Research and Test Department

TRAIN ENERGY MODEL
USER'S MANUAL
VERSION 1.5

REPORT NO. R-711

William F. Drish, Jr.

Chicago Technical Center

ASSOCIATION
OF AMERICAN
RAILROADS

Association of American Railroads
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AAR Technical Center
Chicago, Illinois

W A R N I N G

Program PIX must NOT be used on any computer video display terminal before running program EQUIP to specify your monitor. The file CONFIG.GPC, which is created by running program EQUIP, must specify your monitor correctly. **AN INCORRECT SPECIFICATION MAY RESULT IN DAMAGE TO YOUR MONITOR!**

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13. ABSTRACT

To meet the requirements of the AAR Energy Research Program, a new train simulator, called the Train Energy Model (TEM) has been developed. The Train Energy Model consists of a set of programs which can be run on an IBM-compatible PC. The first version (1.0) of TEM was distributed to the railroad industry in 1986.

A new version (1.5) of TEM incorporates many new features that were suggested by users of Version 1.0, and an improved Automatic Train-handling Algorithm (ATA). All of the programming errors, which were identified in Version 1.0, have been corrected in Version 1.5.

The objective of this manual is to show the reader how TEM Version 1.5 can be used to simulate many types of train operations for the purpose of predicting fuel consumption and other train performance factors.

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EXECUTIVE SUMMARY

In 1982, the AAR began an Energy Research Program to study methods of reducing train resistance and the use of alternative fuels. One of the goals of the Energy Program is to develop a train simulator that can be used to study fuel consumption as it relates to train resistance and train handling techniques.

To meet the requirements of the AAR Energy Research Program, a new train simulator, called the Train Energy Model (TEM), has been developed from fundamental principles. The first version (1.0) of TEM was distributed to the railroad industry in 1986. Since that time, a new version of TEM (Version 1.5) has been developed.

TEM Version 1.5 incorporates many new features that were suggested by users of Version 1.0, and an improved Automatic Train-handling Algorithm (ATA). All of the programming errors, which were identified in Version 1.0, have been corrected in Version 1.5.

The Train Energy Model software package consists of four FORTRAN programs: the simulator itself, also known as TEM; a train consist preprocessor (incorporating other useful editing features), which is called PRE; a batch file editor, which is called BIF; and a data plotter, which is called PIX. These programs can be run on an IBM-compatible PC (286 or 386) with a

math coprocessor (287 or 387) under the DOS operating system.

The TEM was developed from the ground up -- with each level of development serving as a solid foundation for the next level. In ascending order these levels of development are:

1. Physical Model and Equation of Motion
2. Numerical Method (to integrate the equation of motion)
3. Train Control/Command Logic (to run the train)
4. Automatic Train-handling Algorithm (ATA)
5. User Interface

The first level of TEM development has been firmly established since Version 1.0. The realism of TEM results shows that the physical model and equation of motion are sound (for the level of detail appropriate to TEM).

Also, the second level of TEM development has been firmly established since Version 1.0. The accuracy of TEM results shows that the numerical method is sound. For TEM train movements, the computational error is usually less than 1% (even for simulated times exceeding 30 hours).

In TEM the motion of the train is determined by adhesion limited forces (supplied by the locomotives and brake systems), resistance (including the effects of wind), and grade forces. The locomotives and brake systems are controlled by commands that are consistent with the desired motion of the train. These commands can originate from three sources:

The User (manual train handling)
The ATA (Automatic Train-handling Algorithm)
The Stored Command File (preprogrammed train handling)

With the advent of Version 1.5, the third level of TEM development has been firmly established. The ability of the control/command logic in TEM to control all types of trains on all types of routes in a realistic manner (in all three control/command regimes) shows that the set of TEM commands is sound (for the level of detail appropriate to TEM).

In Version 1.5 of TEM, we have added a sentence parser and interpreter that allows the user to prepare English-language commands (in the preprocessor program PRE) or to enter English-language commands (during a simulation being run in manual mode in the simulator program TEM).

The Automatic Train-handling Algorithm (ATA) is a form of "artificial intelligence" that seeks to attain some desired motion of the train for the duration of a train movement. The desired motion of the train (which may not always be possible because of physical limitations) consists of (1) starting the train without inducing unacceptably large drawbar forces; (2) maintaining a constant reference speed or a speed limit (which may vary, depending on track position); and (3) stopping the train within an acceptable distance of the specified destination.

Essentially, ATA makes train handling decisions (i.e., determines locomotive control settings) based on the known equilibrium speeds and equilibrium control settings of the train to be controlled, and the speed error and/or acceleration error.

The fourth level of TEM development, while not as firmly established as the first three levels, has been brought to a fairly advanced state in Version 1.5. The ability of the ATA to make correct train-handling decisions for all types of trains on all types of routes in the majority of cases shows that the set of train-handling rules (which are "hard coded" in the "knowledge base" of ATA) is sound (for the level of detail appropriate to TEM).

Most users of TEM will rely on the ATA to handle the train in the vast majority of their simulations. For example, the use of the ATA is especially helpful in parametric studies to determine the affect on fuel consumption (or some other train performance factor) of a variable not directly related to train handling. That is, for a given train on a given track, the use of the ATA ensures consistent train handling, and thus effectively removes train handling as a variable.

However, the users of TEM must understand something about the limitations of the ATA: We are asking the ATA to be a "universal train controller" -- to handle all trains on all routes, to make the correct train-handling decision in all possible cases 100% of the time! In the real world, this cannot be done. Sure, we can make this our goal, but we must realize that we can only approximate the "universal train controller." Experience indicates that the ATA of Version 1.5 makes no train handling mistakes in at least 19 out of 20 simulations.

This brings us to the fifth level of TEM development. In addition to the use of English-language commands, the TEM Version 1.5 user interface incorporates three new features. First, the existence of all the files required to run a TEM simulation are automatically checked when the simulation is set up by the user in the batch file editor program BIF. If any necessary files are missing, the user is informed immediately.

Also, in program BIF, the train data and track chart files are automatically checked for a possible stall condition (which can exist if the train is underpowered with respect to the given route). If the possibility of a stall exists, the user is informed immediately. However, the user is not prevented from running the simulation, if he or she desires to do so.

Finally, the existence of all the files required to process a TEM train consist are automatically checked when the user wants to generate the corresponding train data file in the preprocessor program PRE. If any necessary files are missing, the user is informed immediately.

The objective of this manual is to show the reader how TEM

Version 1.5 can be used to simulate many types of train operations for the purpose of predicting fuel consumption and other train performance factors. Most users will find that TEM Version 1.5 is a useful and valuable tool.

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1.0 INTRODUCTION TO THE TRAIN ENERGY MODEL

1.1 Background

In 1982, the AAR began an Energy Research Program to study methods of reducing train resistance and the use of alternative fuels. One of the goals of the Energy Program is to develop a train simulator that can be used to study fuel consumption as it relates to train resistance and train handling techniques.

To meet the requirements of the AAR Energy Research Program, a new train simulator, called the Train Energy Model (TEM), has been developed from fundamental principles. The first version (1.0) of TEM was distributed to the railroad industry in 1986. Since that time, a new version of TEM (Version 1.5) has been developed.

TEM Version 1.5 incorporates many new features that were suggested by users of Version 1.0, and an improved Automatic Train-handling Algorithm (ATA). All of the known programming "bugs" (errors), which were identified in Version 1.0, have been corrected in Version 1.5.

The Train Energy Model software package consists of four FORTRAN programs: the simulator itself, also known as TEM; a train consist preprocessor (incorporating other useful editing features), which is called PRE; a batch file editor, which is called BIF; and a data plotter, which is called PIX. These programs can be run on an IBM-compatible PC (286 or 386) with a math coprocessor (287 or 387) under the DOS operating system.

NOTE: In this manual, the term "TEM" is used in two ways: to refer to the software package as a whole; and to refer to the simulator program alone. The meaning of the term "TEM" will be clear from the context in which it appears.

Some of the outstanding features of the TEM simulator include:

1. Manual train handling, including throttle, dynamic brake, and automatic and independent air brakes.
2. Automatic train handling, guided by track chart speed limits or constant reference speed.
3. Stored command train handling by actual train control time histories or by preprogrammed settings.
4. Independent motoring (autonomous) or multiple unit (synchronous) control for helper locomotives (throttle and dynamic brake settings only) in manual or automatic modes.
5. Arbitrary location, number, and type of locomotives in total train consist.
6. Multiple number of destination stops and arbitrary dwell times.
7. Track buffer allows track chart of any size (consistent with the storage capacity of the PC) to be used in a simulation.
8. Trackside lubricators may be specified on the track chart and may be "on" or "off" for a given simulation. Also, the use of vehicle mounted lubricators may be specified by the user.
9. Wind direction and speed may be specified at any point along a given track chart.

The objective of this manual is to show the reader how TEM Version 1.5 can be used to simulate many types of train operations for the purpose of predicting fuel consumption and other train performance factors. However, a brief discussion of some basic train concepts may be helpful to the reader at this point. Also, this chapter contains brief discussions of the mathematical modeling in TEM, the numerical method used in TEM, the train control/command logic in TEM, and the Automatic Train-handling Algorithm (ATA).

1.2 <u>Some Basic Train Concepts</u>

1.2.1 Diesel-Electric Locomotives

Basically, a diesel-electric locomotive consists of a fuel-consuming diesel engine, which drives an electric generator. The generator drives traction motors, which turn the locomotive's axles.

1.2.1.1 Throttle "Notch" Setting

The engineer uses the throttle to apply power to the train. The throttle on a diesel-electric locomotive has ten discrete settings or "notches." There is the setting for engine shutdown (indicated as "-1" in TEM); there is the setting for idle (notch 0); and there are the eight settings for increasing diesel engine power output -- designated "run 1" (notch 1) through "run 8" (notch 8).

1.2.1.2 Tractive Effort

The tractive effort of a locomotive is the force that the locomotive can supply for pulling or pushing. When a locomotive is at a standstill and the throttle is advanced to a notch greater than zero, the maximum tractive effort that the locomotive can supply is limited by the product of the adhesion coefficient of the wheels against the rails and the weight of the locomotive.

As soon as the locomotive starts to roll, the tractive effort becomes a function of the power output of the locomotive's diesel engine and the speed of the locomotive.

The tractive effort, given in units of pound-force (lbs), is directly proportional to the power output of the locomotive's diesel engine, given in units of horsepower (hp), and inversely proportional to the speed of the locomotive in miles/hour (MPH). Therefore, since the power output is directly proportional to the throttle setting at a given speed, the maximum tractive effort corresponds to throttle setting 8 (throttle at "run 8").

Since power can be applied only in steps, there are only eight tractive effort curves (one for each throttle notch "run" setting) for a diesel-electric locomotive. Exhibit 1 shows a set of tractive effort curves (force in lbs VS. locomotive speed in MPH) for a GP40 diesel-electric locomotive. Ideally, if the power output of the locomotive's diesel engine were constant for a given throttle setting, the tractive effort plotted against locomotive speed would be a rectangular hyperbola (i.e., decreasing tractive effort for increasing speed -- an inverse proportion).

Therefore, any deviation of a tractive effort curve from a rectangular hyperbola represents a variation in power output of the locomotive's diesel engine. If we were to draw a set of

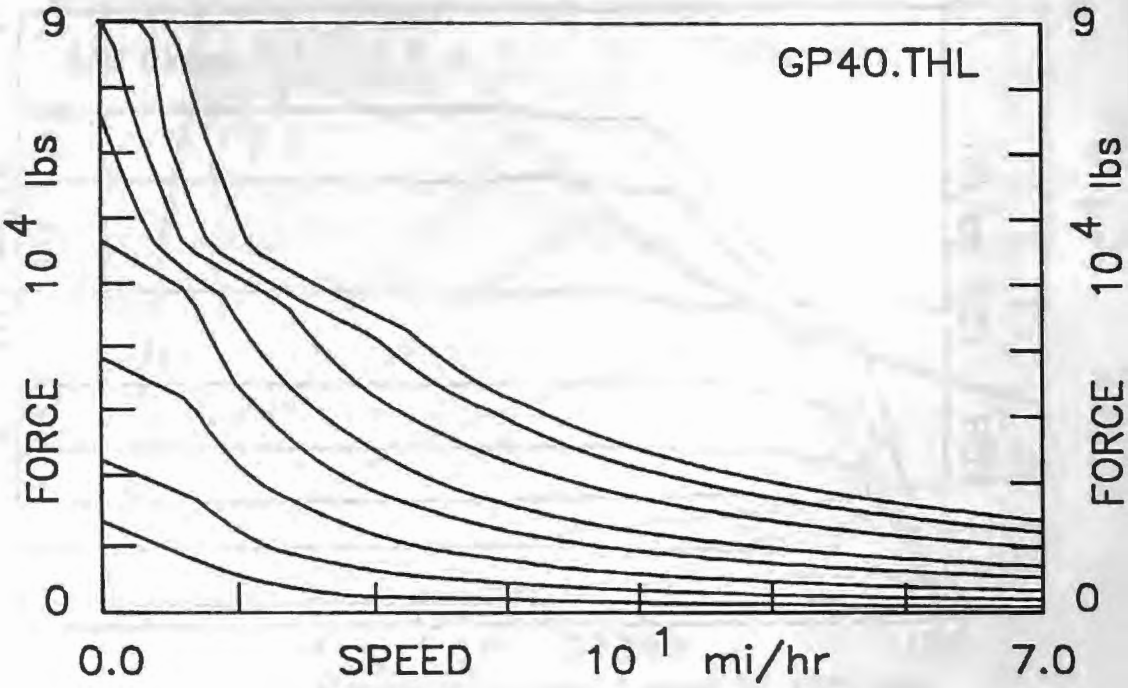


Exhibit 1. **Graph Showing GP40 Diesel-Electric Locomotive Tractive Effort (lbs) VS. Speed (MPH) Curves for Throttle Notch Setting 1 (Bottom) to Throttle Notch Setting 8 (Top).**

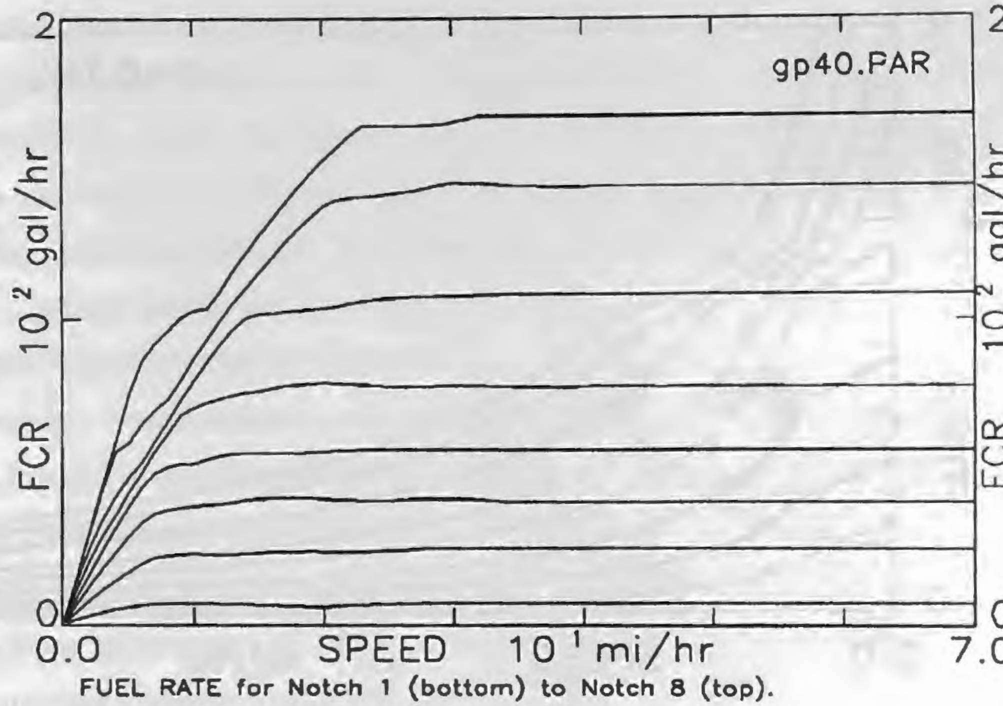


Exhibit 2. Graph Showing GP40 Diesel-Electric Locomotive Fuel Consumption Rate (gal/hr) VS. Speed (MPH) Curves for Throttle Notch Setting 1 (Bottom) to Throttle Notch Setting 8 (Top).

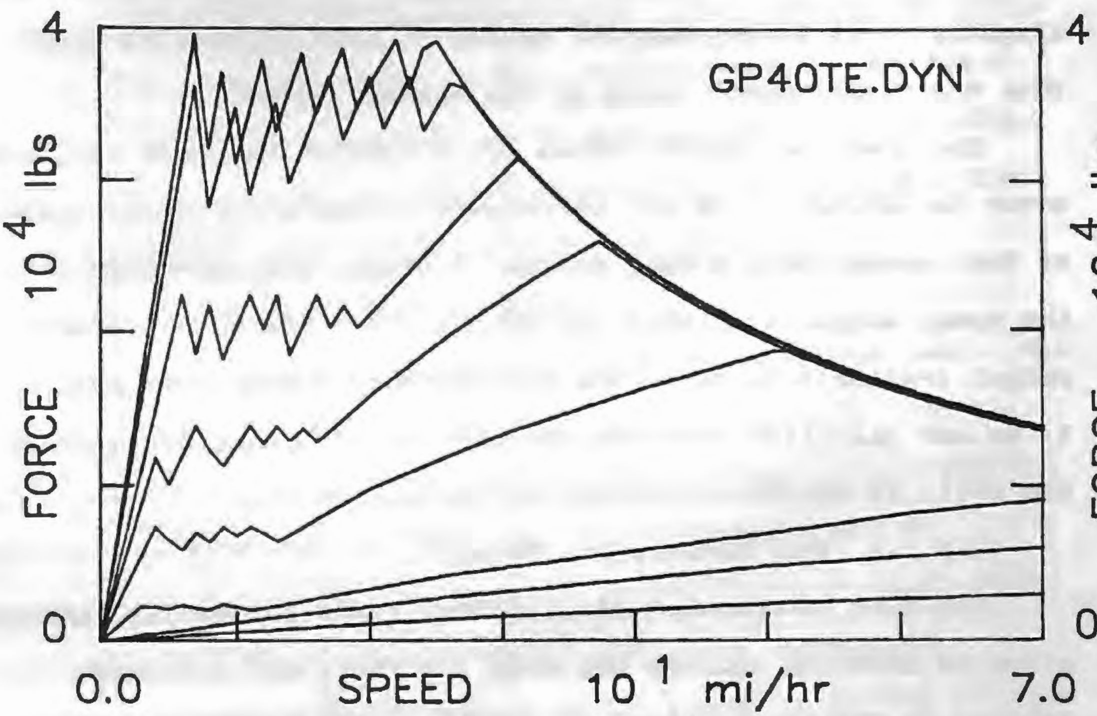


Exhibit 3.Graph Showing GP40 Diesel-Electric Locomotive Dynamic Braking Effort (lbs) VS. Speed (MPH) Curves for Dynamic Setting 1 (Bottom) to Dynamic Setting 8 (Top) for Dynamic Brake Type TE.

rectangular hyperbolas (one for each throttle notch setting) on the figure of Exhibit 1, we would see that the power output for a given throttle setting of the GP40's diesel engine varies with locomotive speed, especially at speeds below about 20 MPH. At very low speeds, it is clear that the maximum tractive effort is adhesion limited. (Actually, the adhesion coefficient decreases slightly -- in an exponential manner -- with increasing speed. Thus the "zero speed" value is the maximum value.)

The tractive effort curves for a locomotive, such as those shown in Exhibit 1, do not correspond to the total power output of the locomotive's diesel engine. Instead, they correspond to the power output available "at the rail" -- the actual power output available to drive the locomotive's axles. From Exhibit 1, we can calculate that the maximum (run 8) power output (at the rail) of the GP40's diesel engine is 2688 hp.

1.2.1.3 Fuel Consumption Rates

The fuel consumption rates (FCRs) for a locomotive, usually given in units of gallons per hour (gal/hr), are directly related to the power output of the locomotive's diesel engine. But, as we have seen, the power output of a diesel engine can vary significantly for a constant throttle setting, especially at low speeds. Therefore, the FCR for a given throttle setting must vary also. This is clear in Exhibit 2, which shows FCR curves for the GP40 locomotive. If we were to draw a set of straight lines (one for each throttle notch setting), which would represent the FCRs for constant power output, on the figure of Exhibit 2, we would see that the FCR for a given throttle setting of the GP40's diesel engine varies with locomotive speed, especially at speeds below about 20 MPH.

1.2.1.4 Diesel Fuel / Work Ratio

In TEM the diesel fuel/work ratio is defined as the ratio of the total fuel consumed by the locomotive(s) in the train consist (in gal) to the total work done by the tractive effort of the locomotive(s) (in kilo-horsepower-hours or Khph). Thus the diesel fuel/work ratio has units of gal/Khph.

1.2.1.5 Dynamic Braking Effort

The engineer uses the dynamic brake to slow the train. The dynamic brake, unlike the throttle, is a continuous control. During dynamic braking, the leads to the locomotive's traction motors are reversed, so that the traction motors act as generators, driven by the rotation of the axles to which they are attached. The traction motors, acting as generators, generate a "back EMF" (voltage), which causes a current to flow through the resistance of the cooling grids on the cab roof of the locomotive. The current heats the cooling grids. The heat dissipated by the grids is at the expense of the locomotive's kinetic energy. The loss of kinetic energy retards the forward motion of the locomotive, which in turn slows the train. (To prevent the grids from melting during dynamic braking, the diesel engine supplies power to grid cooling fans. For this reason, there is a fuel consumption rate for dynamic braking.) To allow for the transition from motor to generator, the diesel engine must be in idle for at least 10 seconds before the dynamic brake can be engaged.

The dynamic braking effort of a locomotive is the force that the locomotive can supply for retarding its own motion. The dynamic brake control varies continuously from a setting of 0 (no retarding force at any speed) to a maximum setting of 8 (maximum retarding force, depending on locomotive speed). When a locomotive is at a standstill, there is absolutely no retarding force due to dynamic braking, because the traction motor armatures are not being rotated by the locomotive's axles.

Exhibit 3 shows the dynamic braking effort curves (retarding force in lbs VS. locomotive speed in MPH) for a GP40 locomotive. There is one curve for each integral setting (1 to 8) of the dynamic brake control. However, the control can be set to values between these curves and to values less than 1. For a given locomotive speed, the dynamic setting 8 curve corresponds to the maximum retarding force available to slow the locomotive.

The characteristic shape of the curves is determined by the internal circuitry of the dynamic brake. There are four types of dynamic brake circuits with distinctly shaped characteristic curves: tapered extended (TE), tapered nonextended (TN), flat extended (FE), and flat nonextended (FN). Exhibit 3 shows an example of type TE dynamic brakes.

The locomotive tractive effort characteristics, dynamic braking characteristics, and fuel consumption rates (constant values) used in TEM simulations are supplied by the locomotive manufacturer.

1.2.2 Air Brakes

1.2.2.1 Automatic Air Brakes

The engineer uses the automatic air brake to slow or stop the train, when the dynamic brake is ineffective or when the use of the dynamic brake is not recommended. The automatic air brake control allows the engineer to generate a decrease in brake pipe pressure (called a "reduction") in units of pounds per square inch (PSI), which propagates through the train to cause an increase in retarding force (due to an increase in brake cylinder pressure) as it arrives at each vehicle. Also, the engineer uses the automatic air brake control to generate an increase in brake pipe pressure (called a "release"), which propagates through the train to cause a decrease in retarding force (due to a decrease in brake cylinder pressure) as it arrives at each vehicle. In general, a release is much quicker than a reduction. The delay time between application and resulting action for a reduction is large compared to the delay for the throttle or dynamic brake. This delay makes the proper use of the automatic air brake slightly complicated.

The automatic air brake operates with a "negative logic"; that is, a decrease in brake pipe pressure (reduction) causes an increase in retarding force (due to an increase in brake cylinder pressure), and an increase in brake pipe pressure (release) causes a decrease in retarding force (due to a decrease in brake cylinder pressure).

1.2.2.2 Independent Air Brakes

The engineer uses the independent air brake to "anchor" the train. This is especially useful when the train is at a standstill on a grade. Unlike the automatic air brake, the independent air brake applies only to the locomotives, and the retarding action is almost instantaneous. The independent air brake control allows the engineer to generate an increase in brake cylinder pressure, which causes a retarding force to act on the locomotive. The magnitude of the retarding force is directly proportional to the setting of the independent air brake control. The engineer "releases" the independent air brake by setting the control to the release position (by specifying 0 independent brake cylinder pressure in TEM).

Thus the independent air brake operates with a "positive logic"; that is, an increase in brake cylinder pressure causes an increase in retarding force, and a decrease in brake cylinder pressure causes a decrease in retarding force.

Also, the engineer can use the independent control to "bail-off" retarding force on the locomotive due to the automatic air brake, thus making the automatic air brake ineffective for the locomotive.

1.2.3 Train Resistance

1.2.3.1 The Davis Equation

Even with no dynamic or air braking applied, a rail vehicle is subject to retarding forces. These retarding forces -- all related to some kind of friction or drag -- are known collectively as "resistance." Resistance is modeled empirically by the Davis equation, which relates total resistance for a given vehicle to the sum of three types of resistances: vehicle dependent (constant) resistance; speed dependent resistance; and curve resistance.

Vehicle dependent or constant (for a given vehicle) resistance is the sum of the rolling resistance and the bearing resistance. The rolling resistance is the product of the coefficient of rolling resistance (in units of lbs/Ton) and the weight of the vehicle in Tons. The bearing resistance is the product of the coefficient of bearing resistance (lbs/axle) and the number of axles on the vehicle.

Speed dependent resistance is the sum of dynamic resistance and aerodynamic resistance. The dynamic resistance (not to be confused with dynamic braking effort) is the product of the coefficient of dynamic resistance (lbs/Ton/MPH) and the weight of the vehicle in Tons and the speed of the vehicle in MPH. The aerodynamic resistance or drag is the product of the coefficient of aerodynamic resistance (lbs/MPH/MPH) and the square of the speed (relative to the wind) of the vehicle in MPH.

The curve resistance is the product of the coefficient of curve resistance (lbs/Ton) and the weight of the vehicle in Tons. The coefficient of curve resistance depends on vehicle axle truck type (constant for a given vehicle). Also, for a given vehicle, the coefficient of curve resistance varies directly (but not linearly) with the curvature of the track that the vehicle is moving over at any given time.

The coefficient of rolling resistance is reduced by track lubrication, regardless of whether or not the track is tangent (straight). Also, depending on truck type and instantaneous track curvature, the coefficient of curve resistance is reduced by track lubrication.

The total train resistance is the sum of all the resistances acting on all the vehicles in the train consist.

1.2.3.2 Grade Force

Sometimes in the literature, grade force, which is just the tangential component of the gravitational force on a vehicle, is lumped with resistance and is called "grade resistance."

However, in this manual, we use the term "resistance" for a force that always retards vehicle motion. But grade force can contribute to forward motion, if the grade is negative (downhill). Thus grade force is a resistance only if the grade is positive (uphill). Therefore, in this manual, we consider grade force as a separate category of force, distinct from resistance.

The grade force is the product of the vehicle weight (in lbs -- instead of Tons, in this case) and the instantaneous grade (in percent) over which the vehicle is moving.

The total grade force acting on a train is the sum of the grade forces acting on all the vehicles in the train consist.

1.2.3.3 Equilibrium Speeds

An equilibrium speed of a train is a speed at which the total tractive effort of the locomotive(s) balances the sum of the total train resistance and the total grade force. At an equilibrium speed, the net force acting on the train is zero, and if this balance of forces can be maintained, the train will continue to move at the equilibrium speed. Since there are eight throttle notch settings for diesel engine power (run 1 through run 8), a train has eight equilibrium speeds for a given total curve resistance and a given total positive (uphill) grade force.

If we consider tangent track (zero curve resistance), then all of the eight equilibrium speeds decrease with increasing uphill grade. If the equilibrium speed for run 8 is zero for a given uphill grade, then the train "stalls." Thus the corresponding grade represents the ultimate physical limit of the ability of the locomotive(s) to move the train. If the same number of cars with the same total weight of lading is to be moved over such a grade, at least one more locomotive must be added to the train consist. However, enough locomotives should be added, so that the resulting speed on the grade is at least 10 MPH. Sustained speeds of less than 10 MPH can result in damage to the traction motors of the locomotives.

One way to characterize a train consist is to specify the maximum power/weight ratio in units of hp/TON. This is the ratio of the total train power (hp at the rail) to the total weight of the train (TONs). For example, consist P1 (which is discussed in the next chapter) includes four GP40s and 40 loaded intermodal cars of a certain type. The total train power is 10752 hp (since each GP40 has a maximum power output of 2688 hp) and the total train weight is 4616 TONs. Thus the maximum power/weight ratio for consist P1 is 2.33 hp/TON.

In general, the equilibrium speeds for a train on a given uphill grade increase as the the maximum power/weight ratio increases (i.e., as more locomotives are added to the consist). However, this direct proportion is not linear. That is, doubling the number of locomotives does not necessarily double the equilibrium speeds for a given uphill grade.

A concept similar to equilibrium speed is that of equilibrium control setting. For dynamic braking, an equilibrium setting is one at which the sum of the total dynamic braking effort of the locomotive(s) and the total train resistance balances the total negative (downhill) grade force for a given train speed.

If we consider tangent track, then the dynamic brake equilibrium setting for a given speed increases with increasing downhill grade. If the equilibrium setting for a given downhill grade and a given speed is the maximum setting (i.e., dynamic control setting 8), then that grade represents the limit of the ability of the dynamic brake to control the train (i.e., maintain the given speed) on a downhill grade.

Similarly, for automatic air braking, an equilibrium reduction is one at which the sum of the total air braking force of all the vehicles in the train (except for locomotives, when they are "bailed off") and the total train resistance balances the total negative (downhill) grade force for a given train speed.

If we consider tangent track, then the air brake equilibrium reduction for a given speed increases with increasing downhill grade. If the equilibrium reduction for a given downhill grade and a given speed is the maximum reduction (usually about 25 PSI), then that grade represents the limit of the ability of the automatic air brake to control the train (i.e., maintain the given speed) on a downhill grade.

Generally, for relatively steep downgrades (say 1 percent or steeper), the automatic air brake is required to control the train.

1.3 Mathematical Modeling in TEM

1.3.1 Physical Model

In TEM the train is considered to be a single "block." In this context, a block is a group of vehicles that maintain the same relative positions (and, thus, maintain zero relative velocities) throughout an entire simulation. Thus, during a given time interval, all of the vehicles in the train have the same common velocity and acceleration. However, the fact that the train is a single block does not mean that the train is modeled as a particle. Instead, the physical model of the train could be likened to a chain (with each link representing a vehicle) that conforms to the contours and curves of the track (as represented by a track chart).

The single-block model has two major advantages. First, since all of the vehicles in the train maintain the same relative positions for an entire simulation, solution of only one equation of motion is required to obtain the acceleration, velocity, and position of the leading vehicle with respect to some initial point specified on the track chart. Second, since the position of each vehicle in the train is known (once the position of the leading vehicle in the train has been computed from the equation of motion), the forces on each vehicle can be summed to compute the total force acting on the train for each time interval in the simulation. As a consequence of this, the computational time required for a given simulated train time varies directly (but not necessarily in a linear fashion) with the number of vehicles in the train.

The major disadvantage of the single-block model is that the coupler forces (intervehicular forces) cannot be computed directly. Computation of all of the coupler forces in a train with even a relatively small number of vehicles would involve the solution of a set of simultaneous equations of motion (one for each vehicle), which would limit the usefulness of the model for certain types of parametric studies, since each solution with a change of parameter would be relatively time consuming. However, in fuel consumption studies, the error due to interaction losses is negligible in comparison with the total train resistance. In such studies it may be sufficient to know the "drawbar" force, where the term "drawbar" refers to the coupler behind the last locomotive in the leading locomotive consist of the train. In TEM, a good estimate of the drawbar force is computed for each time interval in a simulation.

1.3.2 Equation of Motion

In TEM the acceleration of the train is determined by adhesion limited forces (supplied by the locomotives and brake systems), resistance (including the effect of wind), and grade forces. The equation of motion of the train is the relationship between the acceleration and the sum of these forces (Newton's second law).

At any given time, if the sum of the forces acting on the train is known, the acceleration can be computed directly from the equation of motion. However, since the acceleration is the rate of change of velocity with respect to time, and the velocity is the rate of change of position with respect to time, the equation of motion must be integrated (solved) to obtain the velocity of the train and the position of the train.

Unfortunately, the solution of the equation of motion is not simple, because many of the forces are nonlinear. For example, referring to Exhibit 1, we see that the tractive effort of a locomotive is inherently nonlinear.

1.4 Numerical Solution of the Equation of Motion

1.4.1 The TAME Method

Essentially, a TEM simulation consists of solving the equation of motion for each time increment from time zero, when the train leaves its initial position, until the time at which the train arrives at its final destination. Because the equation of motion in TEM is nonlinear, it cannot be integrated directly. A numerical method must be used to generate the solution as the simulation unfolds.

The numerical method used to solve the equation of motion in TEM is the TAME (for Taylor And Modified Euler) method, which was introduced by Drish and Wild in the May, 1983 issue of the American Journal of Physics in the paper entitled "Numerical Solutions of Van der Pol's Equation." The TAME method is ideally suited for PC train simulation programs, because it is (1) simple and easy to program (even for nonlinear equations), (2) stable for long-term solutions, and (3) stable for variable time increment solutions.

1.4.2 Variable Time Increment

The use of the single-block train model and the TAME method in TEM makes it possible to integrate the equation of motion with a simulation time increment that varies inversely with the acceleration of the train. Since acceleration is generally small -- less than 5 MPH/min -- during most of the time required for a typical train movement, the simulation of such a train movement using variable time increments permits simulation time increments that are generally large -- greater than 2 seconds --

without loss of accuracy.

Thus TEM can simulate train movements much quicker (in computer time) than would be possible with a fixed simulation time increment. In TEM, the time increment is allowed to vary between 1 second and 10 seconds, depending on the acceleration of the train. Also, the time increment is limited such that no velocity change greater than one MPH is allowed, and such that no position change greater than 180 feet is allowed during any given step of the simulation.

