73	6:46.61	25.0	25.0	16:46:36	421.71
LV	Schodack Ldg	130.5	307.73	7: 1.02	60.0	60.0	17:01:01	443.51
LV	Stuyvesant	125.9	312.33	7: 5.62	50.0	50.0	17:05:37	450.32
LV	Newton Hook	122.0	316.25	7:10.32	50.0	50.0	17:10:19	455.55
LV	Hudson	118.0	323.70	7:19.32	43.0	44.0	17:19:19	465.19
LV	Rhinecliff	87.5	354.24	7:56.74	50.0	50.0	17:56:44	507.12
AR	Poughkeepsie	73.1	368.60	8:14.19	0.0	50.0	18:14:11	530.59
LV	Poughkeepsie	73.1	368.60	8:19.19	0.0	50.0	18:19:11	530.59
LV	CrotonHarmon	32.2	409.55	9:13.20	35.0	35.0	19:13:12	596.89
LV	MO	5.9	435.89	9:47.43	35.0	35.0	19:47:26	642.34
AR	New York	3.0	439.14	9:53.07	0.0	35.0	19:53:04	648.52

SAMPLE TPS OUTPUT

SAMPLE DETAIL PRINTOUT

JOBI FREIGT TRAIN F001 UTICA TO SELKIRK VIA PENN CENTRAL 24-JUL-76 RUN 1 PAGE 6

STATION	MILE POST	ELAPSED MILES	ELAPSED TIME	MPH ACT	MPH LIM	CLOCK TIME	FUEL (GAL)	DISTANCE (FEET)	GRADE (%)	CURVE (DEG)	DRAWBAR PULL	THROTTLE NOTCH	ACCEL (%G)
	199.6	37.81	0:46.34	50.0	50.0		135.45	199640.	0.000	0.000	10401.	3	00.000
	199.5	37.89	0:46.43	50.0	50.0		135.66	200040.	0.000	2.280	11721.	4	00.000
	199.3	38.08	0:46.66	52.0	50.0		136.28	201040.	0.000	0.000	15339.	4	00.000
	199.2	38.17	0:46.77	50.0	50.0		136.64	201540.	0.033	0.500	16842.	5	00.000
	199.1	38.28	0:46.91	50.0	50.0		137.08	202140.	0.044	0.000	17793.	5	00.000
	198.7	38.72	0:47.43	50.0	50.0		138.77	204420.	0.000	0.000	17316.	5	00.000
	198.6	38.81	0:47.54	50.0	50.0		139.14	204920.	0.000	2.000	17297.	5	00.000
	198.3	39.11	0:47.96	50.0	50.0		140.32	206520.	-0.115	0.000	17653.	5	00.000
	198.[illegible]	39.36	0:48.20	50.0	50.0		141.23	207820.	0.056	0.000	15226.	4	00.000
	198.[illegible]	39.39	0:48.24	50.0	50.0		141.34	208000.	0.071	0.600	14444.	4	00.000
	197.9	39.53	0:48.40	50.0	50.0		141.77	208700.	0.050	0.000	13737.	4	00.000
	197.8	39.64	0:48.53	50.0	50.0		142.14	209300.	0.057	0.880	15543.	4	00.000
	197.6	39.77	0:48.69	50.0	50.0		142.64	210000.	-0.080	0.880	17867.	5	00.000
	197.3	40.06	0:49.[illegible]	50.0	50.0		143.75	211500.	-0.075	0.000	16429.	4	00.000
	197.1	40.28	0:49.31	50.0	50.0		144.47	212700.	0.000	0.000	13207.	4	00.000
	196.7	40.72	0:49.83	50.0	50.0		145.83	214980.	0.000	0.930	15392.	4	00.000
	196.4	40.96	0:50.12	50.0	50.0		146.71	216280.	0.000	0.000	16063.	4	00.000
	196.3	41.06	0:50.23	50.0	50.0		147.06	216780.	0.000	0.830	16361.	4	00.000
	196.3	41.11	0:50.30	50.0	50.0		147.27	217080.	-0.050	0.830	16510.	4	00.000
	196.3	41.15	0:50.35	50.0	50.0		147.41	217280.	-0.063	0.000	16576.	4	00.000
	196.2	41.39	0:50.64	50.0	50.0		148.25	218560.	-0.064	0.000	14624.	4	00.000
LV FONDA	195.8	41.60	0:50.39	50.0	50.0	2:20:53	148.87						
	195.8	41.60	0:50.69	50.0	50.0		148.89	219660.	0.000	0.000	13022.	4	00.000
	195.6	41.81	0:51.14	50.0	50.0		149.52	220760.	0.000	0.480	14143.	4	00.000