1.5 TEM Train Control / Command Logic

As mentioned above, in TEM the motion of the train is determined by adhesion limited forces (supplied by the locomotives and brake systems), resistance (including the effects of wind), and grade forces. The locomotives and brake systems are controlled by commands that are consistent with the desired motion of the train. These commands can originate from three sources:

The User (manual train handling)
The ATA (Automatic Train-handling Algorithm)
The Stored Command File (preprogrammed train handling)

Exhibit 4 is a schematic figure of the train control/command logic in TEM. Train control commands determine the settings of the locomotive's throttle, dynamic brake,

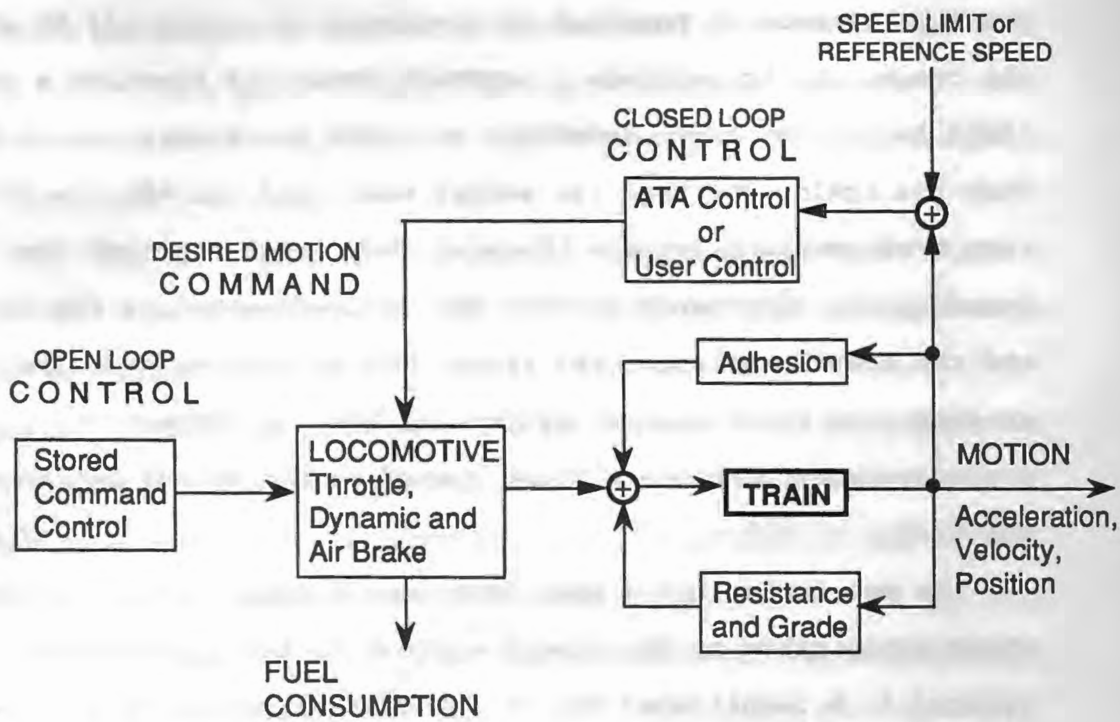


Exhibit 4. Figure Showing the Relationship of TEM Commands for the Desired Motion of the Train to the Actual Motion of the Train and to Fuel Consumption.

automatic air brake, and independent air brake controls. These settings determine the adhesion limited forces applied to the train by the locomotive(s) and the air brake systems. Along with train resistance and grade forces, these forces determine the actual acceleration, velocity, and position of the train.

The desired motion of the train (which may not always be possible because of physical limitations) is either (1) to start the train; (2) to maintain a constant reference speed or a speed limit (which may vary, depending on track position); or (3) to stop the train. The user (in manual mode) and the ATA are closed loop train control systems, because they issue commands that are based on the difference between the desired motion of the train and the actual motion of the train. The stored command file is an open loop train control system, because it issues preprogrammmed commands without regard to the actual motion of the train.

We see in Exhibit 4 that fuel consumption, almost all of which takes place in the diesel engines of the locomotives, is related in a complicated way to the desired motion of the train, the locomotive control settings consistent with the desired motion of the train (train handling), and the resistance and grade forces acting on the train, which determine the actual motion of the train.

1.6 Automatic Train-handling Algorithm (ATA)

Most users of TEM will rely on the Automatic Train-handling Algorithm (ATA) to handle the train in the vast majority of their simulations. For example, the use of the ATA is especially helpful in parametric studies to determine the affect on fuel consumption (or some other train performance factor) of a variable not directly related to train handling. That is, for a given train on a given track, the use of the ATA ensures consistent train handling, and thus effectively removes train handling as a variable.

The ATA is a form of "artificial intelligence" that seeks to attain some desired motion of the train for the duration of a train movement. For the purposes of this manual, a "train movement" is defined as consisting of three parts: (1) departure from a specified origin; (2) movement of the train from the origin to a specified destination; and (3) arrival at the destination. The desired motion of the train consists of (1) starting the train without inducing unacceptably large drawbar forces; (2) maintaining a constant reference speed or a speed limit (which may vary, depending on track position); and (3) stopping the train within an acceptable distance of the specified destination.

Essentially, ATA makes train handling decisions (i.e., determines locomotive control settings) based on the known equilibrium speeds and equilibrium control settings of the train to be controlled, and the speed error and/or acceleration error. The speed error is the difference between the current reference speed (a constant or a speed limit) and the actual speed of the train. In stage 2 of a train movement, speed error is the main factor in the determination of which control is required (throttle, dynamic, or air) and which control setting is required (to correct the error). The acceleration error is the difference between the current reference acceleration and the actual acceleration of the train. In stages 1 and 3 of a train movement, acceleration error, along with speed error, is a major factor in the determination of the required control setting.

Users of TEM must understand something about the limitations of the ATA: We are asking the ATA to be a "universal train controller" -- to handle all trains on all routes, to make the correct train-handling decision in all possible cases 100% of the time! In the real world, this cannot be done. Sure, we can make this our goal, but we must realize that we can only approximate the "universal train controller." Experience indicates that the ATA of TEM Version 1.5 makes no train handling mistakes in at least 19 out of 20 simulations.

2.0 USING THE TRAIN ENERGY MODEL: A PRELIMINARY EXAMPLE

To put into perspective the details presented in the following chapters, this chapter contains a brief discussion of the four TEM programs and a preliminary example showing how the reader can use these four programs to set up, run, and evaluate a simulated train movement.

2.1 TEM Software Overview

The Train Energy Model software package consists of four FORTRAN programs: the simulator itself, which is called TEM; a train consist preprocessor (incorporating other useful editing features), which is called PRE; a batch file editor, which is called BIF; and a data plotter, which is called PIX.

Exhibit 5 is a figure showing the relationship between the four TEM programs. The preprocessor program (PRE) -- in its primary function (Function 1) -- processes train consist data that can be used directly by the simulator program. The batch file editor program (BIF) allows the user to set up a batch file that will inform the simulator program as to how many and which simulations are to be run. The simulator program (TEM) runs the simulation or simulations specified in the batch file. Also, TEM uses the preprocessed train consist data generated by PRE, as well as other data related to train handling and track. The data plotter program (PIX) -- in its primary function (Function 1) --

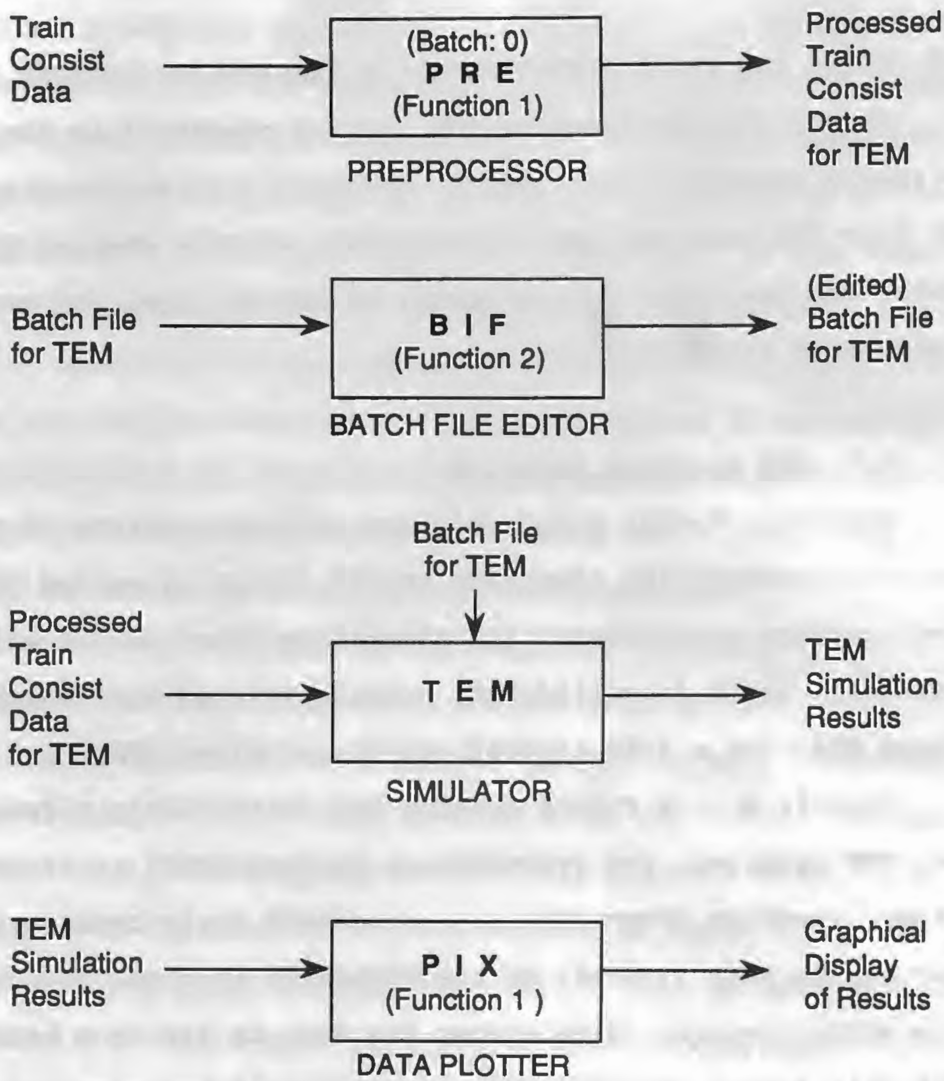


Exhibit 5. **Figure Showing the Relationship Between TEM Programs.**

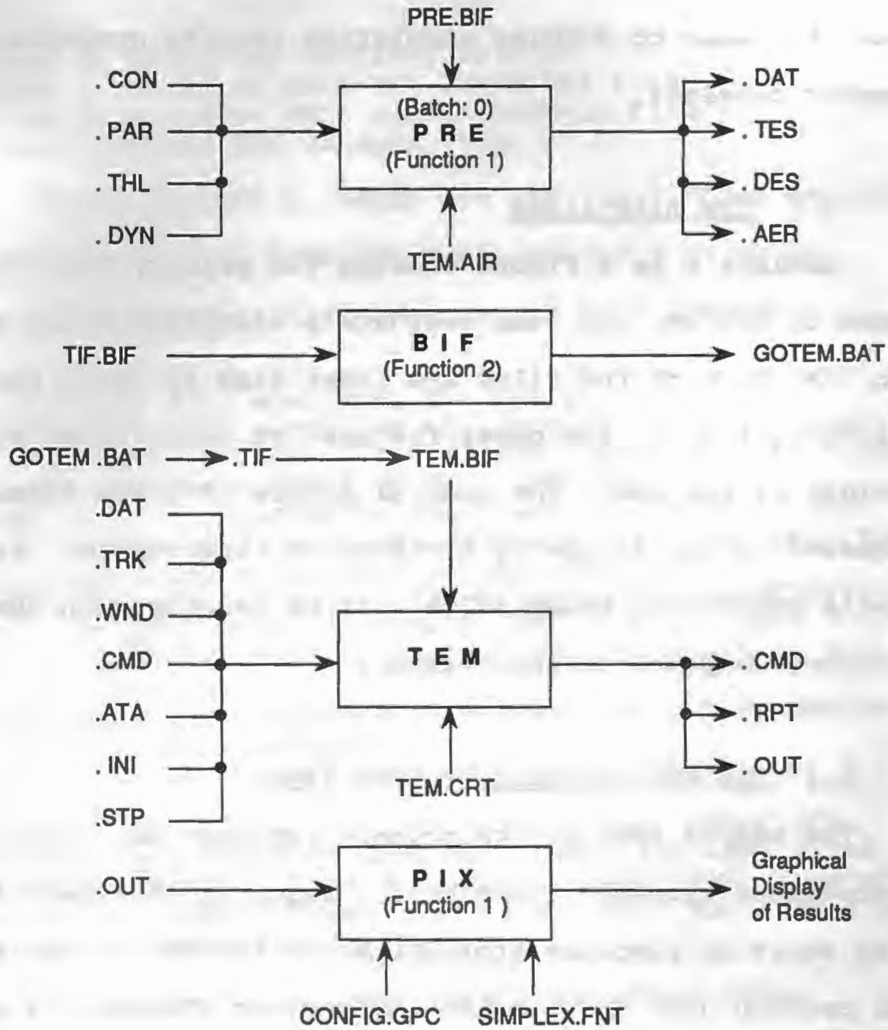


Exhibit 6. Figure Showing the Primary Disk Files Needed to Set Up, Run, and Evaluate a Simulated Train Movement with TEM.

allows the user to display simulation results graphically on the computer terminal.

2.2 TEM Disk Files

Exhibit 6 is a figure showing the primary disk files needed to set up, run, and evaluate a simulated train movement with TEM. Most of the files are identified by their extensions (following a "."). The names for most of these files are provided by the user. The general nature of these files will be discussed in the following sections of this chapter, and the details related to these files will be discussed in the following chapters of this manual.

2.3 The Preprocessor Program (PRE)

The use of PRE, in its primary function as a train consist preprocessor program (Function 1), requires that certain disk files exist in computer storage. Also, the use of TEM requires that certain disk files exist in computer storage. As a convenience for TEM users, PRE has several secondary functions which enable the user to process, create, or modify various files required for PRE or TEM. The functions of PRE are:

Function 1: Process Existing Train Consist File
Function 2: Build New Train Consist File
Function 3: Build New Vehicle Parameter File
Function 4: Build New Track Chart File
Function 5: Build New Wind Chart File

Function 6: Build New Destination File
Function 7: Build or Edit ATA Parameter File
Function 8: Build or Edit Initialization File
Function 9: Build New Command File

Referring to Exhibit 6: There are six input files required to run PRE Function 1 in terminal mode (Batch: 0 -- batch processing of consists is discussed in the next chapter):

.CON	This file specifies the train consist.
.PAR	This file specifies the parameters for a vehicle. There must be a .PAR file for each different type of vehicle named in the .CON file.
.THL	This file contains the tractive effort values. There must be a .THL file for each different type of locomotive named in the .CON file.
.DYN	This file contains the dynamic braking effort values. There must be a .DYN file for each different type of dynamic braking named in the .CON file.
TEM.AIR	This file contains parameters for the automatic air brake system.
PRE.BIF	This is the PRE batch initiation file.

NOTE: The .PAR, .THL, and .DYN files for a number of locomotives are supplied with TEM. Also, the .PAR files for various types of cars are supplied with TEM. However, the user may need to create new .PAR, .THL, and .DYN files for his or her own applications.

Referring to Exhibit 6: There are four output files generated by PRE Function 1:

.DAT	This file contains all of the preprocessed train consist data, including equilibrium speeds and equilibrium control settings.
.TES	This file contains a table of equilibrium speeds for the train under throttle control on various uphill grades.

.DES This file contains a table of dynamic settings required to maintain the train at various equilibrium speeds for various downhill grades.

.AER This file contains a table of brake pipe reductions required to maintain the train at various equilibrium speeds for various downhill grades.

NOTE: All four of these files have the same name as the corresponding .CON file.

2.4 The Batch File Editor Program (BIF)

The purpose of the batch file editor program BIF is to allow the user to set up the files required for PRE or TEM batch jobs. The functions of BIF are:

Function 1: Edit PRE Batch File
Function 2: Edit TEM Batch File

Referring to Exhibit 6: The output file which is generated by BIF Function 2 is:

GOTEM.BAT This file contains computer system commands that (1) copy information to the TEM batch initiation file, TEM.BIF, and (2) run TEM. There is a set of copy and run commands for each simulation to be run by TEM.

2.5 The Simulator Program (TEM)

The use of TEM requires that certain disk files exist in computer storage. Referring to Exhibit 6: There are nine input files required to run TEM:

.DAT This file contains all of the preprocessed train consist data, including equilibrium speeds and equilibrium control settings.

.TRK This file contains track chart data such as elevation, percent grade, and curve at specified track positions.

.WND This file contains wind directions and speeds for various points along the track chart.

TEM.CRT This file contains experimental curve resistance values for (1) regular truck on dry curve, (2) regular truck on lubricated curve (3) radial truck on dry curve, and (4) radial truck on lubricated curve.

.ATA This file contains the values for certain adjustable parameters required by the Automatic Train-handling Algorithm (ATA) to control the train during a TEM simulation.

.CMD This file contains a set of TEM train control and simulation control commands.

.INI This file contains the information required to initialize a TEM simulation, including the initial position of the train on the track chart.

.STP This file contains track position and dwell time for each destination in a given simulation.

TEM.BIF This is the TEM batch initiation file. This file obtains information from GOTEM.BAT for each simulation to be run.

NOTE: The .TRK files for a number of simulation examples are supplied with TEM. However, the user will need to create new .TRK files for his or her own applications.

NOTE: The .ATA, .CMD, .INI, and .STP files all must have the same name in common: the name of the simulation.

Referring to Exhibit 6: There are three output files generated by each run of TEM:

.CMD This file contains a set of TEM train control and simulation control commands. This file may change only if TEM is run manually. Otherwise, it is exactly the same as the input .CMD file.

.RPT This file contains a fuel consumption and energy report.

.OUT This file contains train handling data.

2.6 The Data Plotter Program (PIX)

The purpose of the data plotter program PIX is to allow the user to graphically display on the computer terminal the results of a TEM simulation. The functions of PIX are:

Function 1: Plot Two Dependent Variables from ONE TEM Output File
Function 2: Plot One Dependent Variable from TWO TEM Output Files
Function 3: Plot Locomotive Tractive Effort, Fuel Rate, and Dynamic Brake Curves
Function 4: Plot Track Profiles, Speed Limits, and Track Layout from Track Chart Data

Referring to Exhibit 6: The only input file required by PIX Function 1 is a .OUT file.

2.7 A Simulation Example

2.7.1 Simulation P1: Movement of a Fast Intermodal Train

A preliminary example of a TEM simulation, called Simulation P1, which simulates the movement of a fast (up to 70 MPH) intermodal ("piggyback") train from one fictitious city (Metropolis) to another (Gotham City), over tangent level track (the cities are separated by 50 miles of flat prairie land with no intervening natural barriers), will serve as a simple model to show the reader how the four TEM programs can be used to set up, run, and evaluate a simulated train movement.

The presentation of Simulation P1 will not include all aspects nor detailed explanations of every facet of the simulation. The details relating to the files and procedures involved in any TEM simulation will be presented in the following chapters of this manual. The purpose of this chapter is to give the reader an overview of a TEM simulation.

2.8 Using PRE to Set Up the Disk Files

2.8.1 Train Consist Files

The number and type of vehicles in a train consist, the weight of fuel or lading for each vehicle, and the parameters of each type of vehicle must be specified in disk files. In addition, for each type of locomotive, the tractive effort characteristics, dynamic braking characteristics, and fuel consumption rates must be specified in disk files.

2.8.1.1 P1.CON File

The train for Simulation P1 consists of four GP40 diesel-electric locomotives with type TE dynamic brakes, each loaded with 10 Tons of fuel, pulling forty intermodal ("piggyback") cars, designated "IMODAL". Each intermodal car carries two loaded trailers (the lading) with a combined weight of 60 Tons. The consist is tabulated below:.

CONSIST for SIMULATION P1

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
GP40 (TE)	4	10
IMODAL	40	60

The file P1.CON specifies the train consist for Simulation P1. This file is set up by running program PRE (type "PRE" on the terminal) and selecting Function 2 (Build New Train Consist File). The name of the file does not need to be "P1"; but this name is convenient. File P1.CON, along with other files, is used to compute the contents of file P1.DAT with PRE Function 1, which is discussed below.

2.8.1.2 IMODAL.PAR and GP40.PAR Files

The files IMODAL.PAR and GP40.PAR specify the parameters of the vehicles in the train consist for Simulation P1. The file IMODAL.PAR is set up by running program PRE and selecting Function 3 (Build New Vehicle Parameter File). The IMODAL.PAR file contains the following information:

Number of axles	4
Gross rail load (lbs)	198800
Empty vehicle weight (TONs)	40.0
Vehicle length for couplers in equilibrium (ft)	94.7
"Stand-alone" drag coefficient (lbs/MPH/MPH)	0.1330
Truck type	(regular) 0

The first line of the GP40.PAR file contains the same type of information as the IMODAL.PAR file:

Number of axles	4
Gross rail load (lbs)	257000
Empty vehicle weight (TONs)	144.0
Vehicle length for couplers in equilibrium (ft)	59.0
"Stand-alone" drag coefficient (lbs/MPH/MPH)	0.0660
Truck type	(regular) 0

The second line of the GP40.PAR file contains the constant FCRs (gal/hr) for dynamic braking, idle, and notches 1 through 8 (in that order):

21.0 3.1 8.0 20.7 43.1 59.1 77.5 95.6 127.0 152.4

The third line contains the zero speed adhesion coefficient: 0.285.

Files IMODAL.PAR and GP40.PAR, along with other files, are used to compute the contents of file P1.DAT with PRE Function 1, which is discussed below.

2.8.1.3 GP40.THL and GP40TE.DYN Files

The GP40.THL file contains the tractive effort values (lbs) for each speed from 0 to 70 MPH, in one MPH increments, for each notch from 1 to 8. Exhibit 1 is a graph of the contents of file GP40.THL. The GP40TE.DYN file contains the dynamic braking effort values (lbs) for each speed from 0 to 70 MPH, in one MPH increments, for each integral dynamic setting from 1 to 8. Exhibit 3 is a graph of the contents of file GP40TE.DYN.

Files GP40.THL and GP40TE.DYN, along with other files, are used to compute the contents of file P1.DAT with PRE Function 1.

2.8.1.4 TEM.AIR File

The TEM.AIR file contains parameters for the automatic air brake system. The following parameters are included in TEM.AIR:

Maximum brake pipe pressure (PSI)	90
Characteristic delay time for application (sec)	1.0
Characteristic delay time for release (sec)	1.0
Net braking ratio for empty vehicles	0.3
Net braking ratio for fully loaded vehicles	0.1
Coefficient of friction for brake shoes	0.3

File TEM.AIR, along with other files, is used to compute the contents of file P1.DAT with PRE Function 1.

2.8.1.5 P1.DAT File

File P1.DAT contains all of the preprocessed train consist data, including equilibrium speeds and equilibrium control settings for consist P1. This file is generated by running program PRE and selecting Function 1 (Process Existing Train Consist File). The computation of the contents of file P1.DAT requires information from files P1.CON, IMODAL.PAR, GP40.PAR, GP40.THL, GP40TE.DYN, and TEM.AIR. In addition, the following resistance coefficients were used:

Dynamic (lbs/TON/MPH)	0.03
Bearing (lbs/axle)	18.0
Rolling (lbs/TON)	1.50

2.8.1.6 P1.TES File

File P1.TES contains a table of equilibrium speeds for train consist P1 under throttle control. The equilibrium speeds in MPH are given for notches 1 to 8 and grades from 0 to 3%, in increments of 0.2%. Exhibit 7 shows the contents of file P1.TES (equilibrium speeds less than 10 MPH are not shown).

Consist: P1 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 2.33

%Grade								
3.0								
2.8								
2.6								10
2.4								11
2.2							10	13
2.0						12	14	17
1.8					11	15	18	21
1.6					12	17	22	25
1.4				10	14	19	24	27
1.2				12	16	22	28	31
1.0				14	19	25	32	36
0.8			11	17	23	30	37	41
0.6			14	21	27	36	44	48
0.4		11	19	28	34	44	52	56
0.2		16	27	37	44	54	61	65
0.0	16	29	39	49	56	65	72	76
Notch	1	2	3	4	5	6	7	8

Exhibit 7. Table Showing Train Consist P1 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

From the table, we see that train consist P1 is capable of a top speed of 76 MPH (in run 8) on tangent level track.

2.8.2 Track and Wind Files

2.8.2.1 P1.TRK File

As mentioned above, Metropolis and Gotham City are separated by 50 miles of flat prairie land with no intervening natural barriers. Thus the track between the two cities is tangent (no curves) and level (no changes in elevation). However, there are several speed limit changes with a maximum speed limit of 70 MPH.

The file P1.TRK specifies the track chart for Simulation P1. This file is set up by running program PRE and selecting Function 4 (Build New Track Chart File). The name of the file does not need to be "P1"; but this name is convenient. File P1.TRK contains the following information for each specified track position (ft):

Track elevation (ft) at specified position
Percent grade at (and following) specified position
Curve (degrees) between current specified position and next
Speed limit (MPH) at (and following) specified position
Milepost number at specified position
Place name (if any) at specified position
Trackside lubricator code:
- 1 if a trackside lubricator is present
- 0 if no trackside lubricator is present

2.8.2.2 NOWIND.WND File

The file NOWIND.WND specifies the wind chart for Simulation P1. This file is set up by running program PRE and selecting Function 5 (Build New Wind Chart File). File NOWIND.WND contains the following information for each specified track position (ft):

Wind direction (degrees)	0
Wind speed (MPH)	0

It is assumed that the prevailing winds between Metropolis and Gotham City are calm most of the time.

2.8.3 Train Control and Operations Files

2.8.3.1 P1.ATA File

The P1.ATA file contains the values for the adjustable parameters required by the Automatic Train-handling Algorithm (ATA) to control the train during Simulation P1. This file is set up by running program PRE and selecting Function 7 (Build or Edit ATA Parameter File). The P1.ATA file contains the following information:

1. The use of dynamic brakes is allowed (1 for "yes", 0 for "no")	--->	1
2. Average acceleration to bring train up to speed on departure from origin	--->	12.0 MPH/min
3. Offset speed margin for automatic speed-limit control of train speed	--->	0. MPH
4. Maximum speed allowed for automatic speed-limit control of train speed	--->	100. MPH
5. Average deceleration to stop train on approach to destination	--->	16.0 MPH/min

NOTE: The above values are "default values." These values should allow the ATA to make good train handling decisions for most trains on most tracks. However, the user may need to adjust some of these values for his or her own applications -- in the event that ATA makes inadequate train handling decisions.

2.8.3.2 P1.CMD File

During Simulation P1, we want the ATA to maintain train speed at the speed limits (on track chart P1.TRK) for the entire train movement from Metropolis to Gotham City. The easiest way to accomplish this is to allow the ATA to guide the train from origin to destination. The P1.CMD file contains the TEM train control and simulation control commands required to run Simulation P1. This file is set up by running program PRE and selecting Function 9 (Build New Command File). The P1.CMD file contains (virtually) the following commands:

Maintain speed <u>LIM</u>its for 50 <u>MIL</u>es
<u>END</u> Simulation

NOTE: The underlined and capitalized letter groups in the above command sentences are key letter groups used by TEM to interpret the meaning of English-language commands. The words "maintain", "speed", and "for" are not necessary for TEM; they are merely for the convenience of the user. Thus the commands could just as well have been:

```
LIM 50 MIL
END
```

The actual contents of P1.CMD is the corresponding command number codes:

```
6  -1    50.00 3
0   0     0.00 0
```

2.8.3.3 P1.INI File

The P1.INI file contains the information required to initialize Simulation P1, including the initial position of the train on the track chart (Metropolis is at track position 0 miles and 0 feet). This file is set up by running program PRE and selecting Function 8 (Build or Edit Initialization File). The P1.INI file contains the following information:

```
 1. Train data file name                      ---> P1
 2. Track chart file name                     ---> P1
 3. Wind chart file name                      ---> NOWIND
 4. File output time interval                 --->   30. sec
 5. Terminal output time interval             --->   30. sec
 6. Initial heading of leading vehicle        --->    0. deg
 7. Initial position of leading vehicle       --->    0  miles
 8. (plus)                                    --->    0. feet
 9. Status of vehicle-mounted lubricators---> 0  ("off")
10. Status of trackside lubricators           --->    0  ("off")
11. Effective lubrication distance            ---> 3600. feet
12. Reduction in rolling resistance           --->  0.70 lbs/ton
```

NOTE: The above values for items 4 to 12 are "default values". The user needs to supply the file names. If there is no lubrication, the values for items 11 and 12 have no effect on the simulation.

2.8.3.4 P1.STP File

The P1.STP file contains the track position and dwell time for the destination in Simulation P1. Gotham City is at track position 50 miles and 0 feet and it is the only destination. We will make the nominal dwell time one minute, during which the diesel engines will be in idle (notch 0). This file is set up by running program PRE and selecting Function 6 (Build New

Destination File). File P1.STP contains the following information:

Track position of destination	50 miles
(plus)	0 feet
Dwell time at destination	1 minute
Locomotive dwell setting	0 (idle)

2.9 Using BIF to Set Up the Batch Job

Even if TEM is to run only one simulation at a time, as is the case with Simulation P1, TEM must obtain information from batch file GOTEM.BAT. File GOTEM.BAT contains computer system commands that: (1) copy information to the TEM batch initiation file, TEM.BIF, and (2) run TEM. This file is set up by running program BIF (type "BIF" on the terminal) and selecting Function 2 (Edit TEM Batch File). For Simulation P1, BIF sets up a file called P1.TIF, and puts the following system commands in file GOTEM.BAT:

```
Copy P1.TIF     TEM.BIF
TEM
```

File P1.TIF contains the information that there is one batch job and that the simulation is called "P1".

2.10 Using TEM to Run the Simulation

To run Simulation P1, we type "GOTEM" on the computer terminal. The copy command in GOTEM.BAT informs TEM that the simulation to be run is called "P1". The run command in GOTEM.BAT then starts the simulator program.

2.10.1 Input Files

The file P1.INI informs TEM that the preprocessed consist data is in file P1.DAT, that the track chart is in file P1.TRK, and that the wind chart is in file NOWIND.WND. Also, file P1.INI informs TEM that the leading locomotive has an initial direction of 0 degrees, an initial position of 0 miles and 0 feet, and that there will be no lubrication used in Simulation P1. File P1.CMD informs TEM that the ATA is to issue the train control commands in Simulation P1, and that train speed is to follow the track chart speed limits for the entire 50 mile train movement. Finally, file P1.STP informs TEM that the first and only destination for Simulation P1 is at track position 50 miles and 0 feet.

2.10.2 Computer Terminal Display

While Simulation P1 is in progress, a constantly changing display appears on the computer terminal. The interval between display changes is nominally 30 seconds for Simulation P1 -- as specified in file P1.INI. However, because of the variable simulation time increment, the solution of the equation of motion may not be available at precisely 30 second intervals. In that case, the solution nearest to the nominal interval is displayed on the terminal. The display includes the following information:

Train control settings:	
Leading locomotive throttle	(indicated as "run")
Helper locomotive throttle	(following "/")
Leading locomotive dynamic	(one-tenth resolution)
Helper locomotive dynamic	(following "/")
Automatic air brake reduction	(indicated as "psi")
Elapsed simulated train time:	
Hours	(indicated as "h")
Minutes	(indicated as "m")
Seconds	(indicated as "s")
Track position of leading vehicle:	
Miles	(indicated as "mi")
Feet	(indicated as "ft")
Velocity of train (MPH):	
Actual speed	
Current speed limit	(following "/")
Acceleration of train (mph/min)	
Drawbar force (lbs)	
Track data:	
Milepost number	
Elevation	(indicated as "ft")
Direction with respect to initial heading	(indicated as "deg")

NOTE: If a place name (at one of the specified positions on the track chart) is close to the current track position of the leading vehicle in the train, the place name appears on the terminal display, instead of the three items of track data (milepost number, elevation, and direction).

The terminal display values for a few of the simulated times during the progress of Simulation P1 are shown in Exhibit 8.

```
___ CONTROL ___    Time    Position Velocity  Accel.  Force  MILE- Elev.Direc.
run dynamic psi   h  m  s  mi    ft    MPH    mph/min   lbs  POST ___ft____deg
0/0 0.0/0.0   0.  0  0  0   0     0  0.00/70   0.00      0.(METROPOLIS       )
4/0 0.0/0.0   0.  0  0 30   0   186  9.53/70  21.60 125706.(METROPOLIS       )
4/0 0.0/0.0   0.  0  1  0   0   784 16.55/70  10.80  77115.(METROPOLIS       )
                     .
                     .
                     .
6/0 0.0/0.0  0.   0 28  1  24  4993 60.56/60   6.00  40855.  20.0     0.    0.
                     .
                     .
                     .
0/0 0.0/0.0   5.  0 54 30  49  4060  9.86/70 -19.20-110375.(GOTHAM CITY     )
0/0 0.0/0.0   5.  0 55  0  49  5069  1.51/70  -9.60 -26684.(GOTHAM CITY     )
0/0 0.0/0.0   0.  0 55 30  49  5073  0.00/70   0.00      0.(GOTHAM CITY     )
```

Exhibit 8. Figure Showing a Few of the Display Values That Appear on the Terminal During Simulation P1.

T E M FUEL and ENERGY REPORT for SIMULATION P1
OPERATIONS SUMMARY

CONSIST P1		
No. Vehicles in Consist	44	
No. Leading Locomotives	4	
No. Cars (and shutdown locos.)	40	
No. Helper Locomotives	0	
Total Train Length	4024	feet
Total Train Power (at the rail)	10752	hp
Total Train Weight	4616	Tons
Weight of Fuel	40	Tons
Weight of Lading	2400	Tons
Empty Train Weight	2176	Tons
Maximum Power/Weight	2.33	hp/TON
TRACK P1		
No. Stops	1	
Total Distance Traveled	49 mi 5013	ft
Total Elapsed Time	0 h 54 m 54	s
Over-the-Road Time	0 h 53 m 41	s
Dwell Time	0 h 1 m 13	s
Average Over-the-Road Speed	56	MPH
TOTAL FUEL CONSUMPTION	362	gal
Diesel Fuel/Work	62	gal/Khph

Exhibit 9. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File P1.RPT.

2.10.3 Report and Train Handling Files

The terminal display values for Simulation P1 provide only "snapshots" of the progress of the simulation. As Simulation P1 unfolds, the displayed quantities, as well as others, are written to disk file P1.OUT at intervals of 30 seconds (simulated time) -- as specified in file P1.INI. The file output time interval does not need to be the same as the terminal display output time interval, but 30 seconds is convenient for both time intervals in this simulation.

Also, as Simulation P1 progresses, various quantities are accumulated at each simulation time increment. When the simulation has ended, these quantities are summarized in a report in file P1.RPT. Then program TEM is terminated.

2.10.3.1 P1.RPT File

File P1.RPT contains the fuel and energy report for Simulation P1. The first part of the report is a train consist and train operations summary for Simulation P1. This summary is shown in Exhibit 9.

2.10.3.2 P1.OUT File

File P1.OUT contains train handling data for every 30 seconds (nominally) of Simulation P1. This information can be used to evaluate various train performance factors as functions of elapsed time or track position. The information contained in file P1.OUT includes (for each output interval):

Integral number of elapsed hours:
    (plus) Integral number of minutes
    (plus) Integral number of seconds
Integral number of miles for current position:
    (plus) Integral number of feet
Velocity of train in MPH
Acceleration of train in MPH/min
Cumulative fuel consumption in gallons
Throttle notch setting of leading locomotive consist
Dynamic brake setting of leading locomotive consist
Automatic brake pipe pressure in PSI
Independent brake cylinder pressure in PSI
Reverser switch setting (NOT IMPLEMENTED)
Elevation in ft of leading vehicle in train
Current speed limit in MPH
Drawbar force estimate in lbs
Throttle notch setting of helper locomotive consist
Dynamic brake setting of helper locomotive consist
Rolling resistance coefficient in lbs/TON
Direction angle of leading vehicle in train in degrees
Position projection along tangent to original heading
    in miles
Position projection along normal to original heading
    in miles

2.11 Using PIX to Plot the Results

We can plot various combinations of variables in file P1.OUT by running program PIX (type "PIX" on the terminal) and selecting Function 1 (Plot Two Dependent Variables from ONE TEM Output File). These variables are:

1 Elapsed Time [minutes]
2 Position [miles]
3 Speed [MPH]
4 Acceleration [MPH/min]
5 Fuel Consumed [gallons]
6 Throttle Control [notch]
7 Dynamic Control ["notch"]
8 Brake Pipe Pressure [psi]
9 Independent Pressure [psi]
10 -- NOT IMPLEMENTED --
11 Elevation [feet]
12 Speed Limit [MPH]
13 Drawbar Force [lbs]
14 Helper Throttle [notch]
15 Helper Dynamic ["notch"]
16 Rolling Resistance [lbs/TON]
17 Direction Angle [degrees]
18 Tangent Projection [miles]
19 Normal Projection [miles]

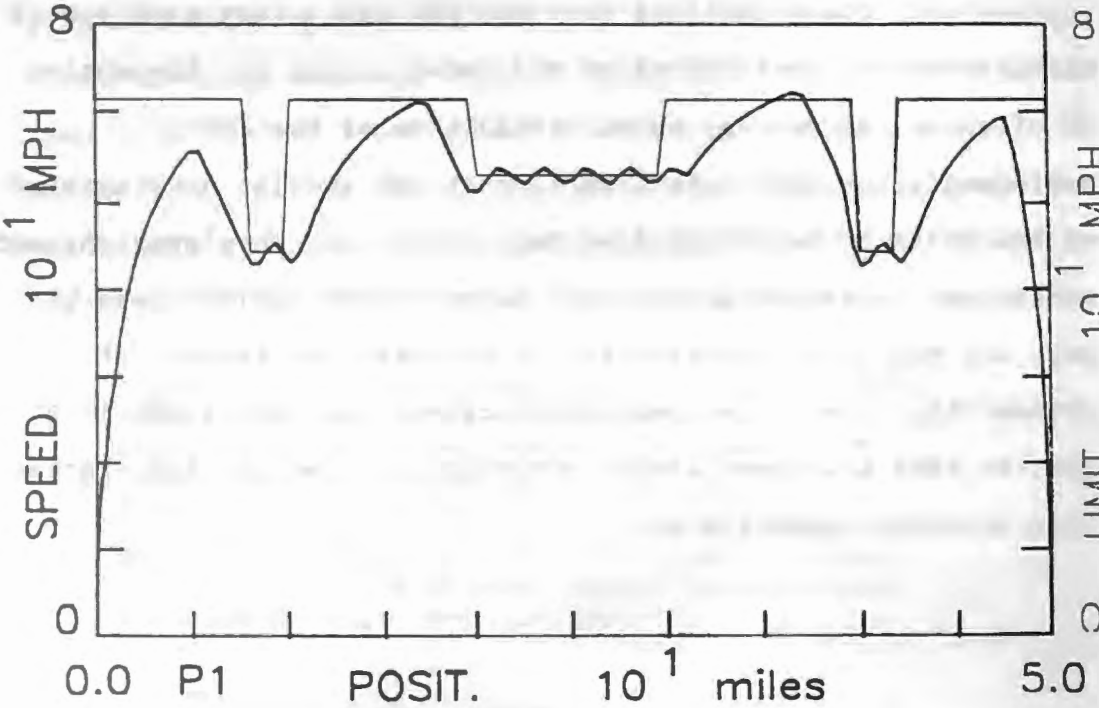


Exhibit 10. Graph Showing Train Speed(MPH) and Speed Limit (MPH) VS. Track Position (miles) for simulation P1.

For example, if we want to evaluate the performance of the ATA for Simulation P1, we can plot speed (item 3) and speed limit (item 12) against track position (item 2) to see how well the ATA matched train speed to the speed limits. Exhibit 10 is a graph of speed (MPH) and speed limit (MPH) VS. track position (miles) for Simulation P1.

We see from Exhibit 10 that the ATA did a very good job of maintaining the train speed at the speed limits for the entire 50 mile run. Of course, in our evaluation of the ATA's performance, we must take into account the initial acceleration of the train on departure from Metropolis, the decelerations and subsequent accelerations to meet slower speed limits along the way, and the final deceleration of the train on arrival at Gotham City. Also, the speed error offset in file P1.ATA is 0 MPH, so that the speed limits act as guides for the ATA, rather than absolute upper limits.

3.0 THE PREPROCESSOR PROGRAM (PRE)

To reduce the time required for any given TEM simulation, all of the train-related computations that can be done prior to a simulation are carried out in the train consist data preprocessor program, which is called PRE.

The use of PRE, in its primary function as a train consist preprocessor program (Function 1), requires that certain disk files exist in computer storage. Also, the use of TEM requires that certain disk files exist in computer storage. As a convenience for TEM users, PRE has several secondary functions which enable the user to process, build, or edit various files required for PRE or TEM. The functions of PRE are:

Function 1: Process Existing Train Consist File
Function 2: Build New Train Consist File
Function 3: Build New Vehicle Parameter File
Function 4: Build New Track Chart File
Function 5: Build New Wind Chart File
Function 6: Build New Destination File
Function 7: Build or Edit ATA Parameter File
Function 8: Build or Edit Initialization File
Function 9: Build New Command File

3.1 <u>Preprocessor Functions</u>

3.1.1 Function 1: Process Existing Train Consist File

This is the primary function of PRE. As mentioned above, all of the train-related computations that can be done prior to a simulation are carried out by this preprocessor function. A train consist file (.CON file) and the associated train data file (.DAT file) generated by PRE must exist before a given train can be used in a TEM simulation. For a given train, it is necessary to run the preprocessor only once. A given .DAT file generated by PRE can be used for any number of different TEM simulations involving the same train.

The contents of a .CON file are described below. A .CON file may be generated by the user with the editor program on the PC or by using the secondary PRE function which is described below.

NOTE: In general discussions of most TEM files in this manual, the files are identified by their extensions (which are three characters in length, following a "."). In practice, the names of these files (which are up to six characters in length, followed by the ".") are provided by the user. Usually, the names are chosen to have some significance related to the nature of the user's application.

3.1.2 Function 2: Build New Train Consist File

This is the secondary PRE function that allows the user to create a new .CON file in the proper format for later processing by PRE (to generate the associated .DAT file). However, once the new .CON file has been created, the user must use the editor program on the PC to make any necessary corrections. The necessity to use the PC editor to make corrections also applies to new vehicle parameter files (.PAR files), new track chart (.TRK) files, new wind chart (.WND) files, new destination files (.STP) files, and new command (.CMD) files created with PRE.

3.1.3 Function 3: Build New Vehicle Parameter File

This is the secondary PRE function that allows the user to create a new vehicle parameter file (.PAR file) in the proper format for later processing by PRE. The contents of a .PAR file are described below. Each different type of vehicle listed in a .CON file must have a corresponding .PAR file.

3.1.4 Function 4: Build New Track Chart File

This is the secondary PRE function that allows the user to create a new track chart file (.TRK file) in the proper format for later use in a TEM simulation. A .TRK file contains track chart data such as elevation, percent grade, and curve at specified track positions. The contents of a .TRK file are described below.

3.1.5 Function 5: Build New Wind Chart File

This is the secondary PRE function that allows the user to create a new wind chart file (.WND file) in the proper format for later use in a TEM simulation. A .WND file contains wind directions and speeds for various points along the track chart. The contents of a .WND file are described below.

3.1.6 Function 6: Build New Destination File

This is the secondary PRE function that allows the user to create a new destination file (.STP file) in the proper format for later use in a TEM simulation. A .STP file contains track position and dwell time for each destination in a given simulation. The contents of a .STP file are described below.

3.1.7 Function 7: Build or Edit ATA Parameter File

This is the secondary PRE function that allows the user to create a new ATA adjustable parameter file (.ATA file) in the proper format for later use in a TEM simulation. A .ATA file contains the values for certain adjustable parameters required by the Automatic Train-handling Algorithm (ATA) to control the train during a TEM simulation. The contents of a .ATA file are described below. Unlike the previous functions, PRE Function 7 allows the user to change or correct an existing .ATA file without using the PC editor. The changes or corrections are made while running PRE Function 7.

3.1.8 Function 8: Build or Edit Initialization File

This is the secondary PRE function that allows the user to create a new initialization file (.INI file) in the proper format for later use in a TEM simulation. A .INI file contains the information required to initialize a TEM simulation, including the initial position of the train on the track chart. The contents of a .INI file are described below. As is the case with Function 7, PRE Function 8 allows the user to change or correct an existing .INI file without using the PC editor. The changes or corrections are made while running PRE Function 8.

3.1.9 Function 9: Build New Command File

This is the secondary PRE function that allows the user to create a new TEM command file (.CMD file) in the proper format for later use in a TEM simulation. A .CMD file contains a set of TEM train control and simulation control commands. The contents of a .CMD file are described below.

3.2 PRE Disk Files

3.2.1 PRE.BIF Batch Initiation File

The PRE batch initiation file, PRE.BIF, must exist in computer storage before PRE can be run. Normally, PRE is not run in batch mode. However, in batch operation, it is assumed that one or more .CON files are to be processed to generate the corresponding .DAT files (the primary function of PRE). The first line of PRE.BIF contains:

Batch indicator (normally "0"; "1" indicates a batch job)

The second line of PRE.BIF contains:

Number of batch jobs (ALWAYS set to "1")

The third line of PRE.BIF contains five items:

Train consist file identifier (the extension .CON is assumed)
Default number for resistance coefficients (If the user wants to use values of the resistance coefficients other than default values, the default number is set to "0".)
Dynamic resistance coefficient in lbs/TON/MPH
Bearing resistance coefficient in lbs/axle
Rolling resistance coefficient in lbs/TON

The default resistance coefficients are:

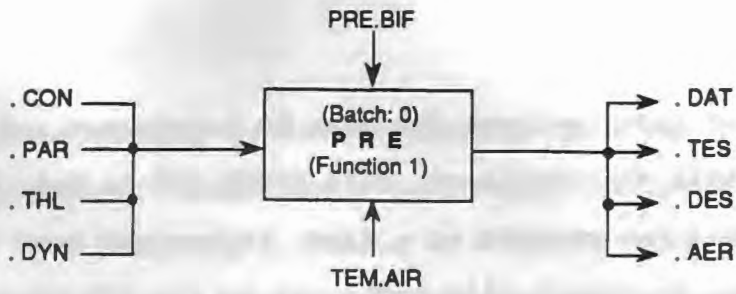
No.	Type of Equation	Dynamic (lbs/TON/MPH)	Bearing (lbs/axle)	Rolling (lbs/TON)
1	Canadian National (new)	0.03	18.0	1.50
2	Canadian National (old)	0.01	29.0	0.60
3	Davis	0.04	29.0	1.30

The PRE.BIF file can be edited (modified) by running program BIF and selecting Function 1 as explained in the next chapter.

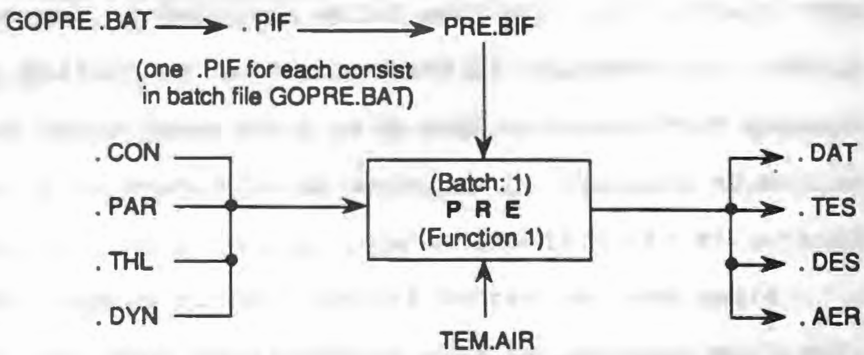
3.2.2 Function 1 Input Files

The use of PRE, in its primary function as a train consist preprocessor program, requires that certain disk files exist in computer storage. The number and type of vehicles in a train consist, the weight of fuel or lading for each vehicle, and the parameters of each type of vehicle must be specified in disk files. In addition, for each type of locomotive, the tractive effort characteristics, dynamic braking characteristics, and fuel consumption rates must be specified in disk files. Exhibit 11 is a figure showing the primary input disk files needed to run PRE Function 1 (at left), and the output disk files generated by PRE Function 1 (at right).

Exhibit 11A shows PRE Function 1 being run in terminal mode and Exhibit 11B shows PRE Function 1 in batch mode. To process one consist from the terminal (or to use any of the secondary functions of PRE), the batch file indicator in PRE.BIF must be set to 0 (Batch: 0). If another consist is to be processed in



(A) Processing of one consist from the terminal. The batch file indicator in PRE.BIF must be set to 0 (Batch: 0). If another consist is to be processed with Batch at 0, program PRE must be terminated and run again. To avoid this inconvenience, file GOPRE.BAT is set up to process more than one consist at a time.



(B) Processing of more than one consist from the batch job file GOPRE.BAT. There is one .PIF file in GOPRE.BAT for each consist to be processed. Also, the batch file indicator in PRE.BIF is set to 1 (Batch: 1).

Exhibit 11. Figure Showing the Primary Input Disk Files Needed to Run the Preprocessor Program PRE in Function 1 (at Left), and the Output Disk Files Generated by PRE Function 1 (at Right).

terminal mode, program PRE must be terminated and run again. To avoid this inconvenience, file GOPRE.BAT is set up to process more than one consist at a time. To process more than one consist, the batch file indicator in PRE.BIF is set to 1 (Batch: 1). The use of the batch file editor program BIF to set up the PRE batch job file GOPRE.BAT is discussed in the next chapter.

3.2.2.1 .CON File

This is the file that specifies the train consist. The user must specify the file name to be prefixed to the extension (.CON). For example, if the consist is identified by the user as consist "X," then the disk file X.CON must exist before PRE can be run in Function 1. The consist file name (identifier) can have up to six characters.

Since PRE can handle trains with up to 250 vehicles, the .CON file can have as many as 250 lines (one line for each vehicle in the train). Each line of the .CON file contains the following data:

```
Locomotive code:
     1 through 5 for locomotives
     0           for unpowered vehicles
Vehicle identifier:
     two blanks followed by four characters for locomotives
     six characters for unpowered vehicles
Dynamic brake type:
    two characters for locomotives
    two blanks for unpowered vehicles
Weight of fuel or lading in TONs
```

The locomotive code can be a number from 1 to 5. This means that there can be as many as five different types of locomotives in a consist. However, there can be any number of locomotives of a given type. The following contents of a sample file, X.CON, although artificial, may help to clarify the above description:

```
1   SD40 FE     12. (1st type of locomotive with 12 tons of fuel)
1   SD40 FE     12. (1st type of locomotive with 12 tons of fuel)
0 BOXCAR        60. (unpowered vehicle with 60 tons of lading)
0 BOXCAR        30. (unpowered vehicle with 30 tons of lading)
2   GP40 TE      8. (2nd type of locomotive with 8 tons of fuel)
0 HOPPER       100. (unpowered vehicle with 100 tons of lading)
0 HOPPER       100. (unpowered vehicle with 100 tons of lading)
3   SD40 TE     12. (3rd type of locomotive with 12 tons of fuel)
```

From this example, we see that the same locomotive (SD40 in this case) is considered to be a different type (with respect to the locomotive code), if it is repeated in the same .CON file with a different dynamic brake type.

3.2.2.2 .PAR File

This is the file that specifies the parameters for a vehicle. For each different type of vehicle in a .CON file, there must exist a .PAR file. The .PAR file for an unpowered vehicle has only one line; the .PAR file for a locomotive has two additional lines. The first line in all .PAR files has the same type of information:

Number of axles
Gross rail load (empty weight plus maximum lading weight) in lbs
Empty vehicle weight in TONs
Vehicle length for couplers in equilibrium in ft
"Stand-alone" drag coefficient in lbs/MPH/MPH

```
Truck type:
     0 for regular trucks
     1 for radial trucks
```

The second line of a .PAR file for a locomotive contains the following fuel consumption rate (FCR) data in gallons per hour (gal/hr):

```
FCR  for dynamic braking
FCR  for idle
FCRs for throttle notch 1 to throttle notch 8
```

The third line of a .PAR file for a locomotive contains one item of information:

Maximum ("zero-speed") adhesion coefficient

The contents of a sample .PAR file for an unpowered vehicle, BOXCAR.PAR, is shown below:

```
4 185000.  32.0  50.0 0.0776 0
```

The contents of a sample .PAR file for a locomotive, SD40.PAR, is shown below:

```
6 368000. 211.0  69.0 0.3255 0
21.0   3.1   8.0  20.7  43.1  59.1  77.5  95.6 127.0 152.4
0.235
```

3.2.2.3 .THL File

This file contains the tractive effort values (lbs) for each speed from 0 to 70 miles per hour, in one mile per hour increments, for each notch from 1 to 8. There must be a .THL file for each different type of locomotive in the .CON file. Thus, in the X.CON file discussed earlier, there must be both an SD40.THL file and a GP40.THL file. Exhibit 1 is a graph of the contents of file GP40.THL.

3.2.2.4 .DYN File

This file contains the dynamic braking effort (lbs) for each speed from 0 to 70 miles per hour, in one mile per hour increments, for the integral dynamic settings from 1 to 8. There must be a .DYN file for each different type of locomotive and each different dynamic brake type in the .CON file. Thus, for the X.CON file, there must be an SD40FE.DYN file, an SD40TE.DYN file, and a GP40TE.DYN file. Exhibit 3 is a graph of the contents of file GP40TE.DYN. As mentioned in the first chapter, there are four types of dynamic brakes: FE and TE (extended range), and FN and TN (non-extended range). The "F" stands for "flat" and the "T" stands for "tapered."

3.2.2.5 TEM.AIR File

This file contains parameters for the automatic air brake system. The file TEM.AIR must exist before PRE can be run. The following parameters are included in TEM.AIR:

Maximum brake pipe pressure in pounds per square inch (PSI)
Characteristic delay time for applications in seconds
Characteristic delay time for releases in seconds
Net braking ratio for empty vehicles
Net braking ratio for fully loaded vehicles
Coefficient of friction for brake shoes.

Values used in TEM Version 1.5 for TEM.AIR are:

90.0	1.0	1.0	0.3	0.1	0.3

The user can edit TEM.AIR with the PC editor to change any of these values. For example, the maximum brake pipe pressure can be changed to 80 PSI.

NOTE: The fact that the characteristic delay times for the application and release of the automatic air brakes in TEM is 1.0 second in both cases, does not mean that the total time required for a reduction or a release to be effective throughout the train is 1.0 second. The characteristic times are multipliers for the logarithmic delay function used in TEM to model brake pipe pressure propagation.

The delay time for a vehicle that is 64 feet or less from the nearest locomotive is considered to be 0 seconds; the delay for 128 feet is 1 second; the delay for 256 feet is 2 seconds; the delay for 512 feet is 3 seconds, and so on.

If the delay function were the only consideration, reductions and releases for a given vehicle in a train would have the same total delay time. Indeed, for a reduction less than 10 PSI, this is true. However, 1 second is added to the total delay time (for a given vehicle in the train) for a reduction for every 2 PSI greater than or equal to 10 PSI, starting with 5 seconds at 10 PSI. Thus, the total delay time (for a given vehicle in the train) for a 12 PSI reduction is 6 seconds longer than the total delay time for the subsequent release.

3.2.3 Function 1 Output Files

The use of PRE, in its primary function as a train consist preprocessor program, generates four output files for each .CON file. The primary output disk files generated by PRE Function 1 are shown at the left in Exhibit 11.

3.2.3.1 .DAT File

This file contains all of the preprocessed train consist data, including equilibrium speeds and equilibrium control settings, that will be used by TEM during any simulation that involves the corresponding train consist, which is specified in a .CON file.

3.2.3.2 .TES File

This file contains a table of equilibrium speeds for a train under throttle control. The equilibrium speeds in MPH are given for notches 1 to 8 and grades from 0 to 3%, in increments of 0.2%. This file has the same designator as the corresponding .CON file. As an example, Exhibit 7 shows the contents of file P1.TES.

3.2.3.3 .DES File

This file contains a table of dynamic brake settings required to maintain the train at equilibrium speeds from 0 to 70 MPH, in five MPH increments, for grades from 0 to -3%, in decrements of 0.2%. This file has the same designator as the corresponding .CON file. As an example, Exhibit 12 shows the contents of file P1.DES.

3.2.3.4 .AER File

This file contains a table of brake pipe reductions (5 to 25 PSI) required to maintain the train at equilibrium speeds from 0 to 70 MPH, in five MPH increments, for grades from 0 to

Consist: P1 DYNAMIC BRAKE EQUILIBRIUM SETTINGS

%Grade(-)															
0.0															
0.2		3	3	2	1	1	1	1	1	1	1	1	1	1	1
0.4		4	4	4	4	4	3	3	2	1	1	1	1	1	1
0.6		6	5	5	5	4	4	4	4	4	3	2	2	2	1
0.8		6	6	6	5	5	4	4	4	4	4	4	4	3	3
1.0		7	6	6	6	5	5	5	5	4	4	4	4	4	4
1.2		7	7	7	7	6	6	5	5	5					
1.4			7	7	7	7	6	6							
1.6			7	8	7	7	7								
1.8				8		8									
2.0															
2.2															
2.4															
2.6															
2.8															
3.0															
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 12. Table Showing Train Consist P1 Dynamic Brake Equilibrium Settings for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

Consist: P1 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6															
0.8	6	6	6	6	5	5	5	5	5						
1.0	7	7	7	7	7	7	7	6	6	6	6	5	5	5	
1.2	9	9	9	9	8	8	8	8	8	7	7	7	6	6	6
1.4	10	10	10	10	10	10	10	9	9	9	9	8	8	8	7
1.6	12	12	12	12	12	11	11	11	11	10	10	10	10	9	9
1.8	14	13	13	13	13	13	13	13	12	12	12	11	11	11	10
2.0	15	15	15	15	15	14	14	14	14	14	13	13	13	12	12
2.2	17	17	16	16	16	16	16	16	15	15	15	14	14	14	13
2.4	18	18	18	18	18	18	17	17	17	17	16	16	16	15	15
2.6	20	20	19	19	19	19	19	19	18	18	18	18	17	17	16
2.8	21	21	21	21	21	21	20	20	20	20	19	19	19	18	18
3.0	23	23	23	22	22	22	22	22	22	21	21	21	20	20	20
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 13. Table Showing Train Consist P1 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

-3%, in decrements of 0.2%. This file has the same designator as the corresponding .CON file. As an example, Exhibit 13 shows the contents of file P1.AER.

The equilibrium speeds and control settings in all three tables (.TES, .DES, and .AER) are incorporated in the .DAT file, and they are used by TEM to control the train in the ATA mode. The tables themselves are for the information of the user.

3.3 PRE Prompts

To run PRE, the user merely types "PRE" on the computer terminal. Assuming that PRE is not being run in batch mode, the following menu prompt appears on the screen below the header ("TRAIN ENERGY MODEL Preprocessor Version 1.5"):

```
(0)          Select Preprocessor Function:
             1. Process existing train consist file
             2. Build new train consist file
             3. Build new vehicle parameter file
             4. Build new track chart file
             5. Build new wind chart file
             6. Build new destination file
             7. Build or edit ATA parameter file
             8. Build or edit initialization file
             9. Build new command file

             0. Exit program PRE
```

NOTE: The "(0)" to the left of the first line does not appear on the screen; it is used in this manual to reference the prompt. As each prompt is presented, it will be assigned a number or a number and a letter in parentheses for future reference.

There is one audible "beep", indicating that the program requires one item of information. The user types the number of the desired preprocessor function.

3.3.1 Prompts for PRE Function 1

If the user selects PRE Function 1, the following prompts appear:

(1) Enter 6-character (or less) train consist file name (extension ".CON")

(2) Default resistance coefficients:

No.	Type of Equation	Dynamic (lbs/TON/MPH)	Bearing (lbs/axle)	Rolling (lbs/TON)
1	Canadian National (new)	0.03	18.0	1.50
2	Canadian National (old)	0.01	29.0	0.60
3	Davis	0.04	29.0	1.30

Select resistance equation coefficients from the above list. Enter "0" if user-defined values are to be entered below.

(3) Enter three quantities, separated by spaces
1) Dynamic resistance coefficient (lbs/ton/mph)
2) Bearing resistance coefficient (lbs/axle)
3) Rolling resistance coefficient (lbs/ton)

There is one "beep" following prompt (1), indicating that the program requires one item of information. The user types the name of the consist file (the ".CON" is assumed). There is one "beep" following prompt (2), indicating that the program requires one item of information. The user types the number of the desired set of default resistance coefficient values.

If the response to prompt (2) is "1", "2", or "3", prompt (3) does not appear. However, if the response to prompt (2) is "0", prompt (3) appears on the screen, and there are three "beeps", indicating that the program requires three items of information. The user types the three coefficient values.

At this point, after the response to prompt (2) or prompt (3), program PRE automatically checks for the existence of all the files required to process the train consist specified by the user: the .CON file itself; the .PAR files for the vehicles in the .CON file; and the .THL and .DYN files for the locomotives in the .CON file. If any necessary files are missing, the user is informed immediately and program PRE is terminated. The following four messages represent the four types of missing files:

File ______.CON must exist before consist ______ can be processed. You can use PRE Function 2 to create this file.

File ______.PAR must exist before consist file ______.CON can be processed. You can use PRE Function 3 to create this file.

File ____.THL must exist before consist file ______.CON can be processed.

File ______.DYN must exist before consist file ______.CON can be processed.

As an example, the PRE prompt responses required to process train consist file P1.CON are:

PRE Prompt		User Response	Comment
(0)	--->	1	PRE Function 1
(1)	--->	P1	consist file P1.CON
(2)	--->	1	coefficient set 1

While the program is computing the data that will go to the P1.DAT file, the following series of status messages appear on the screen as each of the indicated tasks begins in program PRE:

```
Processing consist file P1.CON     .
Program PRE status messages follow:

Reading train data from disk files,                    WAIT ...
Computing air brake delay times,                       WAIT ...
Computing speed-dependent fuel consumption rates,      WAIT ...
Computing speed-dependent adhesion coefficients,       WAIT ...
Computing throttle equilibrium speeds,                 WAIT ...
Computing dynamic brake equilibrium settings,          WAIT ...
Computing air brake equilibrium reductions,            WAIT ...
Writing train data to disk file,                       WAIT ...
```

Then the menu prompt (0) appears on the screen again. To exit the program, the user types "0", and the following message appears on the screen, accompanied by a "beep":

Program PRE terminated.

3.3.2 Prompts for PRE Function 2

If the user selects PRE Function 2, the following prompts appear:

(1) Enter 6-character (or less) train consist file name (extension ".CON")

(2) New T E M Train Consist File: ______.CON
NOTE: Number of vehicles cannot exceed 250.

VEHICLE ___
Is this vehicle a locomotive ? (Y/N)

If the user types "Y" or "y" in response to (2), the following prompts appear:

(2A) Enter 4-character locomotive designator

(2B) Enter number of ____s to place together in this part of train

(2C) Do all of these ____s have the same amount of fuel? (Y/N)

(2D) Enter amount of fuel (to the nearest TON)

NOTE: If the response to (2C) is not "Y", prompt (2D) is repeated for each of the locomotives specified in response to prompt (2B).

(2E) Do all of these ____s have the same type of dynamic braking? (Y/N)

(2F) Enter type of dynamic braking (2 characters)

NOTE: If the response to (2E) is not "Y", prompt (2F) is repeated for each of the locomotives specified in response to prompt (2B).

(3) Is this the last vehicle in the train (Y/N)?

If the user types "N" or "n" or "<ENTER>" in response to (2) (i.e., if the vehicle is a car), the following prompts appear:

(2G) Enter 6-character car designator

(2H) Enter number of ______s to place together in this part of train

(2I) Do all of these ______s have the same amount of lading? (Y/N)

(2J) Enter amount of lading (to the nearest TON)

NOTE: If the response to (2I) is not "Y", prompt (2J) is repeated for each of the cars specified in response to prompt (2H).

(3) Is this the last vehicle in the train (Y/N)?

As an example, the PRE prompt responses required to build train consist file P1.CON are:

PRE Prompt		User Response	Comment
(0)	--->	2	PRE Function 2
(1)	--->	P1	consist called "P1"
(2)	--->	y	1st vehicle a locomotive
(2A)	--->	GP40	locomotive designator
(2B)	--->	4	4 GP40s here
(2C)	--->	y	all same amount fuel
(2D)	--->	10	10 TONs of fuel each
(2E)	--->	y	all same dynamic type
(2F)	--->	TE	dynamic type TE
(3)	--->	n	not end of train, yet
(2)	--->	n	5th vehicle is a car
(2G)	--->	IMODAL	car designator
(2H)	--->	40	40 IMODALs here
(2I)	--->	y	all same amount lading
(2J)	--->	60	60 TONs of lading each
(3)	--->	y	end of train

3.3.3 Prompts for PRE Function 3

If the user selects PRE Function 3, the following prompts appear:

(1) Is the new parameter file for a locomotive? (Y/N)

(2) Enter 4-character designator for a locomotive (extension ".PAR") or
Enter 6-character designator for an unpowered vehicle (extension ".PAR")

(3) New T E M vehicle parameter file: ______.PAR

Enter number of axles

(4) Enter gross rail load in LBs

(5) Enter empty weight of vehicle in TONs

(6) Enter coupler-to-coupler length in FEET

(7) Enter "stand-alone" drag coefficient in LBs/MPH/MPH

(8) Enter truck type (0 for regular, 1 for radial)

(9A) Enter fuel consumption rate (GAL/HR) for dynamic braking

(9B) Enter fuel consumption rate (GAL/HR) for idle

(9C) Enter fuel consumption rate (GAL/HR) for notch 1

(9D) Enter fuel consumption rate (GAL/HR) for notch 2

(9E) Enter fuel consumption rate (GAL/HR) for notch 3

(9F) Enter fuel consumption rate (GAL/HR) for notch 4

(9G) Enter fuel consumption rate (GAL/HR) for notch 5

(9H) Enter fuel consumption rate (GAL/HR) for notch 6

(9I) Enter fuel consumption rate (GAL/HR) for notch 7

(9J) Enter fuel consumption rate (GAL/HR) for notch 8

(10) Enter maximum adhesion coefficient

NOTE: Prompts (9A) through (9J) and (10) appear only if the response to prompt (1) is "Y".

As an example, the PRE prompt responses required to build vehicle parameter file IMODAL.PAR are:

PRE Prompt		User Response	Comment
(0)	--->	3	PRE Function 3
(1)	--->	n	vehicle is a car
(2)	--->	IMODAL	car is called "IMODAL"
(3)	--->	4	4 axles
(4)	--->	190000	gross rail load LBs
(5)	--->	40.0	empty weight in TONs
(6)	--->	94.7	length in FEET
(7)	--->	0.1330	drag coefficient
(8)	--->	0	regular trucks

3.3.4 Prompts for PRE Function 4

If the user selects PRE Function 4, the following prompts appear:

(1) Enter 6-character (or less) track chart file name (extension ".TRK")

(2') New T E M Track Chart File: ______.TRK
NOTE: Use minus (-) to indicate right-hand curves.

POINT 1 (track position: 0 MILES 0 FEET)

NOTE: This merely shows that the first point on the track chart must be at 0 miles and 0 feet.

(2) New T E M Track Chart File: ______.TRK
NOTE: Use minus (-) to indicate right-hand curves.

POINT ___ Milepost: ___ Place: ________________
Position:___mi ____ft Elevation: ____ft Speed limit: __.MPH

POINT ___: Enter track position (with respect to 1st point) number of MILEs plus number of FEET

NOTE: The data for the previous point are listed for reference under the heading. Then the user is asked to enter the position of the next point.

(3) Enter track elevation in FEET

(4) Enter amount of curve in DEGREEs

(5) Enter speed limit in MPH

(6) Enter milepost number

(7) Enter 16-character (or less) place name (if any)
vvvvvvvvvvvvvvvv

(8) Is there a trackside lubricator here? (Y/N)

(9) Is this the last point in the track chart file? (Y/N)

As an example, the PRE prompt responses required to build the first two lines of track chart file P1.TRK are:

PRE Prompt		User Response	Comment
(0)	--->	4	PRE Function 4
(1)	--->	P1	track called "P1"
(2')		-	shows 1st track position
(3)	--->	0	sea level elevation 0 ft
(4)	--->	0	tangent track 0 degrees
(5)	--->	70	speed limit 70 MPH
(6)	--->	0	milepost 0
(7)	--->	METROPOLIS	city at milepost 0
(8)	--->	n	no lubricator here
(2)	--->	1 0	1 mile and 0 feet
(3)	--->	0	sea level elevation 0 ft
(4)	--->	0	tangent track 0 degrees
(5)	--->	70	speed limit 70 MPH
(6)	--->	1	milepost 1
(7)	--->		no place name here
(8)	--->	n	no lubricator here
(9)	--->	n	not last point, yet ...

3.3.5 Prompts for PRE Function 5

If the user selects PRE Function 5, the following prompts appear:

(1) Enter 6-character (or less) wind chart file name (extension ".WND")

(2') New T E M Wind Chart File: ______.WND

POINT 1 (track position: 0 MILES 0 FEET)

NOTE: This merely shows that the first point on the wind chart must be at 0 miles and 0 feet.

(2) New T E M Wind Chart File: ______.WND

```
POINT ___ Position:          ___ mi ____ ft
          Wind Direction:           ____ deg
          Wind Speed:               ____ mph
```

POINT ___
Enter track position (with respect to 1st point)
number of MILEs plus number of FEET

NOTE: The data for the previous point are listed for reference under the heading. Then the user is asked to enter the position of the next point.

(3) Enter wind direction in DEGREEs

(4) Enter wind speed in MPH

(5) Is this the last point in the wind chart file? (Y/N)

As an example, the PRE prompt responses required to build the wind chart file NOWIND.WND are:

PRE Prompt		User Response	Comment
(0)	--->	5	PRE Function 5
(1)	--->	NOWIND	chart called "NOWIND"
(2')		-	shows 1st track position
(3)	--->	0	direction doesn't matter
(4)	--->	0	0 MPH (no wind)
(2)	--->	500 0	500 miles and 0 feet
(3)	--->	0	direction doesn't matter
(4)	--->	0	0 MPH (no wind)
(5)	--->	y	last point

NOTE: The response to (2) -- 500 miles 0 feet -- is arbitrarily large to ensure that the wind chart data includes the entire track chart with which it is used.

3.3.6 Prompts for PRE Function 6

If the user selects PRE Function 6, the following prompts appear:

(1) Enter 6-character (or less) destination file name
        (extension ".STP")

(2) Is the new .STP file for a simulation to be run entirely
        by automatic control? (Y/N)

NOTE: If the response to prompt (2) is "Y", PRE will automatically set up a .CMD file (with the same name as the .STP file), while the .STP file is being created.