	195.3	42.13	0:51.53	52.0	50.0		150.62	222460.	0.000	0.000	16080.	4	00.000
	195.1	42.32	0:51.75	50.0	50.0		151.31	223460.	0.000	0.970	16157.	4	00.000
	194.7	42.73	0:52.25	50.0	50.0		152.82	225640.	-0.025	0.970	17017.	5	00.000
	194.6	42.81	0:52.34	50.0	50.0		153.11	226040.	0.000	0.000	17095.	5	00.000
	194.5	42.89	0:52.43	50.0	50.0		153.40	226440.	-0.020	0.700	16994.	4	00.000
	194.4	42.98	0:52.54	50.0	50.0		153.75	226940.	-0.033	0.000	16739.	4	00.000
	194.3	43.09	0:52.66	50.0	50.0		154.16	227540.	-0.020	1.470	15699.	4	00.000
	194.2	43.19	0:52.79	50.0	50.0		154.49	228040.	-0.016	0.000	15699.	4	00.000
	194.0	43.43	0:53.08	50.0	50.0		155.33	229320.	-0.020	1.030	15249.	4	00.000
	193.8	43.62	0:53.31	50.0	50.0		155.99	230320.	0.111	1.030	15648.	4	00.000
	193.6	43.79	0:53.52	50.0	50.0		156.63	231220.	0.108	0.000	16997.	5	00.000
	193.4	44.04	0:53.81	50.0	50.0		157.70	232520.	-0.133	0.750	20307.	5	00.000
	193.3	44.15	0:53.95	50.0	50.0		158.21	233120.	-0.127	0.000	18430.	5	00.000
	193.[illegible]	44.36	0:54.2[illegible]	50.0	50.0		158.95	234220.	0.048	0.000	13089.	4	00.000
	193.[illegible]	44.66	0:54.56	49.2	50.0		159.61	235819.	0.048	0.000	943.	0	-0.210
	193.[illegible]	44.68	0:54.58	48.0	50.0		159.62	235920.	0.048	0.000	1016.	0	-3.554
	193.[illegible]	44.70	0:54.[illegible]	47.0	50.0		159.63	236019.	0.048	0.000	1089.	0	-3.556
	193.[illegible]	44.72	0:54.62	46.0	50.0		159.64	236116.	0.048	0.000	1161.	0	-3.558
	193.[illegible]	44.74	0:54.[illegible]	45.0	50.0		159.65	236211.	0.048	0.000	1234.	0	-3.560
	192.7	44.75	0:54.67	44.0	44.0		159.66	236300.	0.056	4.000	1307.	0	-3.727
	192.5	44.92	0:54.9[illegible]	44.0	50.0		160.31	237200.	-0.057	1.020	17596.	4	00.000
	192.2	45.19	0:55.20	44.[illegible]	50.0		161.40	238600.	-0.101	0.000	18111.	4	00.000
	192.2	45.47	0:55.44	45.[illegible]	50.0		162.83	240085.	-0.101	0.000	40668.	8	0.199
	192.2	45.55	0:55.75	46.[illegible]	50.0		163.60	240530.	-0.101	0.000	39646.	8	0.682
	191.[illegible]	45.58	0:55.79	46.4	50.0		163.85	240680.	0.000	0.000	39276.	8	0.822
	191.8	45.64	0:55.[illegible]	47.0	50.0		164.33	240965.	0.000	0.000	38039.	8	0.657
	191.8	45.73	0:55.[illegible]	48.[illegible]	50.0		165.17	241476.	0.000	0.000	37400.	8	0.621

SAMPLE TPS OUTPUT

SAMPLE TONNAGE RATING REPORT

1PSD 4G(160) 19-May-78 Job EBTR Train 3EBC Run 1 Page 9

TONNAGE RATING RUN NUMBER 1

From Hobart Yard to Barstow via A, T, & Santa Fe

With 4 units, including:
SD45
SD45
SD45
SD45

Horsepower: 14400.

Adhesion limit: 0.230
tons per car: 64.667

SEQ NO.	GRADE MILEPOST	GRADE FOOTAGE	MIN SPEED	HP/TT	TRAILING TONS	NO. OF CARS TOT	LD	MT	TRAIN LENGTH	GROSS TONS
4*	62.0	448843.	20.00	5.302	2716.	42	24	18	2364.	3496.
7	62.0	453372.	19.00	5.179	2781.	43	24	19	2414.	3561.

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