(2A) Is the new .STP file for a simulation involving a train
        with helper units? (Y/N)

NOTE: Prompt (2A) appears only if the response to prompt (2) is "Y". If the response to prompt (2A) is "Y", PRE will include the appropriate helper commands in the automatically generated .CMD file.

(3') New T E M Destination File: ______.STP

DESTINATION 1:
Enter track position:
number of MILEs plus number of FEET

NOTE: Prompt (3') appears only for the first destination.

(3) New T E M Destination File: ______.STP

DESTINATION ___ : Position: ___mi ____ft

DESTINATION ___:
Enter track position:
number of MILEs plus number of FEET

NOTE: The position for the previous destination is listed for reference under the heading. Then the user is asked to enter the position of the next destination. This prompt appears only if there is more than one destination.

(3A) Enter type of helper control to use until train reaches destination ___:
1) synchronous 2) autonomous

(3B) Should helpers be shutdown during train movement? (Y/N)

NOTE: Prompts (3A) and (3B) appear only if the response to prompt (2A) is "Y" (and the response to (2) is "Y").

(3C) Enter type of automatic control to use until train reaches destination ___:
1) speed limit 2) constant speed

NOTE: prompt (3C) appears only if the response to prompt (2) is "Y".

(4) Enter dwell time in minutes

(5) Should locomotives be shutdown during dwell time? (Y/N)

(6) Is this the last point in the destination file? (Y/N)

As an example, the PRE prompt responses required to build the destination file P1.STP are:

PRE Prompt		User Response	Comment
(0)	--->	6	PRE Function 6
(1)	--->	P1	file called "P1.STP"
(2)	--->	n	don't build P1.CMD now
(3')	--->	50 0	GOTHAM CITY at 50 miles
(4)	--->	1	1 minute dwell (nominal)
(5)	--->	n	let locomotives idle
(6)	--->	y	last destination

3.3.7 Prompts for PRE Function 7

If the user selects PRE Function 7, the following prompts appear:

(1) Enter 6-character (or less) ATA parameter file name (extension ".ATA")

(2) Is this .ATA file an existing file that is to be edited? (Y/N)

(3) Contents of file ______.ATA:

```
1. The use of dynamic brakes is allowed
   (1 for "yes", 0 for "no")                   --->  1
2. Average acceleration to bring train
   up to speed on departure from origin --->  12.0 MPH/min
3. Offset speed margin for automatic
   speed-limit control of train speed     --->  0.   MPH
4. Maximum speed allowed for automatic
   speed-limit control of train speed     --->  100. MPH
5. Average deceleration to stop train
   on approach to destination             --->  16.0 MPH/min
```

Enter number of item to be changed (0 for none)

NOTE: The above values are "default values". These values should allow the ATA to make good train handling decisions for most trains on most tracks. However, the user may need to adjust some of these values for his or her own applications -- in the event that ATA makes inadequate train handling decisions. If the response to prompt (3) is a number other than "0", an appropriate prompt appears for the desired change. If the response to prompt (3) is "0", the program returns to menu prompt (0).

As an example, the PRE prompt responses required to build the ATA parameter file P1.ATA are:

PRE Prompt		User Response	Comment
(0)	--->	7	PRE Function 7
(1)	--->	P1	file called "P1.ATA"
(2)	--->	n	this is a new file
(3)	--->	0	use default values

3.3.8 Prompts for PRE Function 8

If the user selects PRE Function 8, the following prompts appear:

```
(1)  Enter 6-character (or less) initialization file name
          (extension ".INI")

(2)  Is this .INI file an existing file that is to be edited?
          (Y/N)

(3)  Contents of file ______.INI:
      1. Train data file name                     --->
      2. Track chart file name                    --->
      3. Wind chart file name                     --->
      4. File output time interval                --->   30. sec
      5. Terminal output time interval            --->   30. sec
      6. Initial heading of leading vehicle       --->    0. deg
      7. Initial position of leading vehicle      --->    0  miles
      8. (plus)                                   --->    0. feet
      9. Status of vehicle-mounted lubricators--->    0  ("off")
     10. Status of trackside lubricators          --->    0  ("off")
     11. Effective lubrication distance           ---> 3600. feet
     12. Reduction in rolling resistance          --->  0.70 lbs/ton

     Enter number of item to be changed (0 for none)

     NOTE: The above values for items 4 to 12 are "default
     values". The user needs to supply the file names. If
     there is no lubrication, the values for items 11 and 12
     have no effect on the simulation.
```

3.3.9 Prompts for PRE Function 9

If the user selects PRE Function 9, the following prompts appear:

```
(1)  Enter 6-character (or less) command file name
          (extension ".CMD")
```

(2') New T E M Command File: ______.CMD

COMMAND 1:

NOTE: Prompt (2') appears only for the first command.

(2) New T E M Command File: ______.CMD

COMMAND ___ : __ __ __ __

COMMAND ___:

NOTE: The previous command is listed (in terms of four command number codes) for reference under the heading. Then the user is asked to enter the next command.

(3) Is this the last command in the file? (Y/N)

Following prompt (2') or prompt (2) there are four "beeps", indicating that the program requires four items of information. The user can enter the command in two ways: as a four number command code sequence; or as a command sentence in English, using certain three-letter key groups. (The TEM command structure will be discussed in the chapter on the TEM simulator program.)

As an example, the PRE prompt responses required to build the command file P1.CMD are:

PRE Prompt		User Response	Comment
(0)	--->	9	PRE Function 9
(1)	--->	P1	file called "P1.CMD"
(2')	--->	Maintain speed limits for 50 miles	key groups are LIM and MIL (and, of course, 50 specifies number miles)
(3)	--->	n	not the last command
(2)	--->	End simulation	key group is END
(3)	--->	y	last command

4.0 THE BATCH FILE EDITOR PROGRAM (BIF)

The purpose of the batch file editor program, which is called BIF, is to allow the user to set up the files required to run the preprocessor program (PRE) or the simulator program (TEM) in batch mode (i.e., to run the programs repetitively without intervention). The files set up by using the batch file editor program are (1) batch job file GOPRE.BAT, which runs PRE Function 1 once for each consist specified by the user, and (2) batch job file GOTEM.BAT, which runs TEM once for each simulation specified by the user. Therefore, the functions of BIF are:

Function 1: Edit PRE Batch File
Function 2: Edit TEM Batch File

4.1 Batch File Editor Functions

4.1.1 Function 1: Edit PRE Batch File

This is the BIF function that allows the user to set up the PRE batch job file GOPRE.BAT, which runs PRE in Function 1 (Process Existing Train Consist File) once for each consist to be processed. For each consist specified by the user, GOPRE.BAT copies information to the PRE batch initiation file PRE.BIF.

4.1.2 Function 2: Edit TEM Batch File

This is the BIF function that allows the user to set up the TEM batch job file GOTEM.BAT, which runs TEM once for each simulation specified by the user. For each simulation, GOTEM.BAT copies information to the TEM batch initiation file TEM.BIF. File TEM.BIF gets information from GOTEM.BAT, even if there is only one simulation to be run. In fact, TEM can be run only in batch mode. This system of running TEM eliminates the need for the user to respond to a large number of terminal prompts during each run of the simulator program.

4.2 BIF Input / Output Disk Files

4.2.1 PIF.BIF and GOPRE.BAT Batch Job Files

When BIF is run in Function 1, the virtual contents of GOPRE.BAT are obtained by the program from a file called "PIF.BIF", which must exist in computer storage before BIF can be run. When the user sets up a new GOPRE.BAT file, he or she is actually modifying the contents of PIF.BIF, which is then used by program BIF to create the corresponding GOPRE.BAT file.

GOPRE.BAT contains computer system (DOS) commands that (1) clear the screen, (2) copy information to the PRE batch initiation file, PRE.BIF, and (3) run PRE in Function 1. There is a set of copy and run commands for each consist to be processed by PRE.

As an example, the contents of GOPRE.BAT, required to run PRE twice in order to process two consists (which we will call "A1" and "A2") in PRE Function 1 without the intervention of the user, are:

```
CLS                                 (clear screen)
copy A1.PIF        PRE.BIF          (copy A1 information to PRE.BIF)
PRE                                 (run PRE in Function 1)

CLS                                 (clear screen)
copy A2.PIF        PRE.BIF          (copy A2 information to PRE.BIF)
PRE                                 (run PRE in Function 1)
```

NOTE: The contents of A1.PIF and A2.PIF are in the same format as the contents of PRE.BIF, which was discussed in the previous chapter on the preprocessor program PRE. The .PIF files are generated along with the GOPRE.BAT file when BIF is run in Function 1.

4.2.2 TIF.BIF and GOTEM.BAT Batch Job Files

When BIF is run in Function 2, the virtual contents of GOTEM.BAT are obtained by the program from a file called "TIF.BIF", which must exist in computer storage before BIF can be run. When the user sets up a new GOTEM.BAT file, he or she is actually modifying the contents of TIF.BIF, which is then used by program BIF to create the corresponding GOTEM.BAT file.

GOTEM.BAT contains computer system (DOS) commands that (1) clear the screen, (2) copy information to the TEM batch initiation file, TEM.BIF, and (3) run TEM. There is a set of copy and run commands for each simulation to be performed by TEM.

As an example, the contents of GOTEM.BAT, required to run TEM twice in order to perform two simulations (which we will call "A1" and "A2") without the intervention of the user, are:

```
CLS                              (clear screen)
copy A1.TIF        TEM.BIF       (copy A1 information to TEM.BIF)
TEM                              (run TEM)

CLS                              (clear screen)
Copy A2.TIF        TEM.BIF       (copy A2 information to TEM.BIF)
TEM                              (run TEM)
```

NOTE: The contents of A1.TIF and A2.TIF are in the same format as the contents of TEM.BIF, which is discussed in the next chapter on the simulator program TEM. The .TIF files are generated along with GOTEM.BAT when BIF is run in Function 2.

4.3 BIF Prompts

To run BIF, the user merely types "BIF" on the computer terminal. The following menu prompt appears on the screen below the header ("TRAIN ENERGY MODEL Batch File Editor Version 1.5"):

```
(0)          Select File to Edit:
             1. PRE batch file
             2. TEM batch file

             0. Exit program BIF
```

There is one audible "beep", indicating that the program requires one item of information. The user types the number of the desired batch file to be generated: "1" for GOPRE.BAT (and the corresponding .PIF files) or "2" for GOTEM.BAT (and the corresponding .TIF files).

4.3.1 Prompts for BIF Function 1

If the user selects BIF Function 1, the following prompts appear:

```
(1)  Virtual contents of GOPRE.BAT:
     1. Batch indicator ("1" for batch job)          ---> _
     2. Number of batch jobs                         ---> __

     Enter number of item to be changed (0 for none)

(2)  Virtual contents of GOPRE.BAT: Batch Job __
     1. Consist identifier                           ---> ______
     2. Default resistance coefficient identifier ---> 1
     3. Dynamic resistance coefficient               ---> 0.03
     4. Bearing resistance coefficient               ---> 18.0
     5. Rolling resistance coefficient               ---> 1.50

     Enter number of item to be changed (0 for none)
```

NOTE: Prompt (2) appears only if the value of item 1 in prompt (1) is set to "1" (indicating a batch job). Also, Prompt (2) is repeated for each batch job, the number of which is specified as the value of item 2 in prompt (1). After a batch job, item 1 in prompt (1) must be reset to "0", if PRE is to be run in any Function other than Function 1.

The contents of GOPRE.BAT are referred to as "virtual contents", because the responses to prompts (1) and (2) actually go to form the contents of file PIF.BIF, which is used by program BIF to build file GOPRE.BAT, which consists of DOS commands, and to build the batch initiation (.PIF) files for each of the batch jobs. For each consist to be processed by PRE, a copy command in GOPRE.BAT copies the contents of the corresponding .PIF file into file PRE.BIF. The only thing that the reader needs to know about PIF.BIF is that it must exist in computer storage before BIF can be run. After the first execution of BIF in Function 1, file PIF.BIF is updated automatically by program BIF.

4.3.2 Prompts for BIF Function 2

If the user selects BIF Function 2, the following prompts appear:

```
(1)  Virtual contents of GOTEM.BAT:
     1. Number of batch jobs                       ---> __

     Enter number of item to be changed (0 for none)

(2)  Virtual contents of GOTEM.BAT: Batch Job __
     1. Output identifier                          ---> ______
     2. Command identifier                         ---> ______

     Enter number of item to be changed (0 for none)

     NOTE: Prompt (2) is repeated for each batch job, the number
     of which is specified as the value of item 1 in prompt (1).
```

The contents of GOTEM.BAT are referred to as "virtual contents", because the responses to prompts (1) and (2) actually go to form the contents of file TIF.BIF, which is used by program BIF to build file GOTEM.BAT, which consists of DOS commands, and to build the batch initiation (.TIF) files for each of the batch jobs. For each simulation to be run by TEM, a copy command in GOTEM.BAT copies the contents of the corresponding .TIF file into file TEM.BIF. The only thing that the reader needs to know about TIF.BIF is that it must exist in computer storage before BIF can be run. After the first execution of BIF in Function 2, file TIF.BIF is updated automatically by program BIF.

After the user enters a simulation command identifier as item 2 in response to prompt (2), program BIF automatically checks for the existence of all the files required to perform the simulation specified by the user: the .CMD file; the .STP file; the .ATA file; the .INI file; the .DAT file for the consist specified in the .INI file; the .TRK file for the track chart specified in the .INI file; and the .WND file for the wind chart specified in the .INI file. If any necessary files are missing, the user is informed immediately and program BIF returns to prompt (2). The following seven messages represent the seven types of missing files:

```
File ______.INI must exist before simulation ______ can be run.
You can use PRE Function 8 to create this file.

File ______.CMD must exist before simulation ______ can be run.
You can use PRE Function 9 to create this file.

File ______.STP must exist before simulation ______ can be run.
You can use PRE Function 6 to create this file.

File ______.ATA must exist before simulation ______ can be run.
You can use PRE Function 7 to create this file.

File ______.DAT must exist before simulation ______ can be run.
You can use PRE Function 1 to create this file.

File ______.TRK must exist before simulation ______ can be run.
You can use PRE Function 4 to create this file.

File ______.WND must exist before simulation ______ can be run.
You can use PRE Function 5 to create this file.
```

Assuming that all the files required to perform the simulation exist; then, after the user enters a simulation command identifier as item 2 in response to prompt (2), program BIF automatically checks the train data (.DAT) and track chart (.TRK) files specified in the initialization (.INI) file for a possible stall condition (which can exist if the train is underpowered with respect to the given route). If the possibility of a stall exists, the user is informed immediately and program BIF returns to prompt (2). However, the user is not prevented from running the simulation, if he or she desires to do so. While the program checks the .TRK file for a possible stall condition (using the notch 8 equilibrium speed information from the .DAT file), the following message appears on the screen:

```
Checking for possible stall condition in simulation ______, WAIT ...
```

If a possible stall condition exists, the following message appears on the screen:

```
If simulation ______ is run, consist ______ on track ______
may begin to stall at track position ____mi ____ft!
```

5.0 THE SIMULATOR PROGRAM (TEM)

The Train Energy Model software package consists of four FORTRAN programs: the preprocessor, which is called PRE; the batch file editor, which is called BIF; the data plotter, which is called PIX; and the simulator itself, which is called TEM. In the previous two chapters, we have seen how PRE is used to set up and edit the various files required to supply TEM with the information it needs to perform the simulation of a train movement, and we have seen how BIF is used to set up the batch job file required to run TEM. In the next chapter, we will see how PIX is used to plot the results of a TEM simulation. In this chapter, we will discuss the details related to the simulator program, which is the "center piece" of the Train Energy Model software package.

5.1 TEM Disk Files

5.1.1 TEM.BIF Batch Initiation File

The TEM batch initiation file, TEM.BIF, must exist in computer storage before TEM can be run. The first line of TEM.BIF contains:

Number of simulations for current run (ALWAYS set to "1")

The second line of TEM.BIF contains two items:

TEM Output ID (designator for .OUT and .RPT disk files)
TEM Command ID (designator for .ATA, .STP, .INI and .CMD disk files)

NOTE: Normally, the output identifier and the command identifier are the same. However, there may be certain uses of TEM for which different output and command identifiers are convenient.

As mentioned in the previous chapter, for each simulation to be run by TEM, a copy command in GOTEM.BAT copies the contents of the corresponding .TIF file into file TEM.BIF. The contents of all .TIF files are in the same format as the contents of TEM.BIF.

As an example, the contents of the files needed to run simulation P1 are:

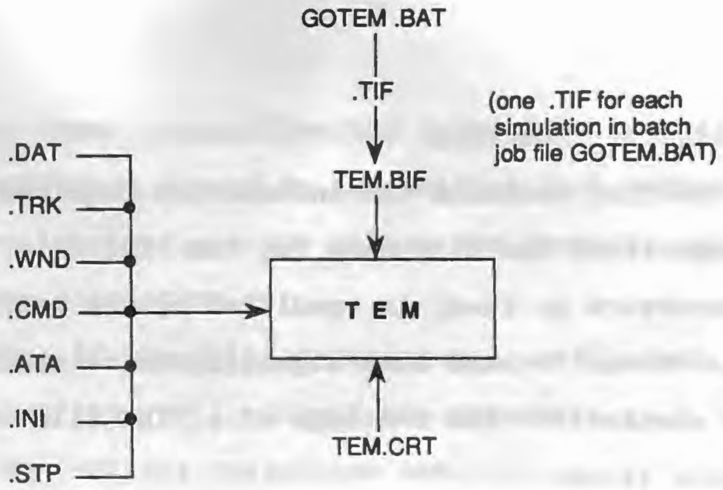
```
P1.TIF:              GOTEM.BAT:                     TEM.BIF:

       1             CLS                                   1
P1     P1     --->   copy P1.TIF     TEM.BIF ---> P1       P1
                     TEM
```

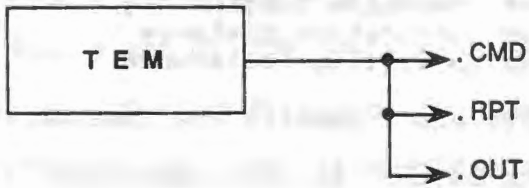
NOTE: Program BIF sets up P1.TIF and GOTEM.BAT automatically with the information obtained from the user responses to the BIF Function 2 prompts. To run the simulation, the user merely types "GOTEM" on the terminal. Then GOTEM.BAT executes the DOS commands.

5.1.2 Input Files

The use of TEM requires that certain disk files exist in computer storage. Exhibit 14A is a figure showing the input disk files needed to run a TEM simulation. The .DAT file was discussed in the chapter on the preprocessor program. In this chapter, we consider some additional aspects of the other files shown in Exhibit 14A.



(A) Input Files



(B) Output Files

Exhibit 14. Figure Showing (A) the Input Disk Files Needed to Run a TEM Simulation, and (B) the Output Disk Files Generated by a TEM Simulation.

5.1.2.1 .INI File

This file contains the information required to initialize a TEM simulation. The file name for the .INI file, which can be six characters or less, is specified by the user. Usually, the name is chosen to have some significance related to the nature of the simulation. The contents of a .INI file include the following items:

```
 1 Train data file name
 2 Track chart file name
 3 Wind chart file name
 4 File output time interval                (default: 30 seconds)
 5 Terminal output time interval            (default: 30 seconds)
 6 Initial heading of leading vehicle       (default: 0 degrees )
 7 Initial position of leading vehicle      (default: 0 miles   )
 8 (plus)                                   (default: 0 feet    )
 9 Status of vehicle-mounted lubricators    (default: 0 -- "off")
10 Status of trackside lubricators          (default: 0 -- "off")
11 Effective lubrication distance           (default: 3600 feet )
12 Reduction in rolling resistance          (default:.70 lbs/ton)
```

Items 1, 2, and 3 specify the consist, track chart, and wind chart files to be used in the simulation. Items 4 and 5 specify the nominal output time intervals for file .OUT and the computer terminal display, respectively. Items 6, 7, and 8 specify the initial direction and track chart position of the leading vehicle in the train (usually a locomotive). Items 9 and 10 specify the "on" / "off" status of vehicle-mounted and trackside lubricators, respectively. Item 11 specifies the "downstream" distance from a trackside lubricator at which the lubrication becomes ineffective (if only trackside lubricators are being used). Finally, item 12 specifies the reduction in rolling resistance coefficient caused by lubrication from either source. (If there is no lubrication, the values for items 11 and 12 have no effect on the simulation.)

For example, if the rolling resistance coefficient is normally 1.50 lbs/ton (dry), and if the reduction is 0.70 lbs/ton, then the rolling resistance coefficient is 0.80 lbs/ton wherever track lubrication is effective. (If vehicle-mounted lubricators are being used, it is assumed that lubrication is effective everywhere on the track over which the train moves.) The effect of lubrication on the curve resistance coefficient is specified by the data in file TEM.CRT, which is discussed below.

5.1.2.2 .CMD File

This file contains a set of TEM train control and simulation control commands. The file name for the .CMD file, which can be six characters or less, is specified by the user. However, it must be the same name used for the corresponding .INI file. The contents of the .CMD file and TEM command structure are discussed later in this chapter.

5.1.2.3 .ATA File

This file contains the values for certain adjustable parameters required by the Automatic Train-handling Algorithm (ATA) to control the train during a TEM simulation. The file name for the .ATA file, which can be six characters or less, is specified by the user. However, it must be the same name used for the corresponding .INI file. The contents of a .ATA file include the following items:

1. The use of dynamic brakes is allowed (1 for "yes", 0 for "no")	(default: 1)
2. Average acceleration to bring train up to speed on departure from origin	(default: 12.0 MPH/min)
3. Offset speed margin for automatic speed-limit control of train speed	(default: 0. MPH)
4. Maximum speed allowed for automatic speed-limit control of train speed	(default: 100. MPH)
5. Average deceleration to stop train on approach to destination	(default: 16.0 MPH/min)

Item 1 specifies whether or not the ATA can use dynamic braking. If item 1 is set to "0", the ATA can use only air brakes to slow or stop the train.

Item 2 is the reference acceleration that the ATA tries to maintain as the train departs from an origin or speeds up to meet a faster target speed; and item 5 is the reference deceleration that the ATA tries to maintain as the train slows down to meet a slower target speed or to stop at a destination. Items 2 and 5 should have values that limit positive ("draft") and negative ("buff") drawbar forces, respectively.

Item 3 is the "offset" speed or margin that the ATA tries to maintain with respect to a speed limit. If item 3 is set to 0 MPH, the speed limit serves as a "guideline", and the ATA will maintain an average speed close to the speed limit (assuming that the speed is physically possible for the train). But, if item 3 is set to some positive value -- say 2 MPH -- the ATA will maintain an average speed that is less than the speed limit by the specified margin (again, assuming that the speed is physically possible for the train). Item 3 should have a value that depends on whether track speed limits are considered to be guidelines or absolute upper limits.

Item 4 is the maximum speed at which the ATA will allow the train to run, assuming that the speed is physically possible for the train. This is convenient for running different kinds of trains on the same track chart. For example, a track chart with a maximum speed limit of 70 MPH for intermodal trains can be used for coal trains that should not exceed 40 MPH by specifying 40 MPH in item 4. Of course, any speed limits on the track chart that are less than 40 MPH will be met by the ATA.

The default values in the list above should allow the ATA to make good train handling decisions for most trains on most tracks. However, the user may need to adjust some of these values for his or her own applications -- in the event that the ATA makes inadequate train handling decisions.

5.1.2.4 .STP File

This file contains track position and dwell time for each destination in a given simulation. The file name for the .STP file, which can be six characters or less, is specified by the user. However, it must be the same name used for the corresponding .INI file. Each line of the .STP file (one for each destination) contains:

```
       Track position of destination: integral number of miles
(plus) Track position of destination: integral number of feet
       Dwell time at destination in minutes (nominal)
       Locomotive dwell setting (0 for idle, -1 for shutdown)
```

The total dwell time (simulated time) for a given TEM simulation may be a few minutes greater than the total dwell time (nominal) specified in the .STP file, because TEM -- under ATA control -- automatically allows time for the release of the automatic air brakes upon arrival at a destination. This total release time, which depends on the length of the train and the placement of helper locomotives (if there are any in the train), is not known to the user directly. But the total release time is known to the ATA through the contents of the .DAT file.

5.1.2.5 .WND File

This file contains wind directions and speeds for various points along the track chart with which it is being used. The file name for the .WND file, which can be six characters or less, is specified by the user. Each line of the .WND file contains the following wind chart data:

```
Position along the track in feet with respect to origin
Wind direction in degrees
Wind speed in miles per hour
```

Although the wind chart must be related to the track chart with which it is being used in a given simulation (in the sense that it gives wind directions and speeds at points that are accessible to a train moving on the track specified in the track chart), the wind chart data does not need to be specified for any particular track position in the corresponding track chart. For example, in the case of wind chart NOWIND.WND, the only requirement for the corresponding track chart is that it cover 500 miles or less. If we wanted no wind on a track chart representing a greater distance, we would build (using PRE Function 5) a wind chart with a final position sufficiently great to cover the corresponding track chart.

5.1.2.6 .TRK File

This file contains track chart data such as elevation, percent grade, and curve at specified track positions. The file name for the .TRK file, which can be six characters or less, is specified by the user. Each line of the .TRK file contains the following track chart data:

- Specified position along the track in ft with respect to origin
- Track elevation in ft at the specified position
- Percent grade at (and following) the specified position
- Curve in degrees between the current specified position and the next
- Speed limit in MPH at (and following) the specified position
- Milepost number at the specified position
- Place name (if any) at the specified position

Trackside lubricator code:
1 if a trackside lubricator exists at the specified position
0 if no trackside lubricator exists at the specified position

The density of a track chart (i.e., the number of points representing a given distance), which can vary from track chart to track chart and even within the same track chart, may affect the results of a TEM simulation. For example, given a "sparse" track chart with varying speed limits, the ATA may appear to "miss" a slower speed target (in the sense that train speed is slightly above the lower speed limit when the train reaches the track position of the lower speed limit), even though it is making the best train handling decision possible with the information available to it.

5.1.2.7 TEM.CRT File

This file contains experimental curve resistance coefficient values in lbs/TON for curves from 0 to 15 degrees, in increments of 0.1 degree, for four cases:

1. Regular truck on dry curve
2. Regular truck on lubricated curve
3. Radial truck on dry curve
4. Radial truck on lubricated curve

Thus, for a given vehicle in a TEM simulation at a given position along the track chart, the curve resistance acting on the vehicle is computed with a curve resistance coefficient (from file TEM.CRT) that depends on the type of truck the vehicle has (regular or radial), the curvature of the track over which the vehicle is moving, and the condition (dry or lubricated) of the track.

5.1.3 Output Files

The use of TEM generates two or three output files for each simulation, depending on whether or not the simulation is run manually (in which case the output .CMD file differs from the input .CMD file, as explained later in this chapter). Exhibit 14B is a figure showing the output disk files generated by a TEM simulation.

5.1.3.1 .OUT File

This file contains train handling data for the corresponding simulation. The name of this file, which (in a sense) is the name of the simulation, is the output designator specified in TEM.BIF. The .OUT file contains the following items of information (for each output interval):

1 Integral number of elapsed hours:
   (plus) Integral number of minutes
   (plus) Integral number of seconds
2 Integral number of miles for current position:
   (plus) Integral number of feet
3 Velocity of train in MPH
4 Acceleration of train in MPH/min
5 Cumulative fuel consumption in gallons
6 Throttle notch setting of leading locomotive consist
7 Dynamic brake setting of leading locomotive consist
8 Automatic brake pipe pressure in PSI
9 Independent brake cylinder pressure in PSI
10 Reverser switch setting (NOT IMPLEMENTED)

11 Elevation in ft of leading vehicle in train
12 Current speed limit in MPH
13 Drawbar force estimate in lbs
14 Throttle notch setting of helper locomotive consist
15 Dynamic brake setting of helper locomotive consist
16 Rolling resistance coefficient in lbs/TON
17 Direction angle of leading vehicle in train in degrees
18 Position projection along tangent to original heading in miles
19 Position projection along normal to original heading in miles

Item 1 is the elapsed time (simulated time) since the beginning of the simulation (zero time) at the output interval specified in the .INI file. However, because of the variable simulation time increment, the solution of the equation of motion may not be available at precisely the specified intervals. In that case, the values at the solution time nearest to the nominal interval are written to the .OUT file.

Item 2, track position, and item 3, velocity (speed along the instantaneous tangent line with respect to the track), are the values (at the output intervals) of the dynamical variables that are computed when the TAME method integrates the equation of motion.

Item 4 is the acceleration (at the output intervals), which is computed directly from the equation of motion. Item 13, the drawbar force, is estimated by using item 4 and the weights of the leading locomotive consist ahead of the drawbar and the remainder of the train consist behind the drawbar. The two weights are available to TEM from the .DAT file of the train being used in the simulation.

Item 5 is the cumulative fuel consumption (to the nearest gallon), which is computed by using fuel consumption rates (which depend on throttle setting and train speed) that are available to TEM through the contents of the .DAT file.

Items 6 through 10 are the control settings of the leading locomotives, and items 14 and 15 are the control settings (throttle and dynamic brake only) of the helper locomotives (if there are any in the train). Further aspects of the train controls are discussed later in this chapter.

Items 11, 12, 17, 18, and 19 are computed from or obtained directly from the .TRK file of the track being used in the simulation. Items 18 and 19 are the components (with respect to the initial position and direction of the train on the track chart) of the track "layout" or "map", which can be viewed by plotting item 19 against item 18 (as discussed below in the chapter on the data plotter program).

Finally, item 16 is the rolling resistance coefficient. If trackside lubricators are being used exclusively in the simulation (no vehicle-mounted lubricators), this item may be helpful in evaluating the effectiveness of trackside lubricators in saving fuel.

5.1.3.2 .RPT File

This file contains a fuel consumption and energy report for the corresponding simulation. The name of this file, which is the same as that of the .OUT file for the same simulation, is the output designator specified in TEM.BIF. Each .RPT file contains the following tables:

1. Train Consist and Train Operations Summary.
2. Time at Throttle Setting: Fuel consumed and time at each throttle setting for dynamic braking (indicated as "-2"), engine shutdown (indicated as "-1"), idle (0) and notches 1 through 8. This information is given for both leading units and helper units (if any).
3. Time in Speed Range: Fuel consumed and time in each 5 MPH interval from 0 to 100 miles per hour. Also, average over-the-road speed, in miles per hour is given at the bottom of the table.
4. Resistance Coefficients: Values of resistance coefficients used in the simulation -- dynamic, in pounds per ton per miles per hour; bearing, in pounds per axle; rolling, in pounds per ton, without track lubrication; and rolling, in pounds per ton, with track lubrication.
5. Type of Resistance: Fuel consumed for each type of resistance -- bearing, rolling, curve, dynamic, aerodynamic, and uphill grade. This information is given for cars, locomotives, and the train as a whole.
6. Work Done by Each Force: Work in HPH (horsepower-hours) done by each force -- gravity, total resistance, air brakes, dynamic braking, and diesel traction. Also, the total net work is given at the bottom of the table.

As mentioned above in the first chapter, a "train movement" is defined as starting the train, moving the train, and stopping the train. That is, a train movement begins with zero speed and ends with zero speed, so that the net work done on the train by all forces during the train movement is zero (since net work is equal to the total change in kinetic energy). This definition is not trivial. It is important in the evaluation of a TEM simulation to distinguish errors in fuel consumption due to external factors from the computational error in the TEM simulation itself. A good estimate of the computational error is provided by comparing the net work done in the TEM simulation of a train movement (given in the .RPT file) to the actual value, which should be zero for any train movement as defined above.

5.2 TEM Commands

5.2.1 TEM Command Structure

There are two types of TEM commands: 1) direct or "master" commands, and 2) indirect or "helper" commands that determine the type of helper locomotive control (synchronous or autonomous) and the control settings (throttle or dynamic brake only) of the helper locomotives in the train (if any).

There are two types of TEM master commands: 1) train control commands that correspond to actual control settings in the leading locomotive consist in the train, and 2) simulation operation commands. All master commands consist of four numbers:

1. MODE of control or operation.

For helper commands (MODE 9, as defined below), the first number serves only as an indicator that the following three numbers correspond to helper commands.

2. SETTING appropriate for the specified mode.

For helper commands, the second number is the MODE.

3. RANGE of command.

This can be: a time interval that must elapse,
a distance that must be covered, or
a speed that must be attained
before the command is completed.

For helper commands, the third number is the SETTING.

4. METHOD of specifying the range:

For master commands:
"1" indicates a time in minutes (MINutes)
"2" indicates a time in seconds (SEConds)
"3" indicates a distance in miles (MILes or MI_)
"4" indicates a distance in feet (FEEt or FT_)
"5" indicates a speed in MPH (MPH)

For helper commands (which have no RANGE):
"7" indicates synchronous helper control (SYNchronous)
"8" indicates autonomous helper control (AUTonomous)

NOTE: METHOD "6" is not implemented in TEM Version 1.5.

The underlined and capitalized three-character letter groups given in parentheses (including underlined blanks) for the METHODs shown above are key groups that help TEM interpret the meaning of English-language commands. These key groups, along with the key groups for MODEs and submodes (as defined below) may be used to construct English command sentences (either by running PRE Function 9 or by running TEM in manual mode) to be used in place of the usual four number TEM commands. However, the English command sentences are converted to the four-number form by a sentence "parser" subroutine, which is in both program PRE and program TEM. Only the four-number form of a TEM command is stored in a .CMD file.

5.2.2 Train Control Command Modes

5.2.2.1 Mode 1: Throttle

The engineer uses the throttle to apply power to the train. The appropriate SETTINGs for MODE 1 are (key groups for modes, given in parentheses, are capitalized and underlined):

-1	for engine shutdown	(SHUtdown)
0	for engine in idle	(RUN 0)
1 thru 8	for increasing power output	(RUN 1 thru RUN 8)

5.2.2.2 Mode 2: Dynamic Brake

The engineer uses the dynamic brake to slow the train. The appropriate SETTINGs for MODE 2 are:

0.0	for idle (DYNamic 0.0 gives same result as RUN 0)
0.1 thru 8.0	for increasing retarding force (DYNamic 0.1 thru DYNamic 8.0)

NOTE: Although the dynamic brake control has continuous settings, control settings to within one-tenth resolution are adequate. In fact, settings to within 0.2 are used by the ATA to control the train under dynamic braking.

5.2.2.3 Mode 3: Automatic Air Brake

The engineer uses the automatic air brake to slow or stop the train, when the dynamic brake is ineffective or when the use of the dynamic brake is not recommended. The appropriate SETTINGs for MODE 3 are:

5 to 25 psi	for an initial reduction	(REDuction)
-1	for release	(RELease)

NOTE: Prior to release, total reductions made by the engineer (including the initial reduction) cannot exceed the maximum reduction of 25 psi. However, in many cases, if the automatic air brake is being used skillfully, the initial reduction should be sufficient to control the train.

5.2.2.4 Mode 4: Independent Air Brake

The engineer uses the independent air brake to "anchor" the train. This is especially useful when the train is at a standstill on a grade. The appropriate SETTINGs for MODE 4 are:

0.1 to 50.0 psi	for application	(INDependent)
0.0 psi	for "release"	(INDependent 0.0)
-1	for "bail-off"	(BAIloff)

NOTE: Any appropriate setting of MODE 4 other than "-1" allows automatic air brake retarding force to be applied to locomotives (the opposite of "bail-off"). Thus, if "bail-off" is not desired, the use of a MODE 4 command with a setting of 0.0 or greater is required.

NOTE: MODE 5 (Reverser Switch) is not implemented in TEM Version 1.5.

5.2.3 Simulation Operation Command Modes

5.2.3.1 Mode 6: ATA Command Control

The user can specify that the Automatic Train-handling Algorithm (ATA) is to issue the train control commands by invoking MODE 6. There are two ways to use ATA control: 1) the user can specify a constant reference speed, or 2) the user can specify that the train follow the speed limit profile of the track chart. The appropriate SETTINGs for MODE 6 are:

0 to 100 MPH	for constant reference speed	(CONstant)
-1	for speed-limit tracking	(LIMits)

5.2.3.2 Mode 7: Manual Control

The user can command TEM to accept manual control settings from the terminal by invoking MODE 7. The appropriate SETTING for MODE 7 is:

1 to put the train under manual control

NOTE: For the manual control command, the RANGE and METHOD numbers are ignored, because they have no significance. Thus, the user can use "0" for the RANGE and "0" for the METHOD in a MODE 7 master command.

If a simulation is to be run entirely by manual control (user supplied train control settings from the terminal) or by a combination of manual and ATA control, then to start the process of building a stored command file, the first and only command in the .CMD file (which can be set up by running PRE Function 9) for input to the simulation may be:

7 1 0 0 (MANual)

While the simulation is running in manual mode, the program automatically writes the user supplied commands (from the terminal) to the .CMD file (following the MAN command). Thus, when the simulation is finished and the program is terminated, the user has a complete record of his or her train handling decisions (including the decision to use ATA).

If the user wants to use this .CMD file as a stored command file for another simulation, then the MAN command in the output .CMD file must be deleted (using the PC editor). However, a final MAN command can be added to the new input .CMD file, so that the process of building up stored commands can continue indefinitely. A more detailed discussion (including an example) of manual control is given in the final chapter of this manual.

5.2.3.3 Mode 8: Track Chart Display

During a simulation under manual control, the user can command TEM to display the track profile on which the train is positioned and the track profile immediately ahead of the train to any specified "look-ahead" distance (consistent with the contents of the track buffer at the time) by using MODE 8. For this command, the SETTING, RANGE, and METHOD are "0".

NOTE: This display is not a true graphics display; it is a "character display". The advantage of this type of display is that it can be used on a mainframe or PC computer terminal without any special graphics capabilities.

A MODE 8 command is not written to the .CMD file. A more detailed discussion of this display mode is given in the final chapter of this manual.

5.2.3.4 Mode 9: Helper Control

The user can command TEM to accept helper control settings by invoking MODE 9. A TEM helper command consists of four numbers:

1. "9" (HELper)

   This number serves only as an indicator that the following three numbers correspond to helper commands.

2. HELPER MODE of control:

   "1" indicates throttle control (RUN)
   "2" indicates dynamic brake control (DYNamic)

3. HELPER SETTING for the specified mode.

   The appropriate settings are the same as those for MODE 1 and MODE 2.

4. HELPER METHOD of implementing control:

   "7" indicates synchronous control (SYNchronous)
   "8" indicates autonomous control (AUTonomous)

5.2.3.5 Mode 0: End Simulation

The user can command TEM to terminate the simulation by invoking MODE 0. The SETTING, RANGE, and METHOD numbers are ignored, because they have no significance. Thus, the user can

T E M ENGLISH COMMAND MODE KEY GROUPS

Command MODE	Special SETTING	Key Letter GROUP	Key Letter ALTERNATIVES		Key WORD
Throttle:					
1		RUN	run	Run	RUN
1	-1	SHU	shu	Shu	SHUTDOWN
Dynamic Brake:					
2		DYN	dyn	Dyn	DYNAMIC
Automatic Air Brake:					
3		RED	red	Red	REDUCTION
3	-1	REL	rel	Rel	RELEASE
Independent Air Brake:					
4		IND	ind	Ind	INDEPENDENT
4	-1	BAI	bai	Bai	BAILOFF
ATA Command Control:					
6		CON	con	Con	CONSTANT
6	-1	LIM	lim	Lim	LIMIT
Manual Control:					
7	1	MAN	man	Man	MANUAL
Track Chart Display:					
8		DIS	dis	Dis	DISPLAY
Helper Control:					
9		HEL	hel	Hel	HELPER
End Simulation:					
0		END	end	End	END

Exhibit 15. Table Showing TEM English Command MODE Key Letter Groups and Key Words.

T E M ENGLISH COMMAND METHOD KEY GROUPS

Command METHOD	Key Letter GROUP	Key Letter ALTERNATIVES	Key WORD
A time interval that must elapse:			
1	MIN	min	MINUTE
2	SEC	sec	SECOND
A distance that must be covered:			
3	MIL	mil MI_ mi_	MILE
4	FEE	fee FT_ ft_	FEET
A speed that must be attained:			
5	MPH	mph	MPH
Type of helper control:			
7	SYN	syn	SYNCHRONOUS
8	AUT	aut	AUTONOMOUS

Exhibit 16. Table Showing TEM English Command METHOD Key Letter Groups and Key Words.

use "0" for the SETTING, RANGE, and METHOD in a MODE 0 master command:

0 0 0 0 (END)

Following an END command, the program stops and the following message appears on the terminal:

Program TEM terminated.

5.2.4 Summary of TEM English Command Words

The TEM English-language command MODE three-letter key groups and the corresponding key words are summarized in the table shown in Exhibit 15. The TEM English-language command METHOD three-letter key groups and the corresponding key words are summarized in the table shown in Exhibit 16. A more detailed discussion (including examples) of TEM English commands is given in the final chapter of this manual.

5.3 Stored Command File (.CMD)

As mentioned earlier in this chapter, the .CMD file contains a set of TEM train control and simulation control commands. Now that we have discussed TEM command structure, we can consider the contents of a .CMD file. Each line (one for each command) of the .CMD file consists of four numbers:

TEM Master Command:

1 MODE of control or operation.
2 SETTING appropriate for the specified mode.
3 RANGE of command.
4 METHOD of specifying the range.

TEM Helper Command:

1 "9" (This number serves only as an indicator.)
2 HELPER MODE of control.
3 HELPER SETTING for the specified mode.
4 HELPER METHOD of implementing control.

5.4 TEM Simulation Terminal Displays

5.4.1 Simulation Dynamics Display

While a TEM simulation is in progress, a constantly changing display, the simulation dynamics display, appears on the computer terminal. The interval between display changes is nominally equal to the terminal output time interval (simulated time) specified in the .INI file. However, because of the variable simulation time increment, the solution of the equation of motion may not be available at precisely those time intervals. In that case, the solution nearest to the nominal interval is displayed on the terminal. The display includes the following information:

Train control settings:	
Leading locomotive throttle	(indicated as "run")
Helper locomotive throttle	(following "/")
Leading locomotive dynamic	(one-tenth resolution)
Helper locomotive dynamic	(following "/")
Automatic air brake reduction	(indicated as "psi")
Elapsed simulated train time:	
Hours	(indicated as "h")
Minutes	(indicated as "m")
Seconds	(indicated as "s")
Track position of leading vehicle:	
Miles	(indicated as "mi")
Feet	(indicated as "ft")

```
Velocity of train (MPH):
     Actual speed
     Current speed limit            (following "/")
Acceleration of train (mph/min)
Drawbar force (lbs)
Track data:
     Milepost number
     Elevation                      (indicated as "ft")
     Direction with respect
         to initial heading         (indicated as "deg")
```

NOTE: If a place name (at one of the specified positions on the track chart) is close to the current track position of the leading vehicle in the train, the place name appears on the terminal display, instead of the three items of track data (milepost number, elevation, and direction).

If the terminal output time interval specified in the .INI file is "0", then the simulation dynamics display will not appear. In general, TEM simulations tend to run slightly faster (computer time) with no dynamics display.

5.4.2 Manual Command Prompt / Control Status Display

If a TEM simulation is being run in manual mode, and the program requires a new command from the user, a manual command prompt, which incorporates a control status display, appears immediately below the simulation dynamics display (or the track chart display, if the previous command was DISPLAY). The control status display contains the following information (on one line):

```
Throttle setting for:              (indicated as "1)thl " )
     Leading locomotive consist    (followed by  "/")
     Helper locomotives            (followed by "*", if there
                                    are any helpers)
```

Dynamic brake setting for:	(indicated as "2)dyn ")
Leading locomotive consist	(followed by "/")
Helper locomotives	(followed by "*", if there are any helpers)
Automatic brake pipe pressure:	(indicated as "3) air " and given in PSI)
Independent brake pressure:	(indicated as "4) ind " and given in PSI)

When the master command prompt appears, there are four audible "beeps," indicating that the program requires four items of information: the MODE, SETTING, RANGE, and METHOD numbers of the TEM master command. However, as we have seen, the user can enter a TEM English-language command, instead.

In general, the syntax of a TEM English-language command has the same form as a TEM four-number command. A more detailed discussion (including examples) of TEM English commands is given in the final chapter of this manual. Also, TEM English commands are given for each of the example simulations in Chapter 7.

6.0 THE DATA PLOTTER PROGRAM (PIX)

The purpose of the data plotter program, which is called PIX, is to allow the user to graphically display on the computer terminal the results of a TEM simulation. These graphs can be used to evaluate in detail the train handling decisions made during the simulation. Also, PIX can be used to make a direct comparison between results from two TEM simulations. In addition, PIX allows the user to display locomotive characteristics on the terminal, and to plot track chart data on the terminal. The four functions of PIX are:

- Function 1: Plot Two Dependent Variables from ONE TEM Output File
- Function 2: Plot One Dependent Variable from TWO TEM Output Files
- Function 3: Plot Locomotive Tractive Effort, Fuel Rate, and Dynamic Brake Curves
- Function 4: Plot Track Profiles, Speed Limits, and Track Layout from Track Chart Data

The only input file required for PIX Function 1 (except for the special graphics files CONFIG.GPC and SIMPLEX.FNT, which are discussed later in this chapter) is a .OUT file. Exhibit 17 is a figure showing the input disk files for the four PIX functions.

6.1 Data Plotter Functions

6.1.1 Function 1: Plot Two Dependent Variables from ONE TEM Output File

This is the primary function of PIX. As mentioned earlier,

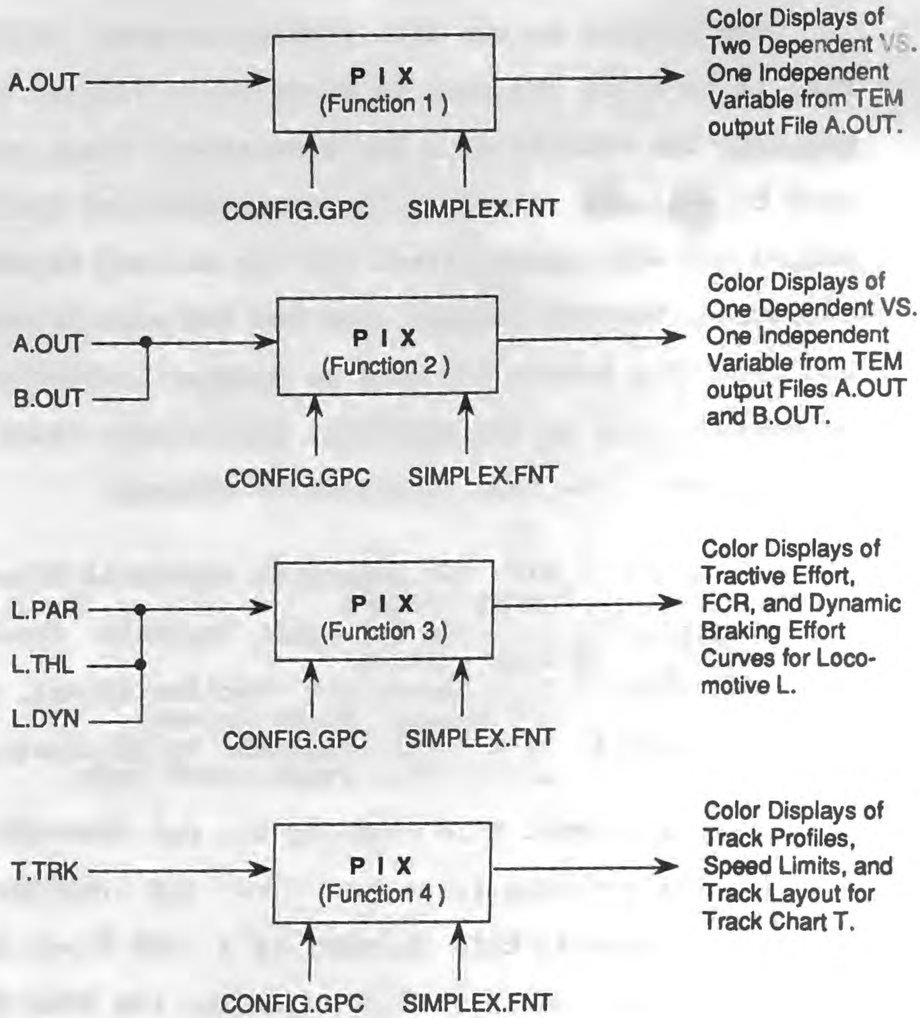


Exhibit 17. Figure Showing the Input Disk Files Needed to Run the Four PIX Functions.

Function 1 allows the user to plot two dependent variables from one TEM output (.OUT) file. In this manual (and in the PIX prompts), the independent variable (which is plotted with scale values on the bottom axis) is called the X-variable, the primary dependent variable (which is plotted with scale values on the left-hand axis) is called the Y-variable, and the secondary dependent variable (which is plotted with scale values on the right-hand axis) is called the Z-variable. For example, Exhibit 10 is a graph of the two dependent variables speed (Y-variable in units of MPH) and speed limit (Z-variable in units of MPH) vs. the independent variable track position (X-variable in units of miles) from file P1.OUT.

6.1.2 Function 2: Plot One Dependent Variable from TWO TEM Output Files

This is the secondary function of PIX that allows the user to plot one dependent variable from two TEM output (.OUT) files. That is, the Y-variable represents a quantity from the first .OUT file, and the Z-variable represents the same quantity from the second .OUT file. Of course, both the Y- and Z-variables are plotted against the same X-variable.

6.1.3 Function 3: Plot Locomotive Tractive Effort, Fuel Rate, and Dynamic Brake Curves

This is the secondary function of PIX that allows the user to plot locomotive tractive effort, speed-dependent fuel consumption rate (FCR), and dynamic braking effort characteristic curves on the computer terminal. For example, Exhibit 1 shows a set of tractive effort curves, Exhibit 2 shows a set of FCR curves, and Exhibit 3 shows a set of dynamic braking effort curves for a GP40 diesel-electric locomotive.

6.1.4 Function 4: Plot Track Profiles, Speed Limits, and Track Layout from Track Chart Data

This is the secondary function of PIX that allows the user to plot (1) the elevation (Y-variable in units of feet) and speed limit (Z-variable in units of MPH) profiles VS. track position (X-variable in units of miles), (2) the grade (Y-variable in units of percent) and elevation (Z-variable in units of feet) profiles VS. track position (X-variable in units of miles), (3) the curve (Y-variable in units of degrees) and elevation (Z-variable in units of feet) profiles VS. track position (X-variable in units of miles), and (4) the track layout of a track chart on the computer terminal.

The track layout is the normal component (with respect to the initial position and direction of the track chart) of the track position (Y-variable in units of miles) VS. the tangent component (with respect to the initial position and direction of the track chart) of the track position (X-variable in units of miles). That is, the layout is the "map view" of the track chart.

6.2 Generating the Proper Configuration File for Program PIX by Running Program EQUIP

Although PIX is an original program copyrighted by AAR, it is necessary to use graphics primitives (commands for drawing lines and letters, etc.) supplied by a commercial graphics library package to get the TEM simulation graphs on the screen of the computer terminal. The PIX program generates plots by calling the Graphic library, which is copyrighted by Scientific Endeavors. AAR is authorized by license to distribute programs compiled with the Graphic library.

The use of PIX requires that two special disk files, called CONFIG.GPC and SIMPLEX.FNT, exist in computer storage. The file SIMPLEX.FNT is a file in the Graphic library that is used to draw letters in a particular font style to form the various labels (scale names and values, etc.) in a PIX graph. The file CONFIG.GPC is a configuration file that is used to define the computer terminal and printer (used for "hard copies", as discussed later in this chapter) for the Graphic library. The proper CONFIG.GPC file for running PIX on a particular computer is generated by running a Graphic library configuration-defining program, which is called EQUIP. (The user should re-read the WARNING given at the front of this manual before attempting to use program PIX. Failure to heed this warning could result in physical damage to the user's computer terminal!)

To run program EQUIP the user merely types "EQUIP" on the terminal. The EQUIP prompts are:

(1) Enter drive:\directory\ .... [list of selections]

(2) Supported computers are .... [list of selections]

(3) Supported graphics boards are .... [list of selections]

(4) Supported printers are .... [list of selections]

(5) Is your printer a serial printer? ... [list of selections]

(6) Color selection .... [list of selections]

Some sample responses to the EQUIP prompts are:

Prompt	User Response	Comment
(1)	---> C:\TEM\	user's TEM directory
(2)	---> 2	selection for AT
(3)	---> 7	selection for EGA board
(4)	---> 2	selection for EPSON FX
(5)	---> 1	selection for parallel printer using port 1
(6)	---> 0 0 0	selections for defaults

WARNING: If you run PIX and strange horizontal or diagonal lines appear when the graph is displayed, turn off the power to your computer immediately! Then turn on the computer and run EQUIP again and specify a different graphics board (response to prompt (3)). The specification of an incorrect graphics board can result in physical damage to your computer terminal!

NOTE: If your EGA board does not support 16 colors, select "1" in response to prompt (3). This will produce a black and white (monochrome) plot.

6.3 PIX Prompts and Displays

To run PIX, the user merely types "PIX" on the computer terminal. The following menu prompt appears on the screen below the header ("TRAIN ENERGY MODEL Data Plotter Version 1.5"):

```
(0)         Select Plotter Function:
            1. Plot two dependent variables from ONE
               TEM output file
            2. Plot one dependent variable  from TWO
               TEM output files
            3. Plot locomotive tractive effort, fuel
               rate, and dynamic braking curves
            4. Plot track profiles, speed limits, and
               track layout from track chart data

            0. Exit program PIX
```

There is one audible "beep", indicating that the program requires one item of information. The user types the number of the desired data plotter function.

6.3.1 Prompts and Displays for PIX Function 1

If the user selects PIX Function 1, the following prompts appear:

```
(1)  Enter TEM output file ID (extension .OUT)

(2)  Identify variables to be plotted:
 1 Elapsed Time [minutes]          11 Elevation [feet]
 2 Position [miles]                12 Speed Limit [MPH]
 3 Speed [MPH]                     13 Drawbar Force [lbs]
 4 Acceleration [MPH/min]          14 Helper Throttle [notch]
 5 Fuel Consumed [gallons]         15 Helper Dynamic ["notch"]
 6 Throttle Control [notch]        16 Rolling Resistance [lbs/TON]
 7 Dynamic Control ["notch"]       17 Direction Angle [degrees]
 8 Brake Pipe Pressure [psi]       18 Tangent Projection [miles]
 9 Independent Pressure [psi]      19 Normal Projection [miles]
10  -- NOT IMPLEMENTED --          NOTE: Track Layout="18 19 19"
```

Enter three numbers, separated by spaces, selected from the above list. The order of entry is: X-independent variable Y-dependent variable Z-secondary dependent variable

NOTE: This prompt is accompanied by three "beeps".

(2A) Should the TIME be given in HOURS instead of minutes?

NOTE: Prompt (2A) appears only if the X-variable is item "1", the elapsed time in minutes.

(3) Should the Z variable be plotted on the same scale as the Y variable?

NOTE: This feature is helpful for comparisons, e.g., to compare actual train speed (item 3) to speed limit profile (item 12).

(4) Enter graph description (60 characters or less):

NOTE: The line serves as a guide to help the user avoid the entry of a caption that is too long. For no caption, press <ENTER>. The graph appears after the response to prompt (4).

(5) Should another plot be made using a new range for [X variable]?

NOTE: To avoid cluttering the graph on the screen, prompt (5) appears only after the user enters an extra <ENTER>.

(5A) The range of [X variable] is __ to __ [X units]. Enter new minimum and maximum range values.

NOTE: Prompt (5A) appears only if the response to prompt (5) is "Y" or "y". The values in the blanks show the user the entire range or interval of the X-variable. The user can "zoom in" on a portion of the X-variable interval by entering a subinterval of his or her choice.

(6) Should another plot be made from the same TEM file(s)?

NOTE: If the response to prompt (6) is "Y" or "y", the program returns to the item prompt (2). Otherwise, the program returns to the menu prompt (0).

As an example, suppose that there is a simulation called "P2", which is the same as simulation P1, except that the offset speed margin specified in file P2.ATA is 2 MPH, instead of 0 MPH. To plot speed (Y-variable) and speed limit (Z-variable) VS. track position (X-variable), the user responds as follows:

PIX Prompt		User Response	Comment
(0)	--->	1	PIX Function 1
(1)	--->	P2	output file P2.OUT
(2)	--->	2 3 12	X-, Y-, and Z-variables
(3)	--->	y	same scale for Y and Z
(4)	--->	<ENTER>	no caption
	--->	<ENTER>	to get prompt (5)
(5)	--->	<ENTER>	don't "zoom in"
(6)	--->	<ENTER>	no more graphs
(0)	--->	0	exit program PIX

NOTE: If the response to a prompt is not affirmative ("Y" or "y"), an <ENTER> is sufficient to go to the next prompt. This is true in general for all four Train Energy Model programs.

Exhibit 18 is a graph of speed (MPH) and speed limit (MPH) VS. track position (miles) for Simulation P2. Except for color, Exhibit 18 shows the graph as it appears on the screen after prompt (4) and before the extra <ENTER> (to make prompt (5) appear on the screen).

A PIX Function 1 graph is color-coded. That is, the left-hand scale values, Y-variable designator, power-of-ten, Y-variable units, and the plot of the Y-variable are in yellow; the right-hand scale values, Z-variable designator, power-of-ten, Z-variable units, and the plot of the Z variable

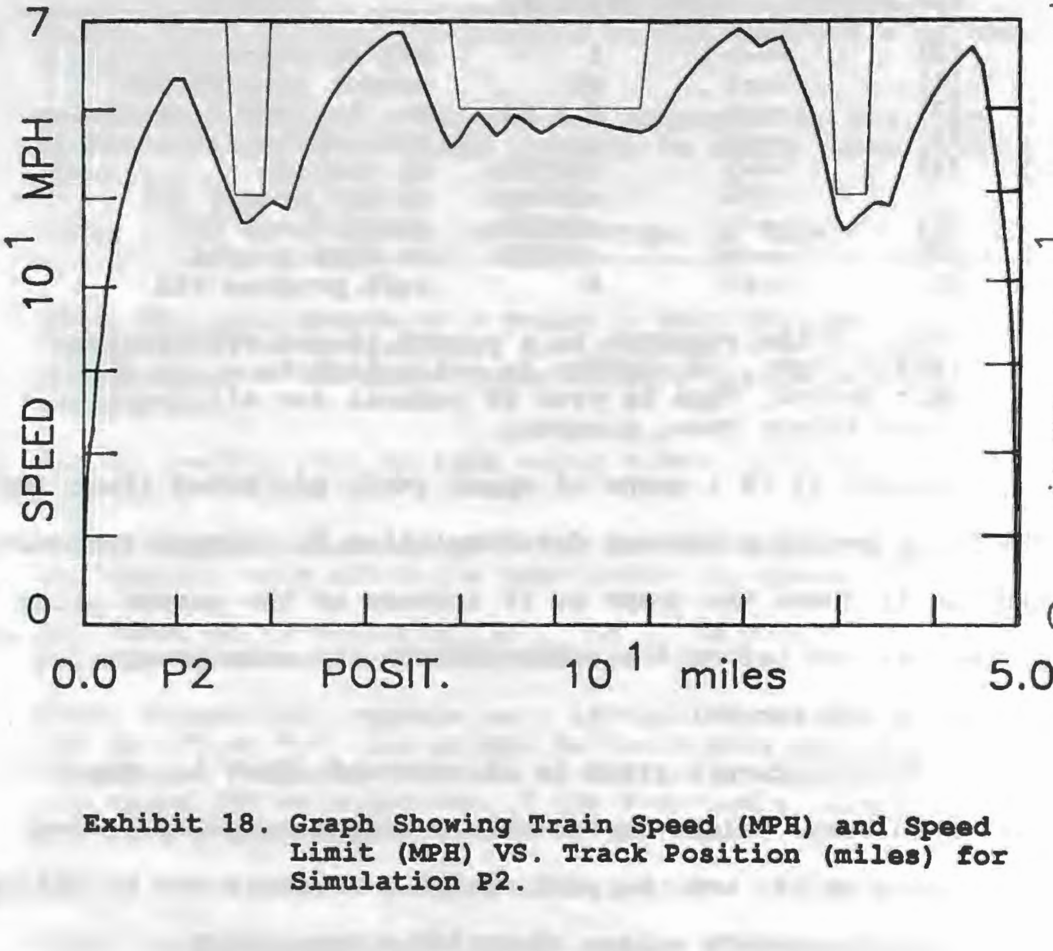


Exhibit 18. Graph Showing Train Speed (MPH) and Speed Limit (MPH) VS. Track Position (miles) for Simulation P2.

are in green; and the scale values, X-variable designator, power-of-ten, and X-variable units, and the entire border of the graph are in blue. Finally, the .OUT file designator (near the bottom left-hand corner) is in orange. The background is black.

6.3.2 Prompts and Displays for PIX Function 2

If the user selects PIX Function 2, the following prompts appear:

```
(1)  Enter TEM output file ID (extension .OUT)

(1B) Enter other TEM file ID (extension .OUT)

(2B) Identify variables to be plotted:
 1 Elapsed Time [minutes]          11 Elevation [feet]
 2 Position [miles]                12 Speed Limit [MPH]
 3 Speed [MPH]                     13 Drawbar Force [lbs]
 4 Acceleration [MPH/min]          14 Helper Throttle [notch]
 5 Fuel Consumed [gallons]         15 Helper Dynamic ["notch"]
 6 Throttle Control [notch]        16 Rolling Resistance [lbs/TON]
 7 Dynamic Control ["notch"]       17 Direction Angle [degrees]
 8 Brake Pipe Pressure [psi]       18 Tangent Projection [miles]
 9 Independent Pressure [psi]      19 Normal Projection [miles]
10  -- NOT IMPLEMENTED --          NOTE: Track Layout="18 19 19"

     Enter two numbers, separated by spaces, selected from the
     above list. The order of entry is: X-independent variable
     Y-dependent variable

(2A) Should the TIME be given in HOURS instead of minutes?

(4)  Enter graph description (60 characters or less):
     ------------------------------------------------------------

(5)  Should another plot be made using a new range for
     [X variable]?

(5A) The range of [X variable] is __ to __ [X units].
     Enter new minimum and maximum range values.

(6)  Should another plot be made from the same TEM file(s)?
```

As an example, suppose that we want to compare the speed in simulation P1 to the speed in simulation P2 with respect to track position. To plot the P1 speed (Y-variable) and the P2 speed (Z-variable) VS. track position (X-variable), the user responds as follows:

PIX Prompt		User Response	Comment
(0)	--->	2	PIX Function 2
(1)	--->	P1	output file P1.OUT
(1B)	--->	P2	output file P2.OUT
(2B)	--->	2 3	X-, and Y-variables (in Function 2, Y- and Z-variables automatically plotted on same scale)
(4)	--->	<ENTER>	no caption
	--->	<ENTER>	to get prompt (5)
(5)	--->	<ENTER>	don't "zoom in"
(6)	--->	<ENTER>	no more graphs
(0)	--->	0	exit program PIX

Exhibit 19 is a graph of P1 speed (MPH) and P2 speed (MPH) VS. track position (miles). Except for color, Exhibit 19 shows the graph as it appears on the screen after prompt (4) and before the extra <ENTER>.

A PIX Function 2 graph is color-coded in the same way as a PIX Function 1 graph, except that the Y- and Z- variables represent the same quantity from two different files, the Y-variable file ID (near the bottom left-hand corner) is in yellow, and the Z-variable file ID (near the bottom right-hand corner) is in green. The background is black.

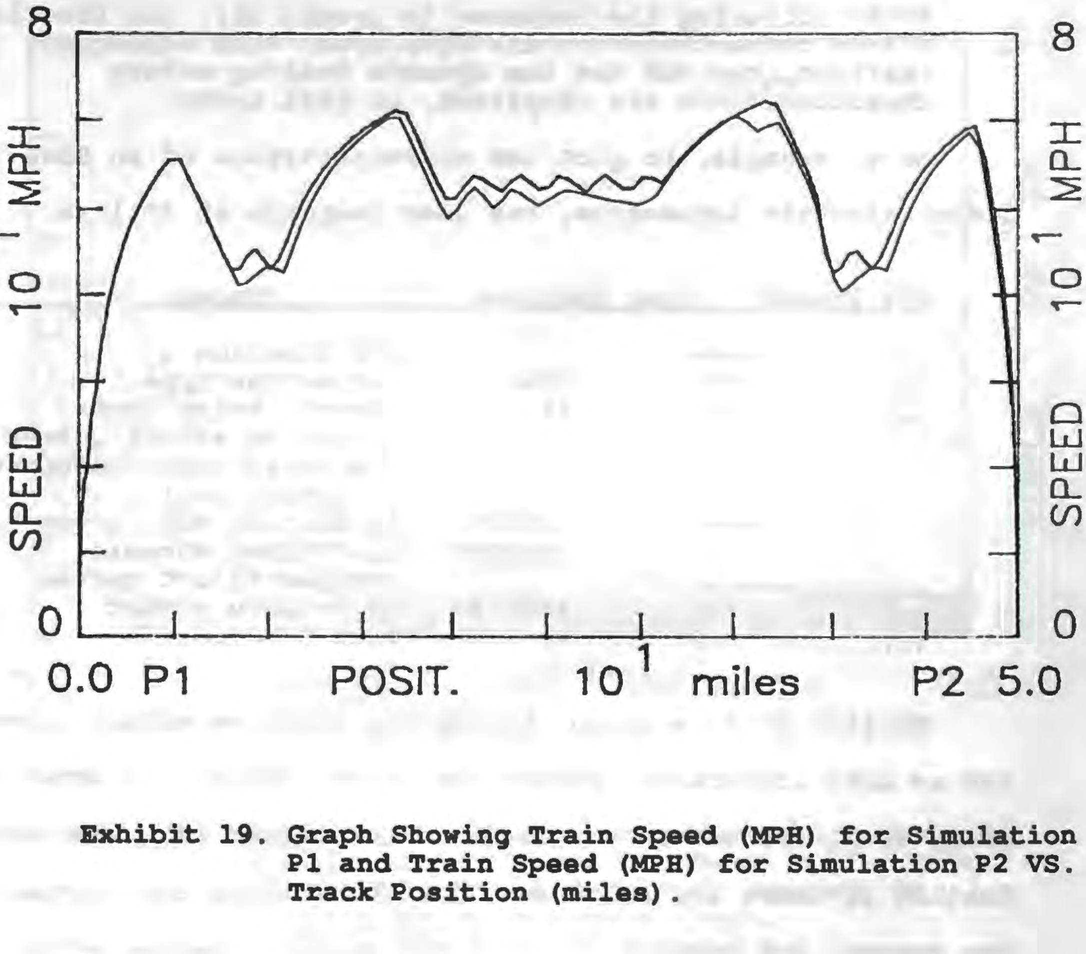


Exhibit 19. Graph Showing Train Speed (MPH) for Simulation P1 and Train Speed (MPH) for Simulation P2 VS. Track Position (miles).

6.3.3 Prompts and Displays for PIX Function 3

If the user selects PIX Function 3, the following prompts appear:

(1) Enter 4-character diesel locomotive type

(2) Enter 2-character dynamic braking type

NOTE: Following the response to prompt (2), the tractive effort characteristics are displayed. With subsequent <ENTER>s, the FCR and the dynamic braking effort characteristics are displayed, in that order.

As an example, to plot the characteristics of an SD40 diesel-electric locomotive, the user responds as follows:

PIX Prompt		User Response	Comment
(0)	--->	3	PIX Function 3
(1)	--->	SD40	locomotive type
(2)	--->	FE	dynamic brake type (tractive effort curves displayed after response to prompt (2))
	--->	<ENTER>	to display FCR curves
	--->	<ENTER>	to display dynamic braking effort curves
	--->	<ENTER>	go to menu prompt
(0)	--->	0	exit program PIX

Exhibit 20 is a graph showing the tractive effort curves for an SD40 locomotive. Except for color, Exhibit 20 shows the graph as it appears on the screen after prompt (2). Similarly, Exhibit 21 shows the FCR curves for the SD40 as they appear on the screen, and Exhibit 22 shows the dynamic braking effort curves for the SD40 as they appear on the screen.

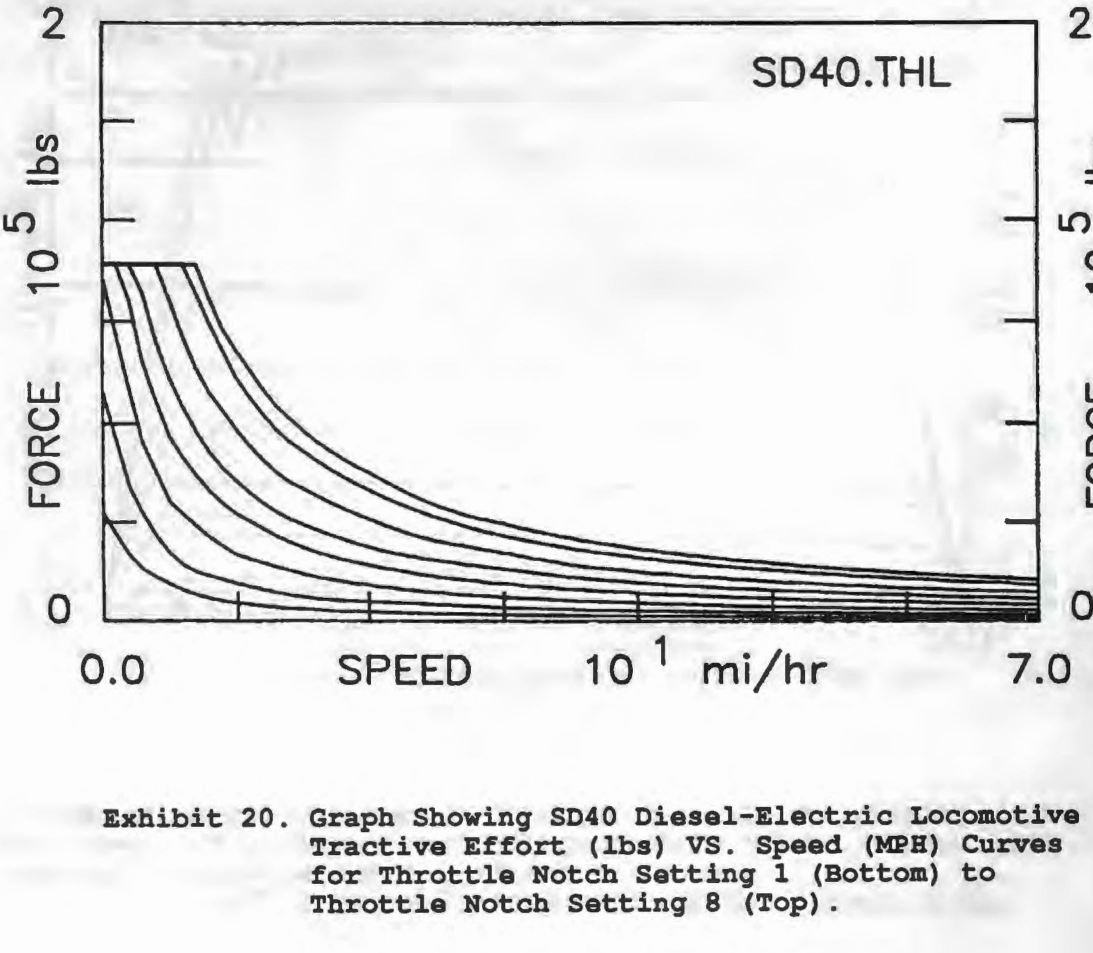


Exhibit 20. Graph Showing SD40 Diesel-Electric Locomotive Tractive Effort (lbs) VS. Speed (MPH) Curves for Throttle Notch Setting 1 (Bottom) to Throttle Notch Setting 8 (Top).

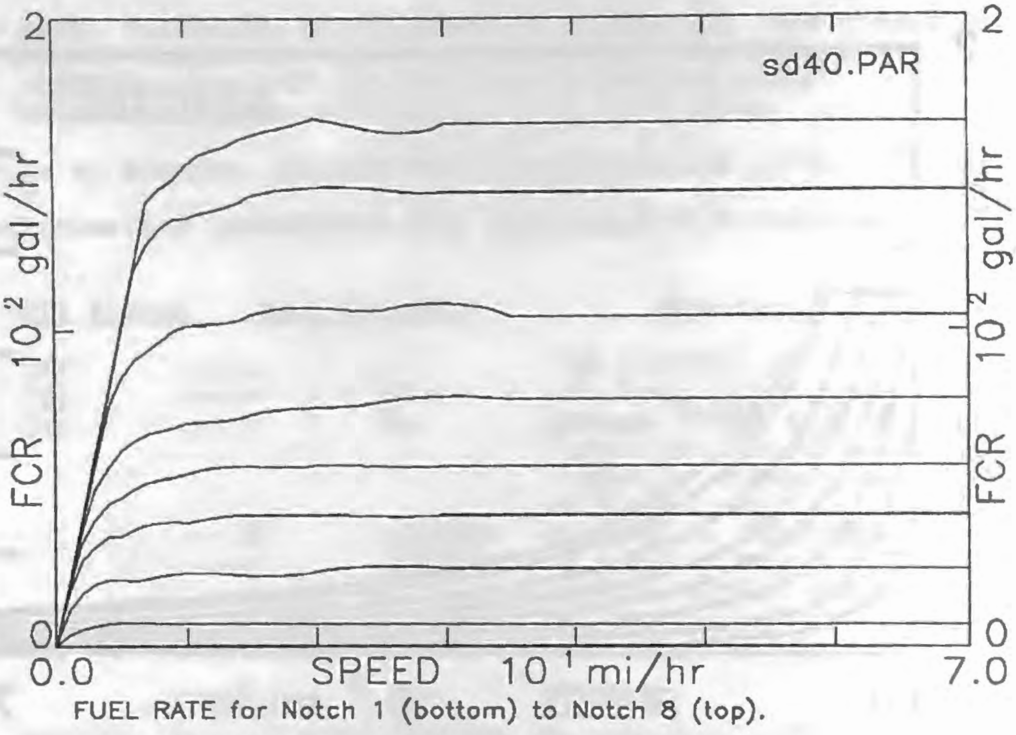


Exhibit 21. Graph Showing SD40 Diesel-Electric Locomotive Fuel Consumption Rate (gal/hr) VS. Speed (MPH) Curves for Throttle Notch Setting 1 (Bottom) to Throttle Notch Setting 8 (Top).

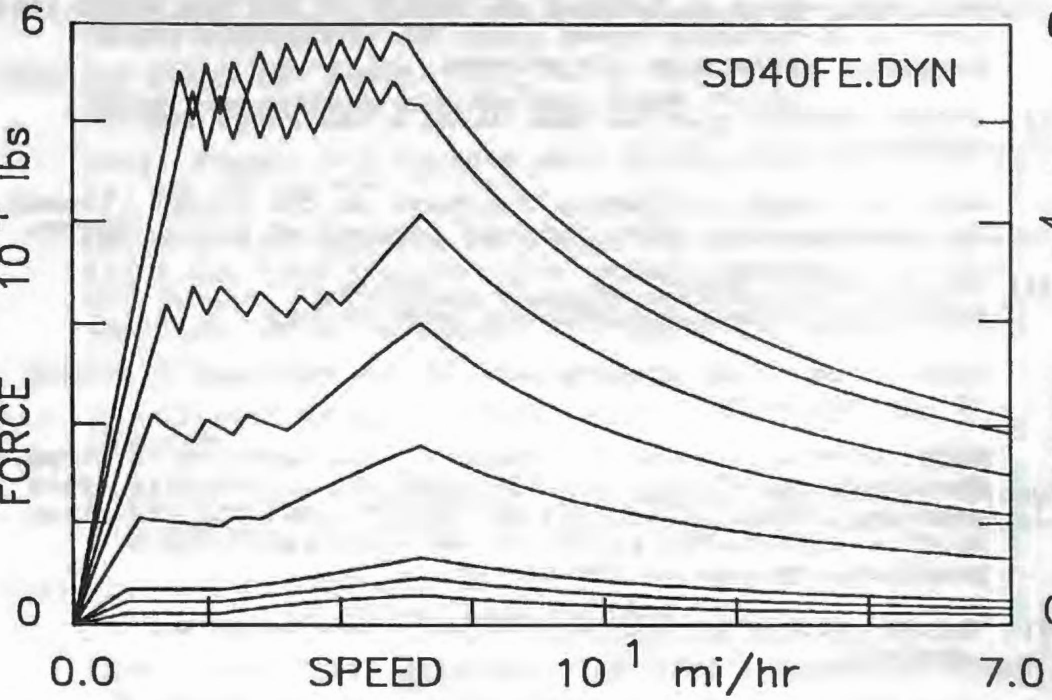


Exhibit 22. Graph Showing SD40 Diesel-Electric Locomotive Dynamic Braking Effort (lbs) VS. Speed (MPH) Curves for Dynamic Setting 1 (Bottom) to Dynamic Setting 8 (Top) for Dynamic Brake Type FE.

6.3.4 Prompts and Displays for PIX Function 4

If the user selects PIX Function 4, the following prompts appear:

(1) Enter TEM track file ID

NOTE: After the response to prompt (1), a graph of the track profile (Y-variable elevation VS. X-variable track position, which is labeled as "POSIT.") and the speed limit profile (Z-variable speed limit VS. X-variable track position) appears on the screen.

(2) Should another plot be made using a new range for POSIT.?

NOTE: To avoid cluttering the graph on the screen, prompt (2) appears only after the user presses an extra <ENTER>.

(2A) The range of POSIT. is __ to __ miles.
Enter new minimum and maximum range values.

NOTE: Prompt (2A) appears only if the response to prompt (2) is "Y" or "y".

NOTE: If the response to prompt (2) is negative, a graph of the grade profile (Y-variable grade VS. X-variable track position, which is labeled as "GRADE") and the elevation profile (Z-variable elevation VS. X-variable track position) appears on the screen.

(3) Should another plot be made using a new range for POSIT.?

NOTE: To avoid cluttering the graph on the screen, prompt (2) appears only after the user presses an extra <ENTER>.

(3A) The range of POSIT. is __ to __ miles.
Enter new minimum and maximum range values.

NOTE: Prompt (3A) appears only if the response to prompt (3) is "Y" or "y".

NOTE: If the response to prompt (3) is negative, a graph of the curve profile (Y-variable curve VS. X-variable track position, which is labeled as "CURVE") and the elevation profile (Z-variable elevation VS. X-variable track position) appears on the screen.

(4) Should another plot be made using a new range for POSIT.?

NOTE: To avoid cluttering the graph on the screen, prompt (4) appears only after the user presses an extra <ENTER>.

(4A) The range of POSIT. is __ to __ miles.
Enter new minimum and maximum range values.

NOTE: Prompt (4A) appears only if the response to prompt (4) is "Y" or "y".

NOTE: If the response to prompt (4) is negative, a graph of the track layout (Y-variable normal component of track position VS. X-variable tangent component of track position, which is labeled as "TANGENT") appears on the screen.

(5) Should another plot be made using a new range for TANGENT?

NOTE: To avoid cluttering the graph on the screen, prompt (5) appears only after the user presses an extra <ENTER>.

(5A) The range of TANGENT is __ to __ miles.
Enter new minimum and maximum range values.

NOTE: Prompt (5A) appears only if the response to prompt (5) is "Y" or "y".

As an example, to plot the data in track chart D1.TRK (by "zooming in" on the track positions between 2 and 10 miles), the user responds as follows:

PIX Prompt		User Response	Comment
(0)	--->	4	PIX Function 4
(1)	--->	D1	track chart called "D1" (elevation and speed limit profiles displayed after response to prompt (1))
	--->	<ENTER>	to get prompt (2)
(2)	--->	y	"zoom in" on part of the track position range
(2A)	--->	2 10	subinterval 2 to 10 miles
	--->	<ENTER>	to get prompt (2)
(2)	--->	n	to display grade and elevation profiles
(3)	--->	y	"zoom in" on part of the track position range
(3A)	--->	2 10	subinterval 2 to 10 miles
	--->	<ENTER>	to get prompt (3)
(3)	--->	n	to display curve and elevation profiles
(4)	--->	y	"zoom in" on part of the track position range
(4A)	--->	2 10	subinterval 2 to 10 miles
	--->	<ENTER>	to get prompt (4)
(4)	--->	n	to display track layout
	--->	<ENTER>	to get prompt (5)
(5)	--->	y	"zoom in" on part of the track position range
(5A)	--->	2 10	subinterval 2 to 10 miles
	--->	<ENTER>	to get prompt(5)
(5)	--->	n	go to menu prompt
(0)	--->	0	exit program PIX

Exhibit 23 is a graph showing the track and speed limit profiles for the 2 to 10 mile subinterval of the data in file D1.TRK. Except for color, Exhibit 23 shows the graph as it appears on the screen after an appropriate response to prompt (2A). Similarly, Exhibit 24 shows the graph of the 2 to 10 mile subinterval of the grade profile as it appears on the screen after an appropriate response to prompt (3A); Exhibit 25 shows

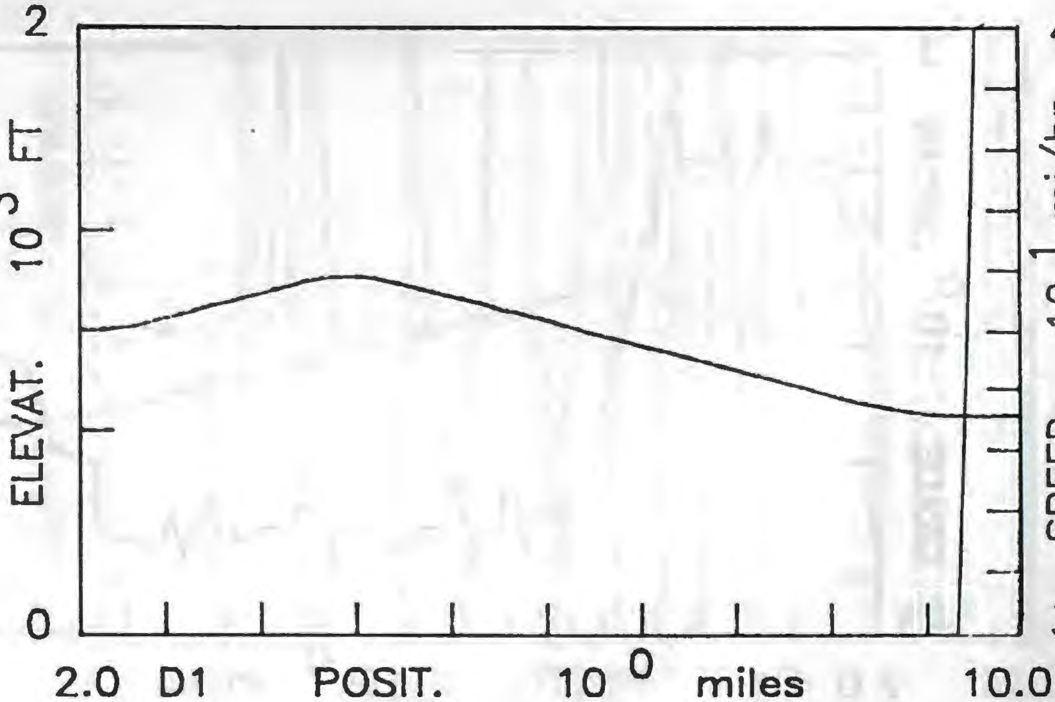


Exhibit 23. Graph Showing the Track Profile and Speed Limit Profile for the Track Chart Data in File D1.TRK.

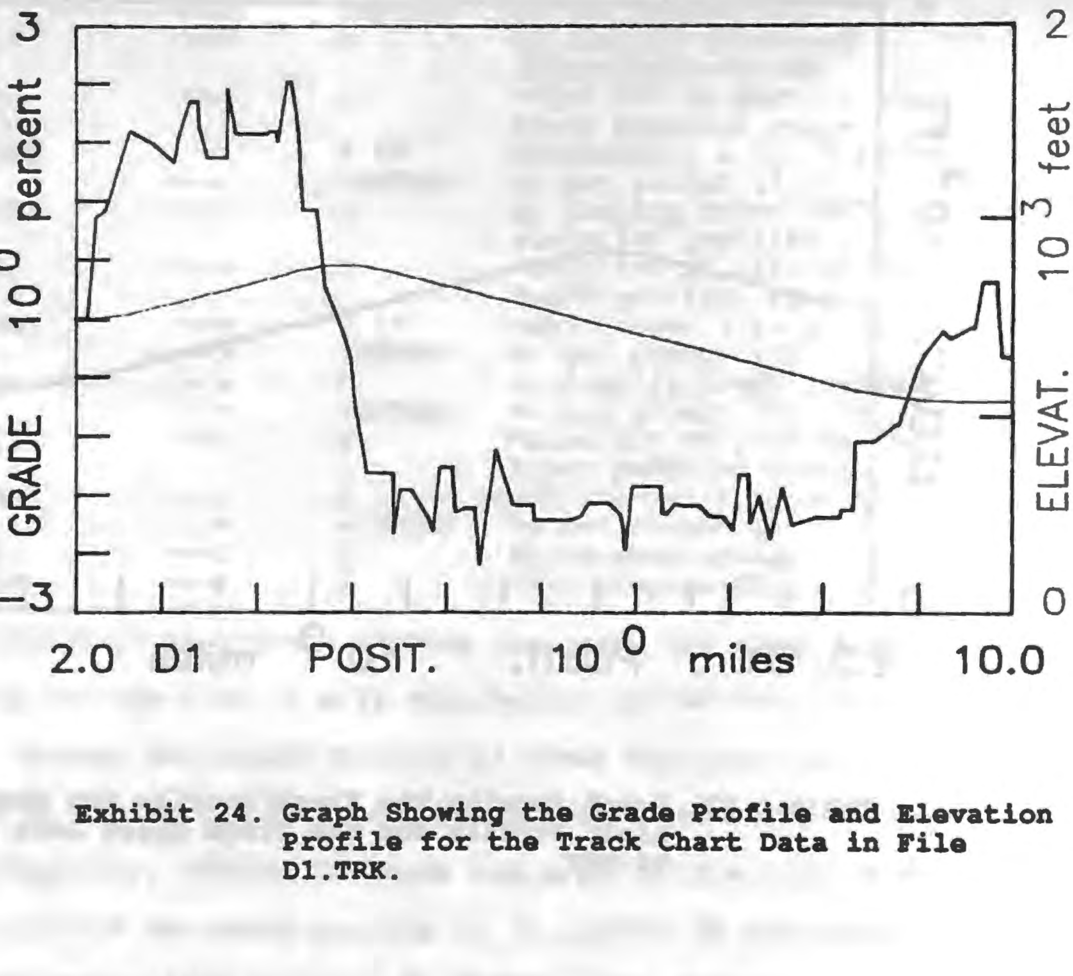


Exhibit 24. Graph Showing the Grade Profile and Elevation Profile for the Track Chart Data in File D1.TRK.

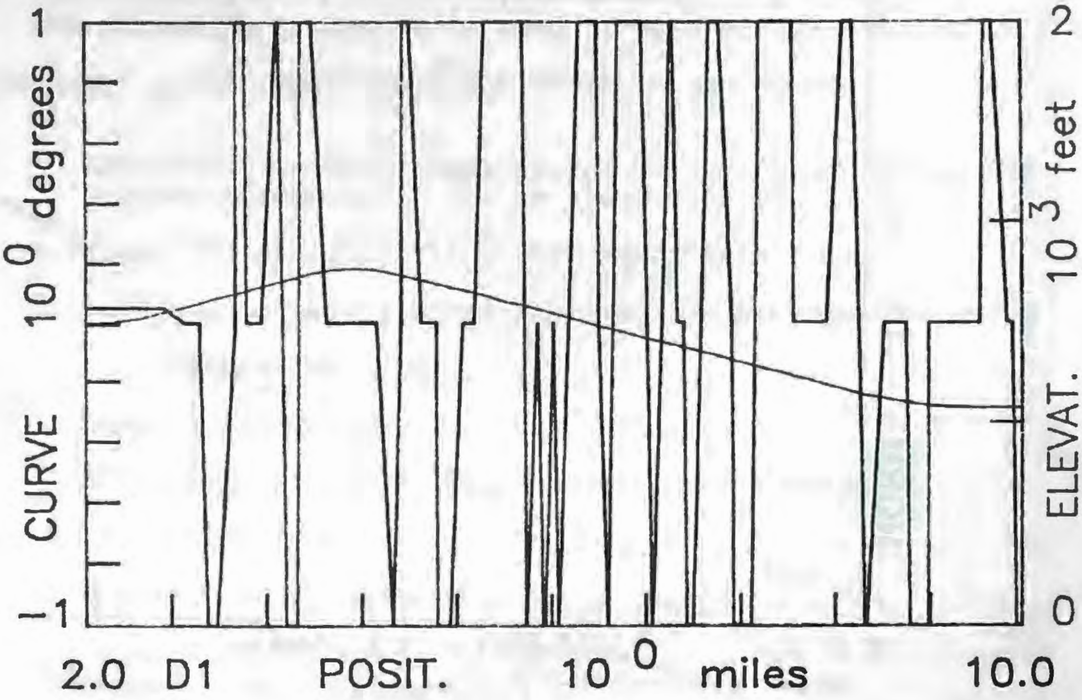
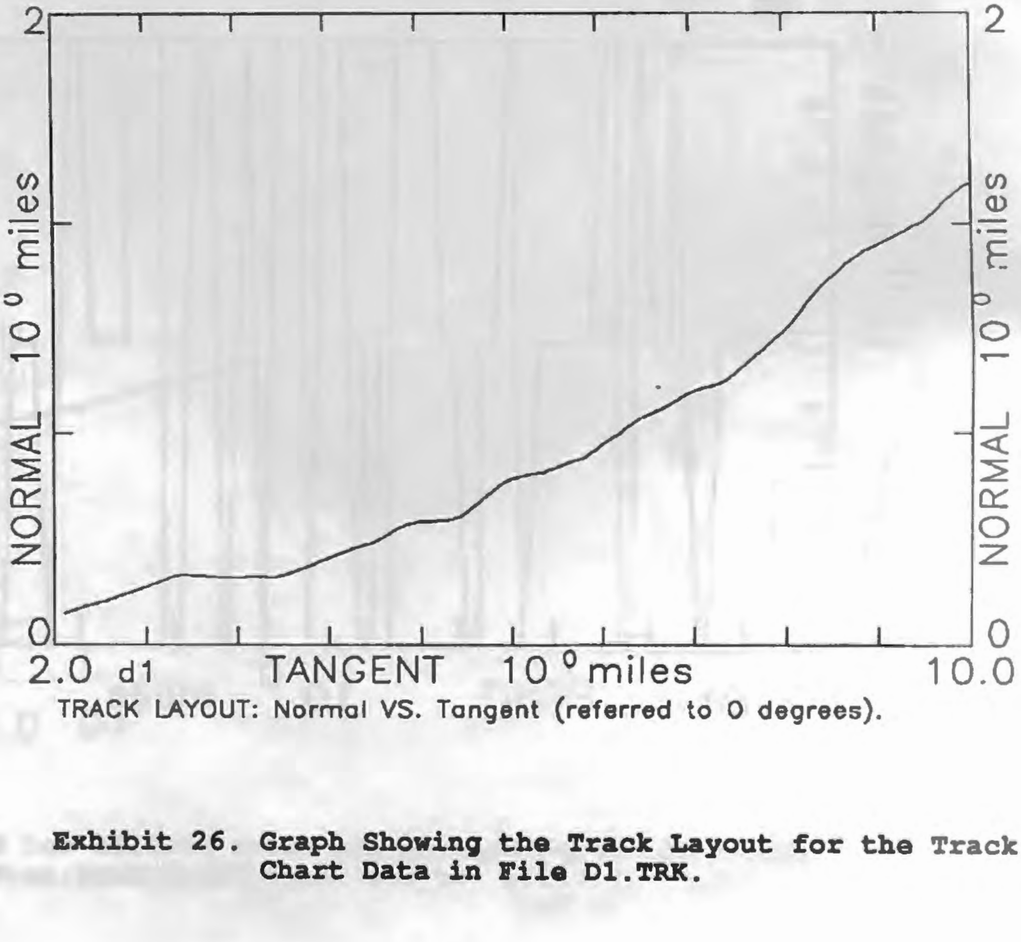


Exhibit 25. Graph Showing the Curve Profile and Elevation Profile for the Track Chart Data in File D1.TRK.



TRACK LAYOUT: Normal VS. Tangent (referred to 0 degrees).

Exhibit 26. Graph Showing the Track Layout for the Track Chart Data in File D1.TRK.

the graph of the 2 to 10 mile subinterval of the curve profile as it appears on the screen after an appropriate response to prompt (4A); and Exhibit 26 shows the graph of the 2 to 10 mile subinterval of the track layout as it appears on the screen after an appropriate response to prompt (5A).

6.4 PIX "Hard Copy" Procedure

The following procedure is used to make a high-resolution "hard copy" on the printer of any graph on the screen:

1. Obtain the desired graph on the screen by using the PIX prompts discussed in the previous section.
2. Enter "L" (capital "L" -- NOT lower case "l").
3. Wait approximately three minutes; the message

   GENERATING PRINT

   appears three times (one for each minute).
4. After approximately three minutes, the message

   PRINT MADE

   appears and there is an audible "beep".
5. Press the <ENTER> key to continue.

Instead of using PIX, the user can display and print TEM simulation results with a commercial PC program that has data plotting capabilities. Exhibit 27 is a table showing the FORTRAN format for each line of the .OUT file. This information can be used to convert the .OUT file format suitable for PIX to a format suitable for another data plotter program.

FORTRAN FORMAT FOR EACH LINE IN .OUT FILE

Quantity		FORTRAN Format
1	Integral number of elapsed hours	I2
2	Integral number of minutes	I2
3	Integral number of seconds	I2
4	Integral number of miles for current position	I4
5	Integral number of feet	I4
6	Velocity of train in MPH	F6.2
7	Acceleration of train in MPH/min	F6.2
8	Cumulative fuel consumption in gallons	F6.0
9	Throttle notch setting of leading locomotive consist	I2
10	Dynamic brake setting of leading locomotive consist	F2.0
11	Automatic brake pipe pressure in PSI	F4.0
12	Independent brake cylinder pressure in PSI	F3.0
13	Reverser switch setting (NOT IMPLEMENTED)	F3.0
14	Elevation in ft of leading vehicle in train	F6.0
15	Current speed limit in MPH	F4.0
16	Drawbar force estimate in lbs	F8.0
17	Throttle notch setting of helper locomotive consist	I2
18	Dynamic brake setting of helper locomotive consist	F2.0
19	Rolling resistance coefficient in lbs/TON	F7.3
20	Direction angle of leading vehicle in train in degrees	F6.0
21	Position projection along tangent to original heading in miles	F8.2
22	Position projection along normal to original heading in miles	F8.2

Exhibit 27. Table Showing the FORTRAN Format for Each Line in the .OUT File.

7.0 TRAIN ENERGY MODEL SIMULATIONS

The purpose of this chapter is to demonstrate Train Energy Model capabilities through the presentation of a number of varied simulation examples. However, these simulation examples by no means exhaust the possibilities inherent in TEM.

The table in Exhibit 28 gives the train (simulated) time, computer time (for separate runs of the simulator program), destination error (difference between nominal and actual stopping positions), and an estimate of the overall computational error for each of the TEM simulation examples in this chapter. All of the simulations were run individually (i.e., with one set of copy and execute commands in the GOTEM.BAT file) on the same IBM-compatible 386 PC with a 387 math coprocessor and a clock rate of 16 MHz.

From the table in Exhibit 28, we see that the speed of TEM simulations (for this set of simulations) varies from about 40 times faster than "real" time down to about 10 times faster than "real" time. In general, the greater the number of vehicles in the train and/or the smaller the output time intervals (specified in the .INI file), the slower the simulation in terms of computer time.

In the table in Exhibit 28, the computer time for each TEM simulation does not include the preprocessing time required to obtain the .DAT file for the consist used in the simulation. The

OVERVIEW of T E M SIMULATION EXAMPLES

RUN	TRAIN	TRACK	Train TIME h	m	s	Computer h	m	s	Stopping Error (ft)	Computation Error (%)	FUEL (gal)
Basic Dynamics:											
A1	A1	A		16	0		1	38	N/A	< 2.94	N/A
A2	A2	A		25	0		2	29	N/A	< 0.30	0
Effect of Wind:											
B1	B	B	1	2	59		1	20	- 79	0.15	70
B2	B	B	1	2	59		1	39	- 205	0.11	96
Effect of Lubrication:											
C1	B	C		29	34		2	12	- 39	0.22	55
C2	B	C		29	35		2	19	- 53	0.22	54
C3	B	C		29	25		2	12	+ 141	0.25	47
Cresting a Hill:											
D1	D1	D1		33	44		2	23	- 100	0.33	189
D2	D2	D2		40	27		2	45	+ 70	0.10	144
Change of Consist:											
E1	E1	E	3	21	32		7	33	+ 88	0.46	1977
E2	E2	E	1	18	45		2	17	- 250	0.07	777
E3	E1	E	2	19	1		6	28	- 229	0.11	709
E4	E4	E4		41	45			50	+ 291	2.85	32
No Change of Consist:											
E5	E2	E	6	50	48		18	47	+ 84, - 469, and - 470 (3 stops)	0.08	3678

Exhibit 28. Table Showing the Results of Several TEM Simulation Examples.

total time required to preprocess all eight consists used in the simulation examples (by running program PRE in batch mode on the IBM-compatible PC mentioned above) was 13 minutes and 36 seconds.

7.1 Simulations Demonstrating the Ability of TEM to Model Basic Dynamics

7.1.1 Simulation A1: Single Car Rolling on a Downgrade

The purpose of Simulation A1 is to demonstrate the ability of TEM to model the dynamics of an unpowered car rolling downhill (for example, a car rolling down the "hump" in a railroad yard). In this case, the "train" consists of only one vehicle, as indicated in the table below:

CONSIST for SIMULATION A1 (A1.CON)

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
BOXCAR	1	0

From the table, we see that the weight of lading in the boxcar is 0 tons (i.e., the boxcar is empty). In the corresponding .PAR file, the weight of the boxcar is given as 32 tons. Thus, the total weight of the "train" is 64000 pounds.

The track, which is in disk file A.TRK, is a tangent ramp with a downgrade of 0.5% extending for 2 miles, followed by a tangent level section. At the origin, the track is 52.8 feet above the tangent level portion. At the beginning of the simulation, the center of gravity of the car is at the origin of the track chart. Thus, since the weight of the car is 64000 pounds, the total potential energy of the car at the beginning of the simulation is about 1.7 horsepower-hours (HPH).

Exhibit 29 is a table showing the input information required to run Simulation A1. The information is grouped according to the files from which it is obtained by the simulator program.

File A1.RPT contains the fuel and energy report for Simulation A1. The first part of the report is a train consist and train operations summary for Simulation A1. This summary is shown in Exhibit 30.

Another table in A1.RPT is reproduced below:

WORK DONE by EACH FORCE

Force	Work(hph)
Gravity	1.7
Resistance	-1.7
Air Brakes	0.0
Dynamic Brakes	0.0
Diesel Traction	0.0
NET WORK	0.0

Since the simulation started and stopped with the car at zero MPH, the net work should be zero HPH. Thus, the actual value reported for the net work (the algebraic sum of all the values in the table) can be used to estimate the overall computational error in the simulation. Assuming that the actual

INPUT INFORMATION for SIMULATION A1

A1.INI:		
Train data file name	A1	
Track chart file name	A	
Wind chart file name	NOWIND	
File output time interval (sec)	1	
Terminal output time interval (sec)	1	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
A1.STP:		
Final position of leading vehicle (miles,feet)	10	0
(In this simulation, the final position is determined by "nature"; the specification of 10 miles is arbitrary.)		
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	
A1.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	

A1.CMD:

REDUCTION OF 0 PSI FOR 16 MINUTES
END SIMULATION

NOTE: TEM English commands do not end with a period.

Exhibit 29. Table Showing the Input Information Required to Run Simulation A1.

T E M FUEL and ENERGY REPORT for SIMULATION A1
OPERATIONS SUMMARY

CONSIST A1		
No. Vehicles in Consist		1
No. Leading Locomotives		0
No. Cars (and shutdown locos.)		1
No. Helper Locomotives		0
Total Train Length		50 feet
Total Train Power (at the rail)		0 hp
Total Train Weight		32 Tons
Weight of Fuel		0 Tons
Weight of Lading		0 Tons
Empty Train Weight		32 Tons
Maximum Power/Weight		0.00 hp/TON
TRACK A		
No. Stops		1
Total Distance Traveled	3 mi	33 ft
Total Elapsed Time	0 h 16 m	0 s
Over-the-Road Time	0 h 14 m	49 s
Dwell Time	0 h 1 m	11 s
Average Over-the-Road Speed		12 MPH
TOTAL FUEL CONSUMPTION		0 gal
Diesel Fuel/Work		0 gal/Khph

Exhibit 30. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File A1.RPT.

work done on the car by gravity was 1.7 HPH, the estimated error is 0.05/1.7 or 2.94%. In this case, since the net work given in the table is zero HPH, the estimate is an upper limit. The computational error for simulation A1 is probably much less than 2.94%.

The quantities in file A1.OUT can be plotted in various ways by running program PIX. For this simulation, Exhibits 31, and 32 are particularly interesting, since they allow us to judge the results of the simulation qualitatively.

Exhibit 31 is a plot of velocity and elevation versus time. As expected, the velocity increases exponentially with time as the car moves down the ramp under velocity-dependent acceleration. (Because of the acceleration, the elevation of the car, when plotted against time, appears as an inverted curve, instead of a straight line going down to the tangent level portion of the track.) Just as the car reaches the bottom of the ramp, the velocity is at a maximum of about 22 MPH. Equating the kinetic energy of the car at the bottom of the ramp to the potential energy of the car at the top of the ramp, the predicted velocity (without taking resistance into account) is about 39 MPH. Thus, we see that the resistance acting on the car is very effective in "checking" the velocity as the car moves down the ramp. On the tangent level portion of the track, the car is no longer driven by the force of gravity, and the velocity decreases exponentially with time as velocity-dependent resistance dissipates the kinetic energy of the car.

Exhibit 32 is a plot of velocity and position versus time. On this plot, it is easy to see how the car's position and velocity are related as the car rolls down the ramp and then rolls to a stop at about one mile from the bottom of the ramp. In fact, this plot shows how well the TAME method integrates the equation of motion: the position is a perfect integral of the velocity.

7.1.2 Simulation A2: Unpowered Locomotive and Car Rolling on a Downgrade

The purpose of Simulation A2 is to demonstrate the ability of TEM to model the dynamics of an unpowered train. In this case, the train consists of only two vehicles, as indicated in the table below:

CONSIST for SIMULATION A2 (A2.CON)

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
SD40 (FE)	1	12
BOXCAR	1	60

In the table, we see that the weight of fuel in the locomotive is 12 tons and the weight of lading in the boxcar is 60 tons. In the corresponding .PAR files, the weights of the locomotive and boxcar are given as 211 tons and 32 tons, respectively. Thus, the total weight of the train is 315 tons or

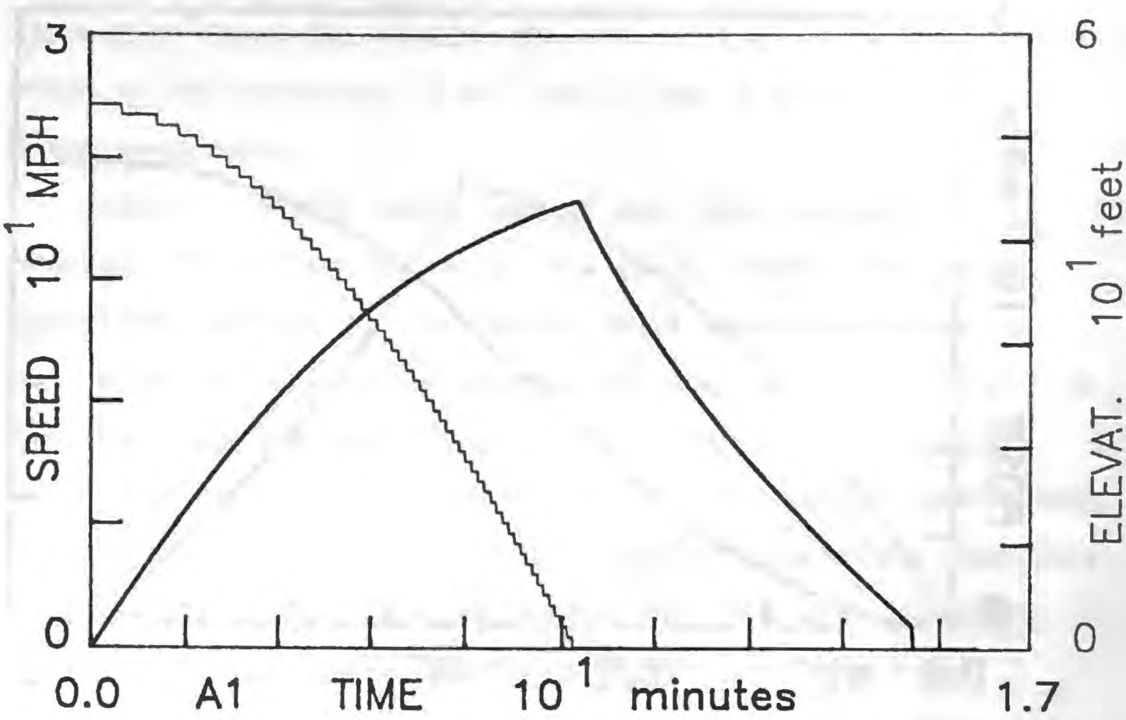


Exhibit 31. Graph for Simulation A1 Showing Velocity and Elevation VS. Elapsed Time for a Single Car (with Brakes Off) Rolling Downgrade and Onto Tangent Level Track.

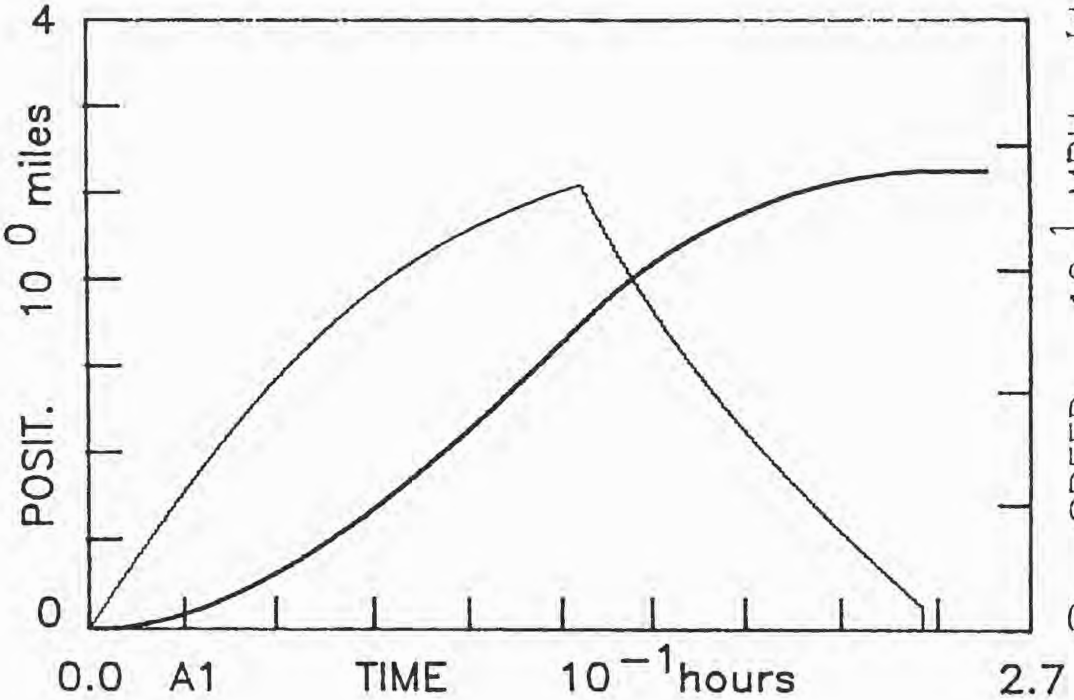


Exhibit 32. Graph for Simulation A1 Showing Velocity and Position VS. Elapsed Time for a Single Car (with Brakes Off) Rolling Downgrade and Onto Tangent Level Track.

630000 pounds -- about 10 times the weight of the empty boxcar in Simulation A1.

The track is the same one used in Simulation A1. The total weight of the train is 0.63 million pounds. Thus, assuming that the center of gravity of the train is close to the center of gravity of the locomotive, and that the initial position of the locomotive is at the origin, the total potential energy of the train at the beginning of the simulation is about 16.8 horsepower-hours.

Exhibit 33 is a table showing the input information required to run Simulation A2. The train consist and train operations summary for Simulation A2 is shown in Exhibit 34.

Since the simulation started and stopped with the train at zero MPH, the net work should be zero HPH. Thus, the actual value reported, 0.0 HPH, can be used to estimate an upper limit for the overall computational error in the simulation. Assuming that the actual work done by gravity was 16.8 HPH, the upper limit of the estimated error is 0.05/16.8 or about 0.30%.

Exhibit 35 is a plot of velocity and elevation versus time. As expected, the velocity increases with time as the train moves down the ramp. Just as the train reaches the bottom of the ramp, the velocity is about 32 MPH. Equating the kinetic energy of the train at the bottom of the ramp to the potential energy of the train at the top of the ramp, the predicted velocity

INPUT INFORMATION for SIMULATION A2

A2.INI:		
Train data file name	A2	
Track chart file name	A	
Wind chart file name	NOWIND	
File output time interval (sec)	1	
Terminal output time interval (sec)	1	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
A2.STP:		
Final position of leading vehicle (miles,feet) (In this simulation, the final position is determined by "nature"; the specification of 10 miles is arbitrary.)	10	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	
A2.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	
A2.CMD:		
SHUTDOWN LOCOMOTIVE FOR 25 MINUTES		
END SIMULATION		

Exhibit 33. Table Showing the Input Information Required to Run Simulation A2.

T E M FUEL and ENERGY REPORT for SIMULATION A2
OPERATIONS SUMMARY

CONSIST A2		
No. Vehicles in Consist	2	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	1	
No. Helper Locomotives	0	
Total Train Length	119	feet
Total Train Power (at the rail)	2667	hp
Total Train Weight	315	Tons
Weight of Fuel	12	Tons
Weight of Lading	60	Tons
Empty Train Weight	243	Tons
Maximum Power/Weight	8.47	hp/TON
TRACK A		
No. Stops	1	
Total Distance Traveled	6 mi 572	ft
Total Elapsed Time	0 h 25 m 0	s
Over-the-Road Time	0 h 23 m 54	s
Dwell Time	0 h 1 m 6	s
Average Over-the-Road Speed	15	MPH
TOTAL FUEL CONSUMPTION	0	gal
Diesel Fuel/Work	0	gal/Khph

Exhibit 34. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File A2.RPT.

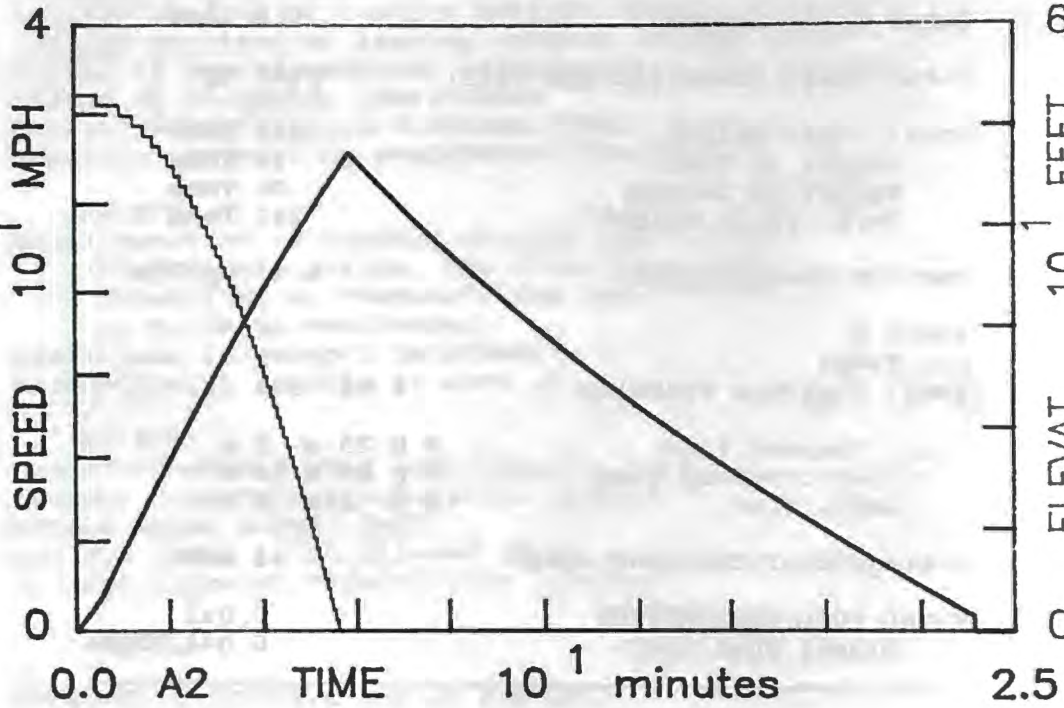


Exhibit 35. Graph for Simulation A2 Showing Velocity and Elevation VS. Elapsed Time for a Train (with Power Off) Rolling Downgrade and Onto Tangent Level Track.

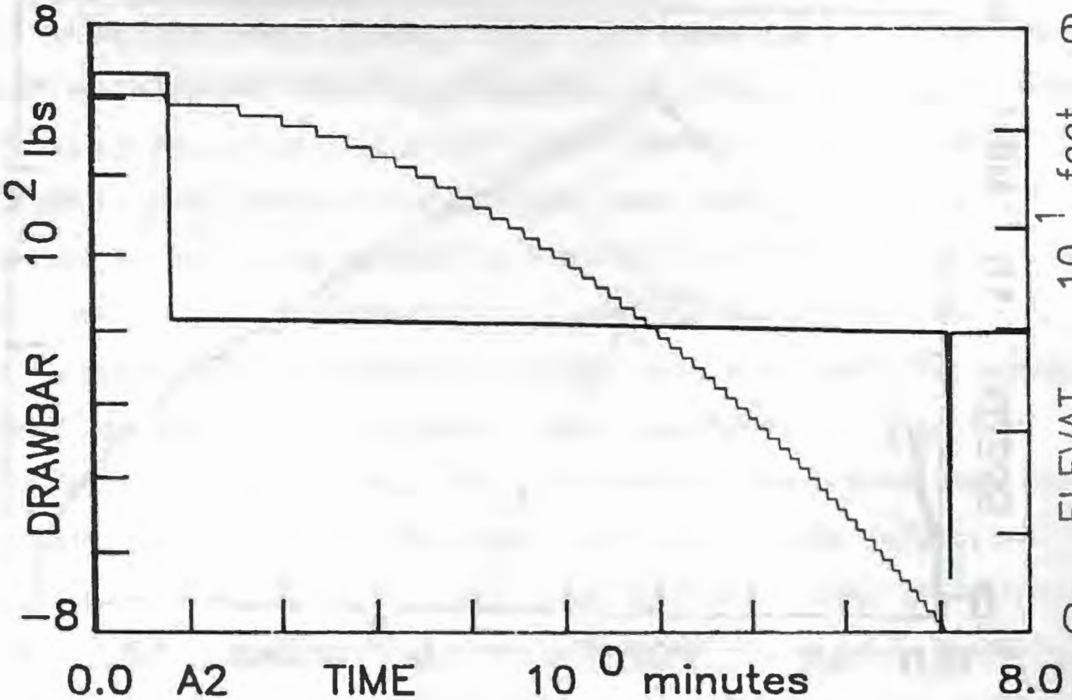


Exhibit 36. Graph for Simulation A2 Showing Drawbar Force and Elevation VS. Elapsed Time for a Train (with Power Off) Rolling Downgrade and Onto Tangent Level Track.

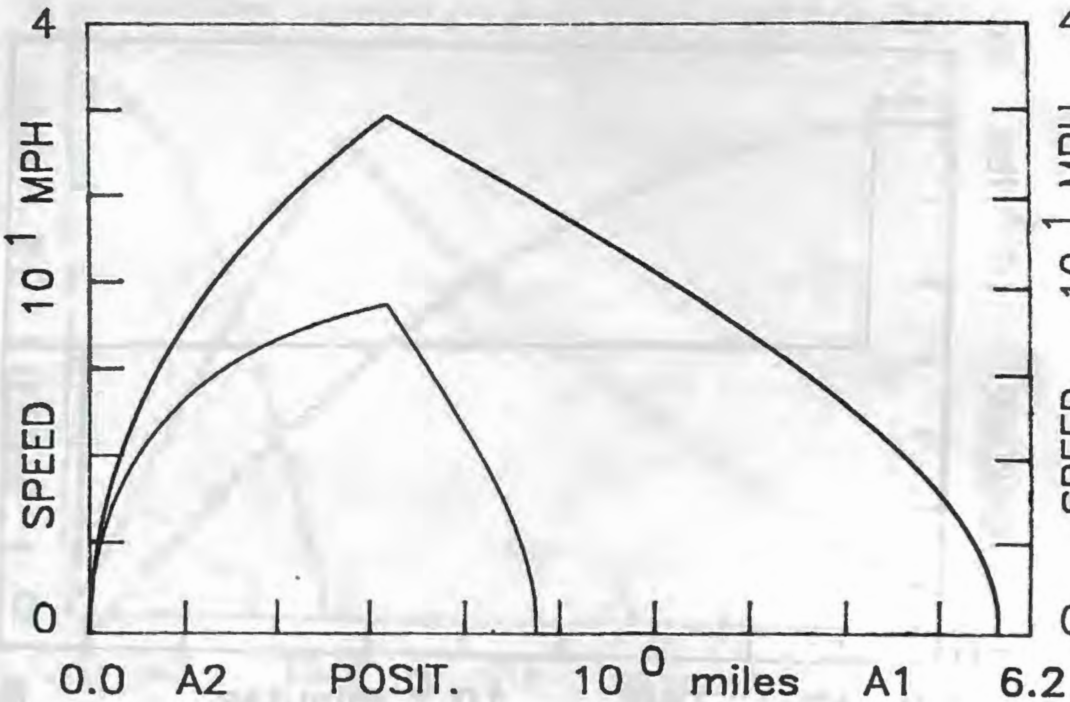


Exhibit 37. Graph Showing a Comparison of Velocity VS. Position for Simulations A2 and A1.

(without taking train resistance into account) is about 39 MPH. Thus, we see in this case that the resistance acting on the train is not very effective in "checking" the velocity as the train moves down the ramp.

Since the locomotive and loaded boxcar together are much more massive than the empty boxcar in Simulation A1, this result is to be expected. In fact, Exhibit 33 shows that the velocity increases almost linearly with time, as if gravity were the only force acting on the train as it moved down the ramp. On the tangent level portion of the track, the train is no longer driven by the force of gravity, and the velocity decreases exponentially as resistance dissipates the kinetic energy.

Exhibit 36 is a plot of drawbar force and elevation versus time. As expected, the drawbar force is positive as the locomotive starts to roll down the ramp and the boxcar lags behind. The motion of the boxcar lags, because the locomotive starts on a downgrade and the boxcar starts on level track. Then, with both vehicles on the downgrade, the drawbar force drops to a small value. When the locomotive reaches the bottom of the ramp first, this causes a sharp negative spike, because the boxcar is still on the downgrade. When both vehicles are on the tangent level portion of the track, the drawbar force again drops to a small value. Finally, the locomotive rolls to a stop, and the drawbar force drops to zero. Exhibit 36 shows only the first 8 minutes of the drawbar time history.

Exhibit 37 is a plot of velocity versus position for both Simulation A2 and Simulation A1. In this plot, it is clear that the momentum of the A2 consist is much greater than that of the A1 consist, even though both consists roll down the same grade.

7.2 Simulations Demonstrating the Ability of TEM to Model the Effect of Wind on Fuel Consumption

The purpose of the next two simulations is to demonstrate the effect of wind on fuel consumption. Simulation B1 provides a "base case" with no wind. Then the results of simulation B2 (with a 20 MPH head wind) can be compared with those of B1.

7.2.1 Simulation B1: Train on Tangent Track with No Wind

The purpose of Simulation B1 is to serve as a "base case" for Simulation B2. However, in so doing, Simulation B1 also demonstrates the ability of the Automatic Train-handling Algorithm (ATA) to start a train, maintain a constant reference speed, and bring the train to a stop close to a specified destination. The train consist for this simulation is indicated in the table below:

CONSIST for SIMULATION B1 (B.CON)

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
SD40 (FE)	1	12
BOXCAR	20	60
CABOOS	1	0

Exhibit 38 is a table showing the input information required to run Simulation B1. The train consist and train operations summary for Simulation B1 is shown in Exhibit 39.

Exhibit 40 is a plot of velocity and throttle setting versus track position. As shown in Exhibit 40, the train accelerates to 40 MPH in about 3 miles. To maintain 40 MPH, the ATA modulates the throttle between notch 4 and notch 5. There are two reasons for this throttle modulation. First of all, the equilibrium speed for this train, running in notch 4 on tangent level track, is about 38 MPH and the corresponding equilibrium speed in notch 5 is about 45 MPH (as indicated in Exhibit 41). Second, the ATA tries to maintain the reference speed with the smallest notch setting possible, in an attempt to conserve fuel. Finally, as shown in Exhibit 40, at a distance of about 1 mile from the destination (track position of 39 miles, in this case), the ATA begins to slow the train according to the average approach deceleration of 16 MPH/min (specified in file B1.ATA).

7.2.2 Simulation B2: Train on Tangent Track with a 20 MPH Head Wind

The purpose of Simulation B2 is to demonstrate the ability of TEM to predict the effect of wind on train dynamics and fuel consumption. This is done by repeating Simulation B1 with a 20 MPH head wind (i.e., a wind from direction 180 degrees with respect to the direction of the locomotive, which remains at

INPUT INFORMATION for SIMULATION B1

B1.INI:

Train data file name	B	
Track chart file name	B	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	

B1.STP:

Final position of leading vehicle (miles,feet)	40	0
Dwell time for stop 1 (minutes)	0	
Locomotive(s) in idle at stop 1?	yes	

B1.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

B1.CMD:

CONSTANT SPEED OF 40 MPH FOR 40 MILES
END SIMULATION

Exhibit 38. Table Showing the Input Information Required to Run Simulation B1.

T E M FUEL and ENERGY REPORT for SIMULATION B1
OPERATIONS SUMMARY

CONSIST B		
No. Vehicles in Consist	22	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	21	
No. Helper Locomotives	0	
Total Train Length	1110	feet
Total Train Power (at the rail)	2667	hp
Total Train Weight	2095	Tons
Weight of Fuel	12	Tons
Weight of Lading	1200	Tons
Empty Train Weight	883	Tons
Maximum Power/Weight	1.27	hp/TON
TRACK B		
No. Stops	1	
Total Distance Traveled	39 mi 5201	ft
Total Elapsed Time	1 h 2 m 59	s
Over-the-Road Time	1 h 2 m 43	s
Dwell Time	0 h 0 m 16	s
Average Over-the-Road Speed	38	MPH
TOTAL FUEL CONSUMPTION	70	gal
Diesel Fuel/Work	57	gal/Khph

Exhibit 39. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File B1.RPT.

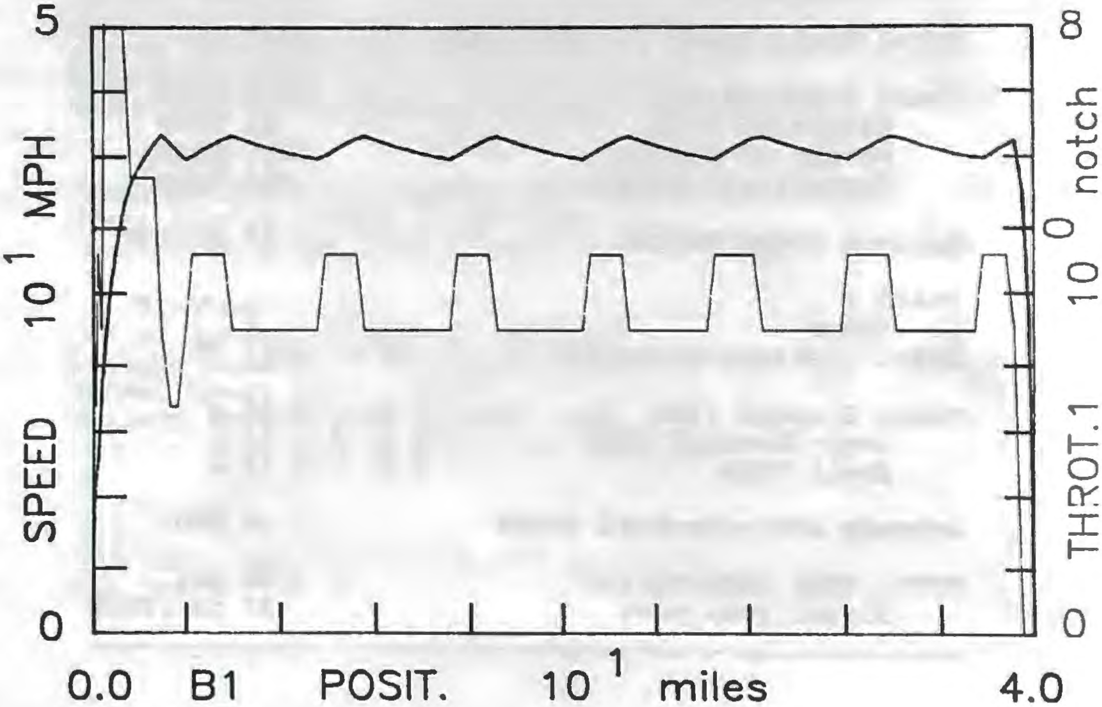


Exhibit 40. Graph for Simulation B1 Showing Velocity and Throttle Setting VS. Track Position for a Train on Tangent Level Track with No Wind.

Consist: B THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 1.27

%Grade								
3.0								
2.8								
2.6								
2.4								
2.2								10
2.0							10	11
1.8							11	12
1.6							12	13
1.4						11	14	15
1.2						12	16	18
1.0					10	14	19	21
0.8				10	13	17	22	24
0.6				13	16	22	27	30
0.4			11	17	22	28	34	38
0.2		10	17	24	31	37	44	48
0.0	11	19	29	38	45	51	58	61
Notch	1	2	3	4	5	6	7	8

Exhibit 41. Table Showing Train Consist B Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

0 degrees for the entire 40 miles). The consist, track, and operation are exactly the same as those for Simulation B1.

Exhibit 42 is a table showing the input information required to run Simulation B2. The train consist and train operations summary for Simulation B2 is shown in Exhibit 43.

Exhibit 44 is a plot of velocity and throttle setting versus track position. Simulation B2 and Simulation B1 differ significantly in only one respect: In Simulation B2, the ATA had to modulate the throttle between notch 5 and notch 6 to maintain virtually the same speed profile. As a result, the fuel consumption for Simulation B2 is 37% greater than that for B1. Apparently, the cost of going against the wind is quite high.

7.3 Simulations Demonstrating the Ability of TEM to Model the Effect of Lubrication on Fuel Consumption

The purpose of the next three simulations is to demonstrate the effect of lubrication on fuel consumption. Simulation C1 provides a "base case" with no lubrication. Then the results of Simulation C2 (with lubrication from a trackside lubricator) and the results of Simulation C3 (with lubrication from a vehicle-mounted lubricator) can be compared with those of Simulation C1.

INPUT INFORMATION for SIMULATION B2

B2.INI:

Train data file name	B	
Track chart file name	B	
Wind chart file name	B2	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	

B2.STP:

Final position of leading vehicle (miles,feet)	40	0
Dwell time for stop 1 (minutes)	0	
Locomotive(s) in idle at stop 1?	yes	

B2.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

B2.CMD:

CONSTANT SPEED OF 40 MPH FOR 40 MILES
END SIMULATION

Exhibit 42. Table Showing the Input Information Required to Run Simulation B2.

T E M FUEL and ENERGY REPORT for SIMULATION B2
OPERATIONS SUMMARY

CONSIST B	
No. Vehicles in Consist	22
No. Leading Locomotives	1
No. Cars (and shutdown locos.)	21
No. Helper Locomotives	0
Total Train Length	1110 feet
Total Train Power (at the rail)	2667 hp
Total Train Weight	2095 Tons
Weight of Fuel	12 Tons
Weight of Lading	1200 Tons
Empty Train Weight	883 Tons
Maximum Power/Weight	1.27 hp/TON
TRACK B	
No. Stops	1
Total Distance Traveled	39 mi 5075 ft
Total Elapsed Time	1 h 2 m 59 s
Over-the-Road Time	1 h 2 m 46 s
Dwell Time	0 h 0 m 13 s
Average Over-the-Road Speed	38 MPH
TOTAL FUEL CONSUMPTION	96 gal
Diesel Fuel/Work	58 gal/Khph

Exhibit 43. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File B2.RPT.

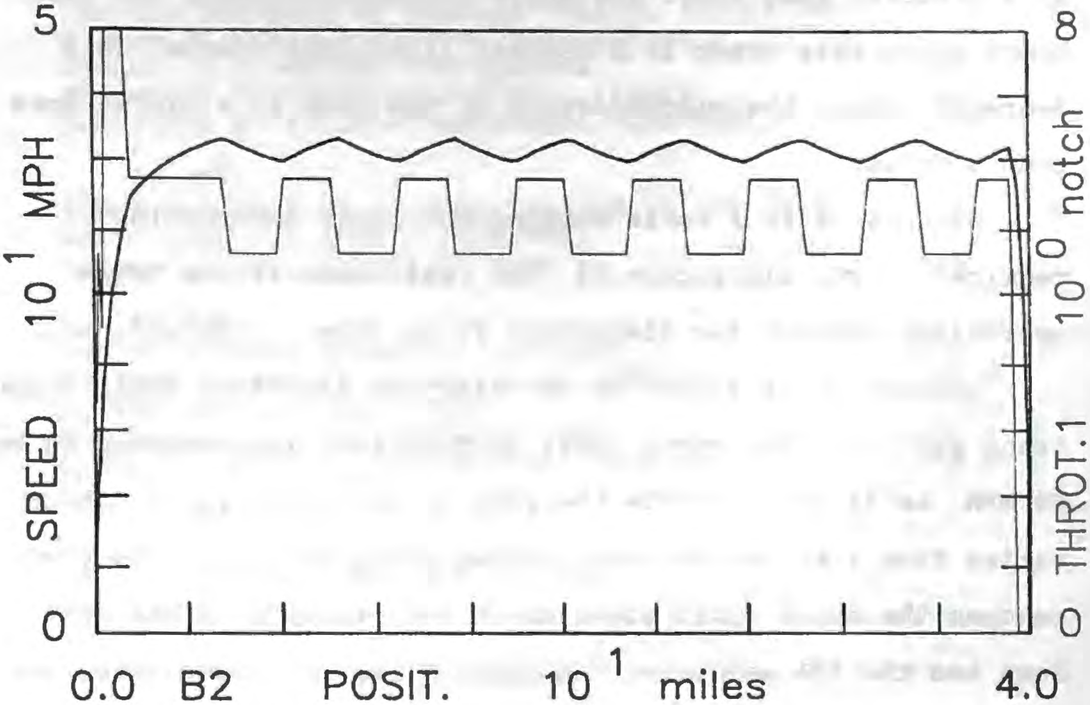


Exhibit 44. Graph for Simulation B2 Showing Velocity and Throttle Setting VS. Track Position for a Train on Tangent Level Track with a 20 MPH Head Wind.

7.3.1 Simulation C1: Train on Circular Track with No Lubrication

The purpose of Simulation C1 is to serve as a "base case" for the corresponding lubricated cases that follow. The consist is the same as that for the previous two simulations. The track is a circular test loop. The angle subtended by each 100-foot chord along this track is 2 degrees (i.e., the "curve" is 2 degrees). Thus, the circumference of the loop is a little more than 3 miles.

Exhibit 45 is a table showing the input information required to run Simulation C1. The train consist and train operations summary for Simulation C1 is shown in Exhibit 46.

Exhibit 47 is a plot of velocity and direction angle versus track position. The speed limit on this test loop happens to be 50 MPH. As is evident from the plot of direction angle (which varies from 0 to 360 degrees) versus track position, the train reaches the speed limit after about two circuits of the test loop and the ATA maintains the speed limit for about three and a half circuits of the loop. Then the ATA slows the train and brings it to a stop about 39 feet short of the specified destination after about one more circuit of the test loop.

Exhibit 48 is a plot of velocity and throttle setting versus track position. To maintain the speed limit of 50 MPH, the ATA modulates the throttle between notch 6 and notch 7.

INPUT INFORMATION for SIMULATION C1

C1.INI:

Train data file name	B	
Track chart file name	C	
Wind chart file name	NOWIND	
File output time interval (sec)	1	
Terminal output time interval (sec)	1	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	

C1.STP:

Final position of leading vehicle (miles,feet)	21	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	

C1.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	18.0

C1.CMD:

MAINTAIN SPEED LIMIT FOR 21 MILES
END SIMULATION

Exhibit 45. Table Showing the Input Information Required to Run Simulation C1.

T E M FUEL and ENERGY REPORT for SIMULATION C1
OPERATIONS SUMMARY

CONSIST B		
No. Vehicles in Consist	22	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	21	
No. Helper Locomotives	0	
Total Train Length	1110	feet
Total Train Power (at the rail)	2667	hp
Total Train Weight	2095	Tons
Weight of Fuel	12	Tons
Weight of Lading	1200	Tons
Empty Train Weight	883	Tons
Maximum Power/Weight	1.27	hp/TON
TRACK C		
No. Stops	1	
Total Distance Traveled	20 mi 2601	ft
Total Elapsed Time	0 h 29 m 34	s
Over-the-Road Time	0 h 28 m 22	s
Dwell Time	0 h 1 m 12	s
Average Over-the-Road Speed	43	MPH
TOTAL FUEL CONSUMPTION	55	gal
Diesel Fuel/Work	61	gal/Khph

Exhibit 46. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File C1.RPT.

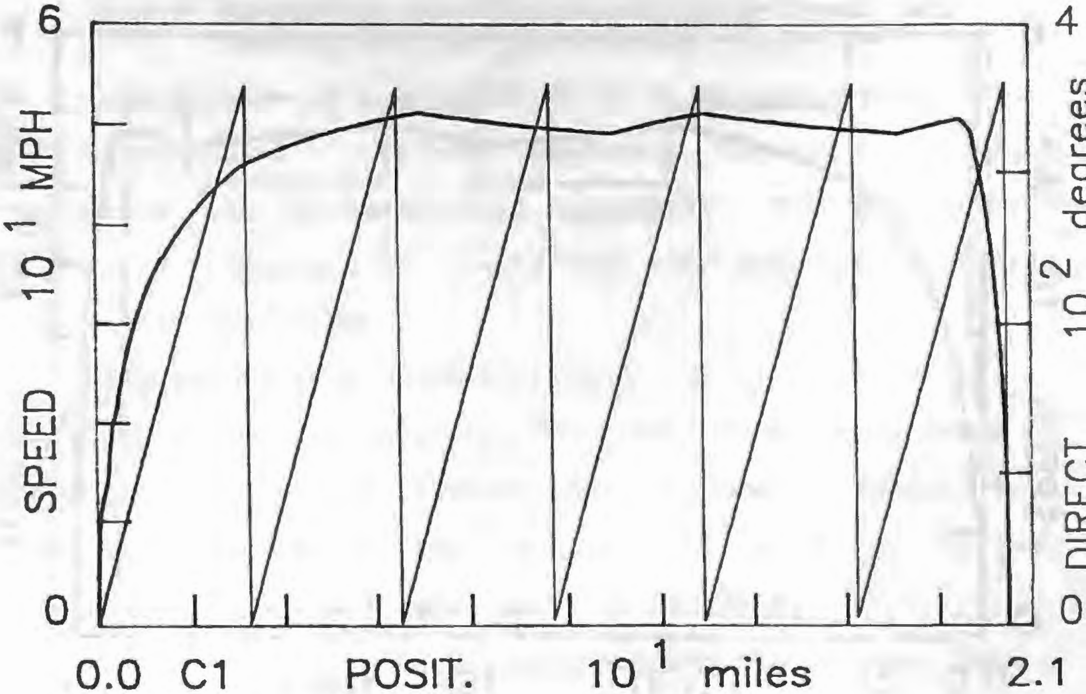


Exhibit 47. Graph for Simulation C1 Showing Velocity and Direction Angle VS. Track Position for a Train on a Test Loop with No Track Lubrication.

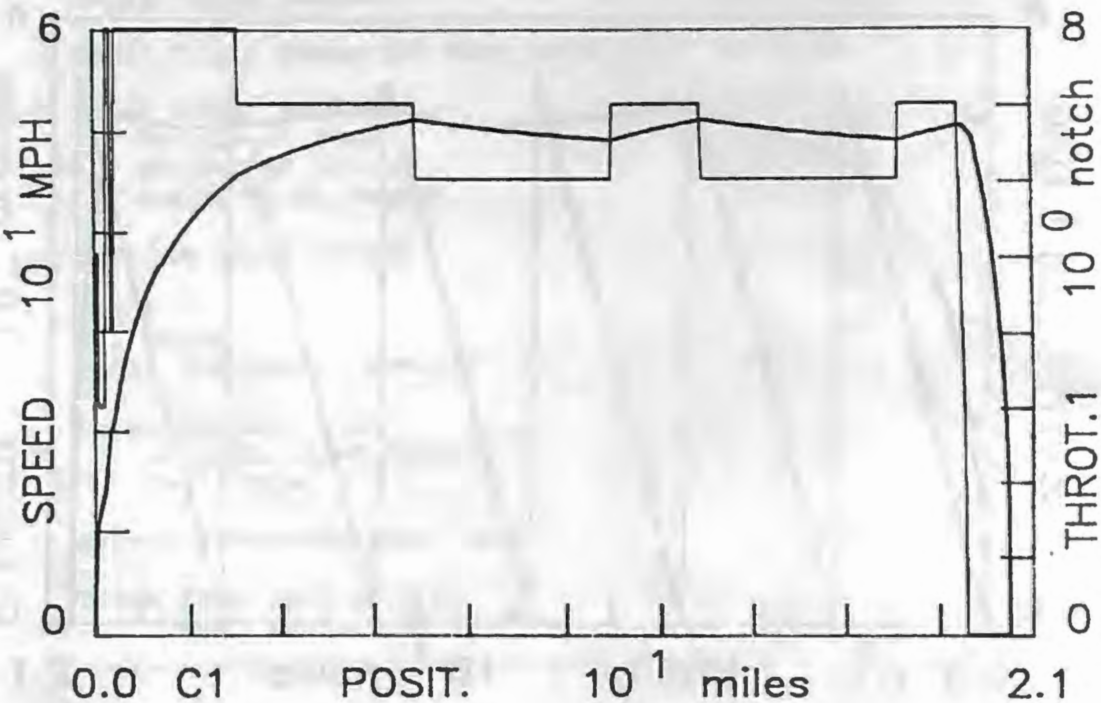


Exhibit 48. Graph for Simulation C1 Showing Velocity and Throttle Setting VS. Position for a Train on a Test Loop with No Track Lubrication.

The curve resistance on the test loop is substantial, because the equilibrium speed for the train, running in notch 6 on tangent level track, is about 51 MPH and the corresponding equilibrium speed in notch 7 is about 58 MPH (as indicated in Exhibit 41).

7.3.2 Simulation C2: Train on Circular Track with Lubrication from a Trackside Lubricator

The purpose of Simulation C2 is to demonstrate the effectiveness of a trackside lubricator, located at the origin of a test loop, to reduce fuel consumption. This simulation is a repeat of Simulation C1 -- only this time with the trackside lubricator operating.

Exhibit 49 is a table showing the input information required to run simulation C2. The train consist and train operations summary for Simulation C2 is shown in Exhibit 50. Comparing Exhibits 46 (for Simulation C1) and 50, we see that the reduction in fuel consumption is negligible.

The reason for this disappointing result is clear from Exhibit 51, which is a plot of rolling resistance and direction angle versus track position. The rolling resistance is reduced from 1.5 lbs/ton to 0.8 lbs/ton (a 0.7 lbs/ton reduction), for only 3600 feet out of more than 3 miles around the test loop.

Assuming that the downstream effectiveness of 3600 feet for the lubricant being used is fixed, more than one trackside

INPUT INFORMATION for SIMULATION C2

C2.INI:

Train data file name	B
Track chart file name	C
Wind chart file name	NOWIND
File output time interval (sec)	1
Terminal output time interval (sec)	1
Initial heading of leading vehicle (deg)	0
Initial position of leading vehicle (miles,feet)	0 0
Status of vehicle-mounted lubricators	OFF
Status of trackside lubricators	ON
Effective lubrication distance (feet)	3600
Reduction in rolling resistance (lbs/TON)	0.70

C2.STP:

Final position of leading vehicle (miles,feet)	21 0
Dwell time for stop 1 (minutes)	1
Locomotive(s) in idle at stop 1?	yes

C2.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	18.0

C2.CMD:

MAINTAIN SPEED LIMIT FOR 21 MILES
END SIMULATION

Exhibit 49. Table Showing the Input Information Required to Run Simulation C2.

T E M FUEL and ENERGY REPORT for SIMULATION C2
OPERATIONS SUMMARY

CONSIST B		
No. Vehicles in Consist	22	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	21	
No. Helper Locomotives	0	
Total Train Length	1110	feet
Total Train Power (at the rail)	2667	hp
Total Train Weight	2095	Tons
Weight of Fuel	12	Tons
Weight of Lading	1200	Tons
Empty Train Weight	883	Tons
Maximum Power/Weight	1.27	hp/TON
TRACK C		
No. Stops	1	
Total Distance Traveled	20 mi 2587	ft
Total Elapsed Time	0 h 29 m 35	s
Over-the-Road Time	0 h 28 m 16	s
Dwell Time	0 h 1 m 19	s
Average Over-the-Road Speed	43	MPH
TOTAL FUEL CONSUMPTION	54	gal
Diesel Fuel/Work	61	gal/Khph

Exhibit 50. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File C2.RPT.

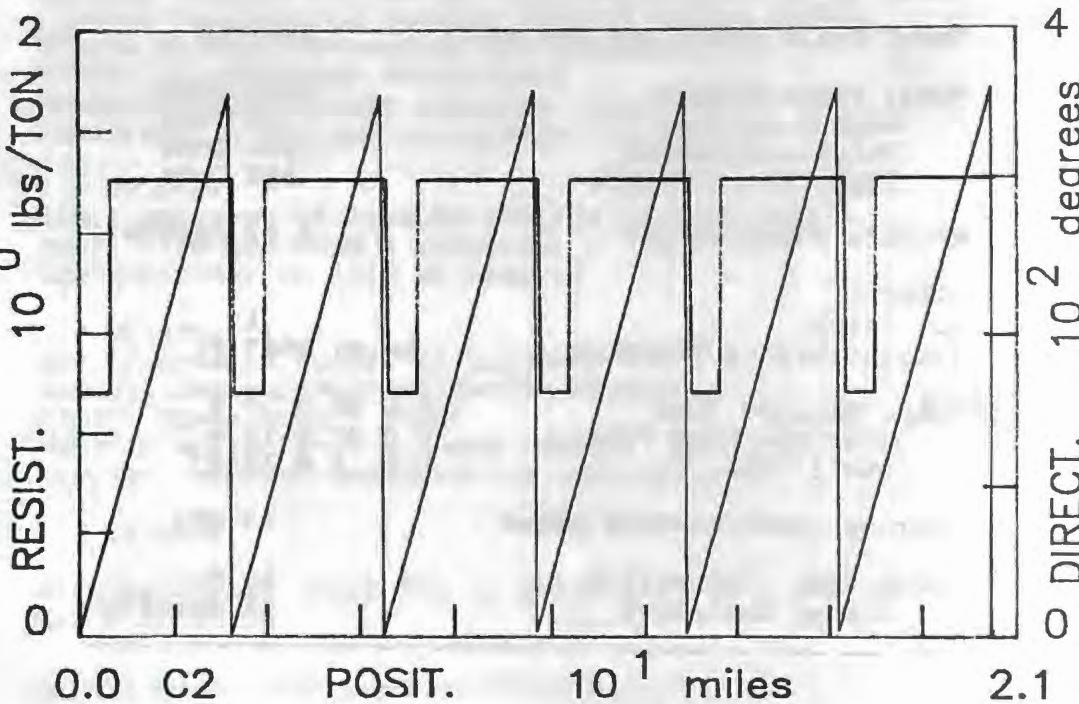


Exhibit 51. Graph for Simulation C2 Showing Rolling Resistance and Direction Angle VS. Position for a Train on a Test Loop with Track Lubricated by a Trackside Lubrication System.

INPUT INFORMATION for SIMULATION C3

C3.INI:		
Train data file name	B	
Track chart file name	C	
Wind chart file name	NOWIND	
File output time interval (sec)	1	
Terminal output time interval (sec)	1	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	ON	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
C3.STP:		
Final position of leading vehicle (miles,feet)	21	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	
C3.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	18.0	
C3.CMD:		
MAINTAIN SPEED LIMIT FOR 21 MILES		
END SIMULATION		

Exhibit 52. Table Showing the Input Information Required to Run Simulation C3.

T E M FUEL and ENERGY REPORT for SIMULATION C3
OPERATIONS SUMMARY

CONSIST B	
No. Vehicles in Consist	22
No. Leading Locomotives	1
No. Cars (and shutdown locos.)	21
No. Helper Locomotives	0
Total Train Length	1110 feet
Total Train Power (at the rail)	2667 hp
Total Train Weight	2095 Tons
Weight of Fuel	12 Tons
Weight of Lading	1200 Tons
Empty Train Weight	883 Tons
Maximum Power/Weight	1.27 hp/TON
TRACK C	
No. Stops	1
Total Distance Traveled	20 mi 2781 ft
Total Elapsed Time	0 h 29 m 25 s
Over-the-Road Time	0 h 28 m 12 s
Dwell Time	0 h 1 m 13 s
Average Over-the-Road Speed	44 MPH
TOTAL FUEL CONSUMPTION	47 gal
Diesel Fuel/Work	60 gal/Khph

Exhibit 53. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File C3.RPT.

lubricator would be necessary to obtain a noticable reduction in fuel consumption. However, instead of increasing the number of trackside lubricators, we will use a vehicle-mounted lubricator on the locomotive in the next simulation. Then the lubricant will be effective on the entire loop.

7.3.3 Simulation C3: Train on Circular Track with Lubrication from a Vehicle-Mounted Lubricator

The purpose of Simulation C3 is to demonstrate the effectiveness of a vehicle-mounted lubricator, located on the locomotive, to reduce fuel consumption. This simulation is a repeat of simulation C1 -- only this time with the vehicle-mounted lubricator operating.

Exhibit 52 is a table showing the input information required to run Simulation C3. The train consist and train operations summary for Simulation C3 is shown in Exhibit 53. Comparing Exhibits 46 (for Simulation C1) and 53, we see that the reduction in fuel consumption due to the use of the vehicle-mounted lubricator is 15%.

7.4 Simulations Demonstrating the Ability of TEM to Handle a Train Automatically with ATA

The purpose of the next two simulations is to demonstrate the ability of TEM to handle a train automatically with ATA in one of the most difficult train handling situations: keeping the train under control as it moves over the crest of a hill. In Simulation D1, the ATA handles a loaded train as it crests a hill on the track chart in file D1.TRK. For this simulation, the train consists of 4 leading locomotives, 60 fully loaded gondolas, and 2 helper locomotives at the rear of the train, as summarized below:

CONSIST for SIMULATION D1 (D1.CON)

Type of Vehicle	Number of These		Fuel/Lading Each (TONs)
SD40 (FE)	4		12
GONDOL	60		100
SD40 (FE)	2	(helpers)	12

In Simulation D2, the ATA handles the same train -- only this time empty -- as it crests the same hill -- in the opposite direction -- on the track chart in file D2.TRK. For this simulation, the two helpers become the leading locomotives, and the four locomotives (which are the leading locomotives in consist D1) are nonoperating (shutdown), so that they are treated as "cars" by the preprocessor and simulator programs (with parameters in file NOSD40.PAR). Thus, the train consists of 2 leading locomotives, 60 empty gondolas, and 4 nonoperating locomotives at the rear of the train, as summarized below:

CONSIST for SIMULATION D2 (D2.CON)

Type of Vehicle	Number of These		Fuel/Lading Each (TONs)
SD40 (FE)	2		12
GONDOL	60		0
NOSD40	4	(shutdown)	12

7.4.1 Simulation D1: Loaded Train with Autonomous Helper Units Cresting a Hill

The purpose of Simulation D1 is to show how the ATA handles the loaded train as it crests the hill, and to demonstrate the way in which the ATA handles helper units in independent motoring (autonomous) operation.

Exhibit 54 is a table showing the input information required to run Simulation D1. The train consist and train operations summary for Simulation D1 is shown in Exhibit 55.

The track chart for Simulation D1 (in file D1.TRK) has a relatively short upgrade with a maximum of about +2% (at the steepest point) followed by a relatively long downgrade with a minimum of about -2% (at the steepest point).

Exhibit 56 is a plot of velocity and speed limit versus track position and Exhibit 57 is a plot of velocity and elevation versus track position.

The ATA starts the train with the goal of attaining the speed limit of 30 MPH, while trying to maintain the constant departure acceleration of 12 MPH/min specified in file D1.ATA. However, the power of the four leading locomotives is quickly overwhelmed by the increasing grade as the train climbs the hill, and the speed begins to decrease after reaching only about 20 MPH. Thus, physical limitations prevent the ATA from reaching its goal -- but the ATA doesn't stop trying!

INPUT INFORMATION for SIMULATION D1

D1.INI:	
Train data file name	D1
Track chart file name	D1
Wind chart file name	NOWIND
File output time interval (sec)	30
Terminal output time interval (sec)	30
Initial heading of leading vehicle (deg)	0
Initial position of leading vehicle (miles,feet)	2 0
Status of vehicle-mounted lubricators	OFF
Status of trackside lubricators	OFF
Effective lubrication distance (feet)	3600
Reduction in rolling resistance (lbs/TON)	0.70
D1.STP:	
Final position of leading vehicle (miles,feet)	17 2048
Dwell time for stop 1 (minutes)	1
Locomotive(s) in idle at stop 1?	yes
D1.ATA:	
Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

D1.CMD:

START HELPERS WITH RUN 0 IN AUTONOMOUS OPERATION
FOLLOW SPEED LIMITS FOR 16 MILES
END SIMULATION

Exhibit 54. Table Showing the Input Information Required to Run Simulation D1.

T E M FUEL and ENERGY REPORT for SIMULATION D1
OPERATIONS SUMMARY

CONSIST D1		
No. Vehicles in Consist	66	
No. Leading Locomotives	4	
No. Cars (and shutdown locos.)	60	
No. Helper Locomotives	2	
Total Train Length	4323	feet
Total Train Power (at the rail)	16000	hp
Total Train Weight	9258	Tons
Weight of Fuel	72	Tons
Weight of Lading	6000	Tons
Empty Train Weight	3186	Tons
Maximum Power/Weight	1.73	hp/TON
TRACK D1		
No. Stops	1	
Total Distance Traveled	15 mi 1948	ft
Total Elapsed Time	0 h 33 m 44	s
Over-the-Road Time	0 h 32 m 24	s
Dwell Time	0 h 1 m 20	s
Average Over-the-Road Speed	28	MPH
TOTAL FUEL CONSUMPTION	189	gal
Diesel Fuel/Work	69	gal/Khph

Exhibit 55. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File D1.RPT.

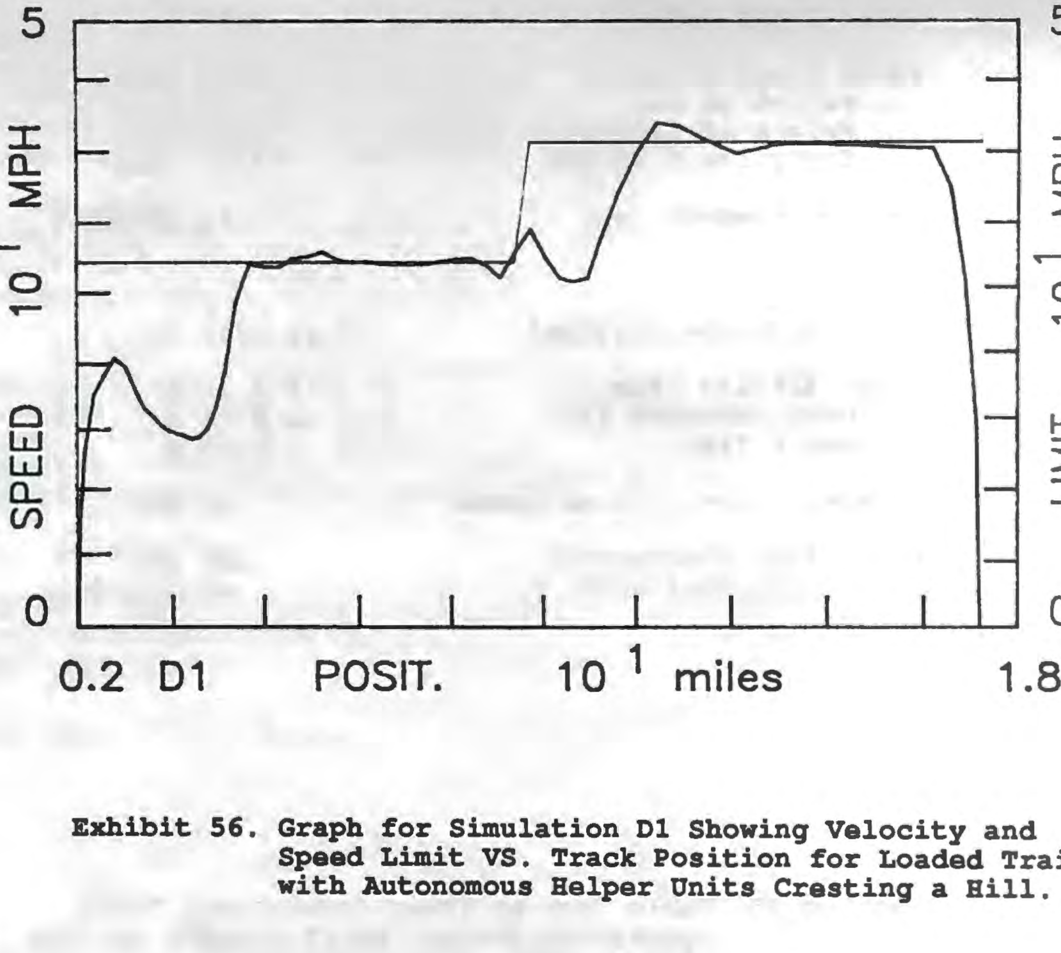


Exhibit 56. Graph for Simulation D1 Showing Velocity and Speed Limit VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

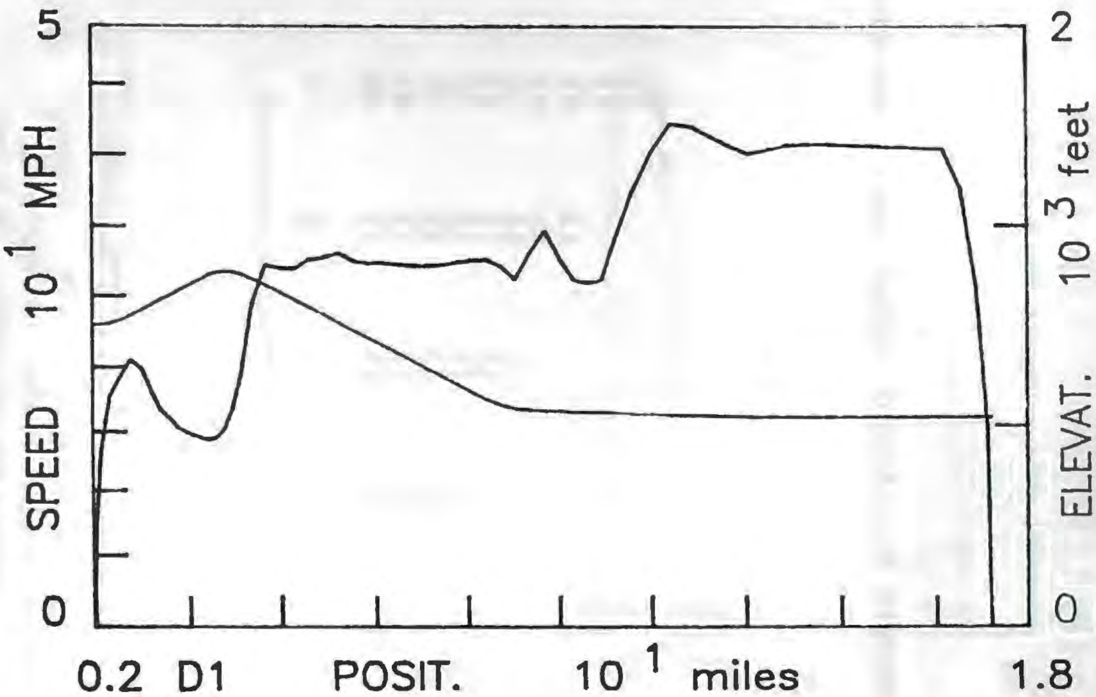


Exhibit 57. Graph for Simulation D1 Showing Velocity and Elevation VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

Consist: D1 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 1.73

%Grade								
3.0								10
2.8							10	11
2.6							10	12
2.4							11	13
2.2							12	14
2.0						10	13	15
1.8						11	15	17
1.6						13	17	19
1.4					11	14	19	21
1.2					12	17	22	24
1.0				11	14	20	25	27
0.8				14	18	23	29	33
0.6			11	17	22	29	36	40
0.4			15	23	30	36	45	49
0.2		13	23	32	41	48	57	62
0.0	15	27	38	49	57	65	73	77
Notch	1	2	3	4	5	6	7	8

Exhibit 58. Table Showing Train Consist D1 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

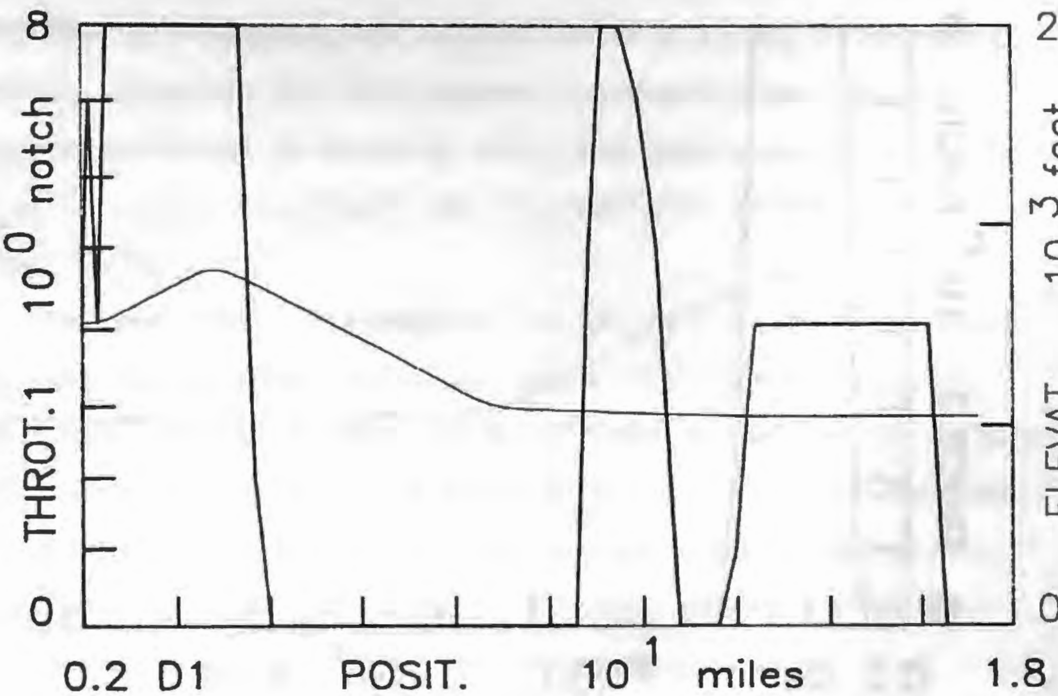


Exhibit 59. Graph for Simulation D1 Showing Throttle Setting (Leading Locomotives) and Elevation VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

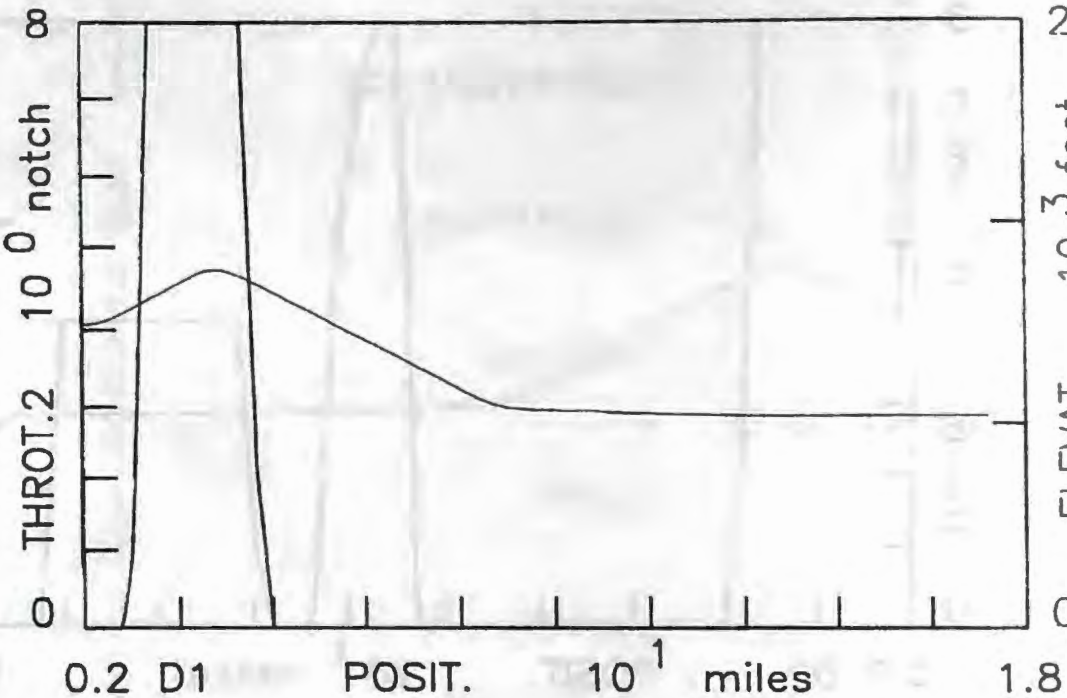


Exhibit 60. **Graph for Simulation D1 Showing Throttle Setting (Helper Locomotives) and Elevation VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.**

In response to the decreasing speed (increasing speed error), which is caused by the increasing grade force as the train climbs the hill, the ATA increases the throttle settings of the leading locomotives to notch 8. But the speed continues to decrease. At this point, the ATA decides to increase the throttle settings of the helper locomotives (which are being simulated as autonomous units) from notch 0 (idle) to notch 8. However, even with all four leading locomotives and the two helper locomotives in notch 8, the speed decreases to about 15 MPH as the train encounters the steepest part of the upgrade (about +2.0%).

For consist D1, the speed of 15 MPH on a +2.0% grade could have been predicted by referring to the throttle equilibrium speed table in file D1.TES, which is shown in Exhibit 58. In the table, which is based on the total power of all six locomotives (rather than the power of the four leading locomotives alone), we see that the equilibrium speed at the intersection of the notch 8 column and the +2.0% row is 15 MPH.

Referring again to the graphs in Exhibits 56 and 57: As the train approaches the crest of the hill, the grade decreases. Thus, the speed increases. But the goal of the ATA continues to be the 30 MPH speed limit. Therefore, while the speed error remains large, the ATA holds the four leading locomotives and the two helper locomotives in notch 8.

The throttle settings for the leading locomotives and the helper locomotives are plotted versus track position in the graphs of Exhibits 59 and 60, respectively. For reference, these throttle settings are plotted with elevation as the secondary dependent variable. In Exhibit 59, leading locomotive throttle setting is indicated as "THROT.1." In Exhibit 60, helper locomotive throttle setting is indicated as "THROT.2."

Referring back to the graphs in Exhibits 56 and 57: As the train moves over the crest of the hill, the grade becomes negative. That is, gravity becomes a driving force and the speed increases. In Exhibits 59 and 60, we see that the ATA throttles down at the right track position to ensure a smooth transition from traction to braking as the train moves over the crest of the hill. (At this point, the helper locomotives have served their purpose: to get the train up the hill and over the crest without a stall.)

The ATA maintains a fairly constant 30 MPH as the train moves down the long descending grade. As shown in the graph of Exhibit 61 (automatic brake pipe pressure and elevation versus track position), the ATA attempts to keep the train from "running away" on the long downgrade (with an average grade of about -1.6%) with a 12 PSI air brake reduction.

For consist D1, the 12 PSI reduction required to maintain a speed of 30 MPH on a -1.6% grade could have been predicted by

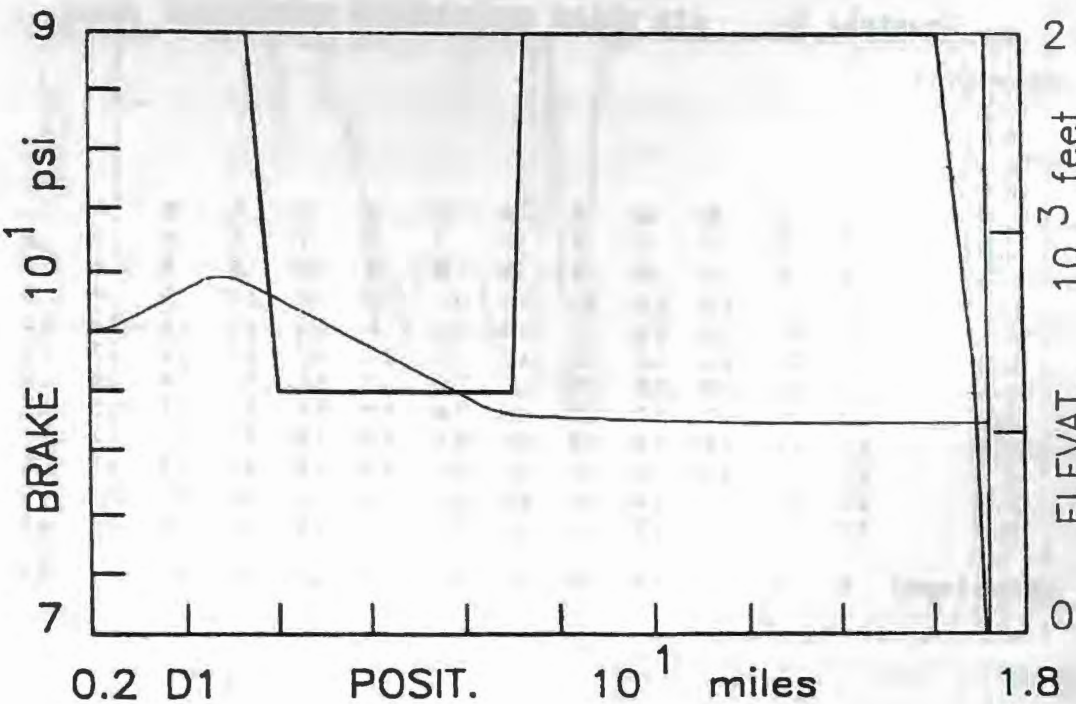


Exhibit 61. Graph for Simulation D1 Showing Automatic Air Brake Pipe Pressure and Elevation VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

Consist: D1 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6															
0.8	6	6	6	6	6	5	5	5	5	5	5	5			
1.0	7	7	7	7	7	7	7	7	7	6	6	6	6	6	5
1.2	9	9	9	9	9	9	8	8	8	8	8	8	7	7	7
1.4	11	11	10	10	10	10	10	10	10	10	9	9	9	9	9
1.6	12	12	12	12	12	12	12	11	11	11	11	11	11	10	10
1.8	14	14	14	13	13	13	13	13	13	13	12	12	12	12	12
2.0	15	15	15	15	15	15	15	15	14	14	14	14	14	13	13
2.2	17	17	17	17	17	16	16	16	16	16	16	15	15	15	15
2.4	18	18	18	18	18	18	18	18	18	17	17	17	17	17	16
2.6	20	20	20	20	20	20	19	19	19	19	19	19	18	18	18
2.8	22	21	21	21	21	21	21	21	21	20	20	20	20	20	19
3.0	23	23	23	23	23	23	22	22	22	22	22	22	21	21	21
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 62. Table Showing Train Consist D1 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

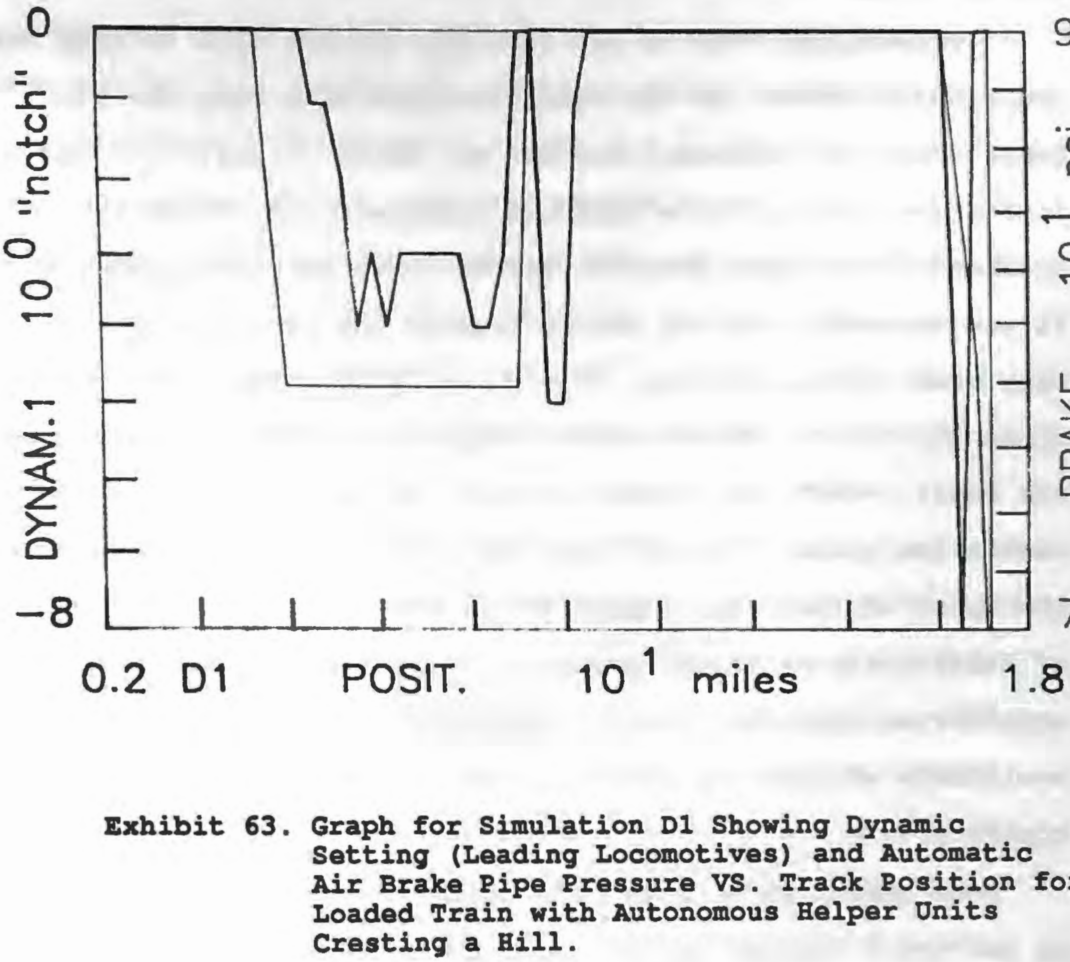


Exhibit 63. Graph for Simulation D1 Showing Dynamic Setting (Leading Locomotives) and Automatic Air Brake Pipe Pressure VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

referring to the air brake equilibrium reduction table in file D1.AER, which is shown in Exhibit 62. In the table, which is based on the total braking force of the sixty loaded cars (with all the locomotives "bailed-off"), we see that the equilibrium setting at the intersection of the 30 MPH column and the -1.6% row is 12 PSI.

From Exhibit 61, we see that the ATA was able to keep the train under control on the long downgrade with only one air brake reduction. However, Exhibit 63, which is a plot of leading locomotive dynamic brake settings (indicated as "DYNAM.1") and automatic brake pipe pressure versus track position, shows that it was necessary for the ATA to augment the 12 PSI reduction with some dynamic braking. This is not surprising, since the air brake is a crude, "brute-force" method of control. Because there are small -- but significant -- grade variations on the long descending grade, the ATA used the dynamic brake to "fine tune" the speed of the train. (Apparently, as indicated in the table of Exhibit 62, an 11 PSI reduction would have allowed an equilibrium speed of 35 MPH or greater, and a 13 PSI reduction would have stopped the train, so that 12 PSI was the right choice.)

Once again, referring to the graphs in Exhibits 56 and 57: As the train reaches the bottom of the hill, the ATA releases the air brake. But, there is a small -- but significant --

undulation at the bottom of the hill. When the train reaches the small undulation at the bottom of the long downgrade, the acceleration due to gravity causes the velocity to exceed the 30 MPH speed limit. (Even though the leading locomotive has already encountered the 40 MPH speed limit, the end of the train has not.) Thus, the ATA tries to prevent the velocity from exceeding the 30 MPH speed limit by applying the dynamic brake (after the release of the air brake) as shown in Exhibit 63.

When the end of the train clears the 30 MPH speed limit, so that the entire train is under the 40 MPH speed limit, the ATA has the new goal of attaining the 40 MPH speed limit. Thus, the ATA throttles up to accelerate the train up to 40 MPH, as indicated in Exhibit 59. Because there is such a large speed error (-10 MPH) when the end of the train clears the 30 MPH speed limit, the ATA overreacts, and there is a small "overshoot" in speed, which ATA corrects by throttling down. The velocity oscillates slowly about 40 MPH (to within about +1 MPH or -1 MPH), because the speed offset margin specified in file D1.ATA is 0 MPH. With a speed offset margin of 1 MPH or 2 MPH, the "overshoot" in speed would be reduced, if not eliminated.

Then, on the relatively level stretch of track beyond the hill, the ATA is able to maintain the velocity close to the speed limit of 40 mph with a throttle setting of notch 4, as shown in Exhibit 59. Referring to the table in Exhibit 58: The

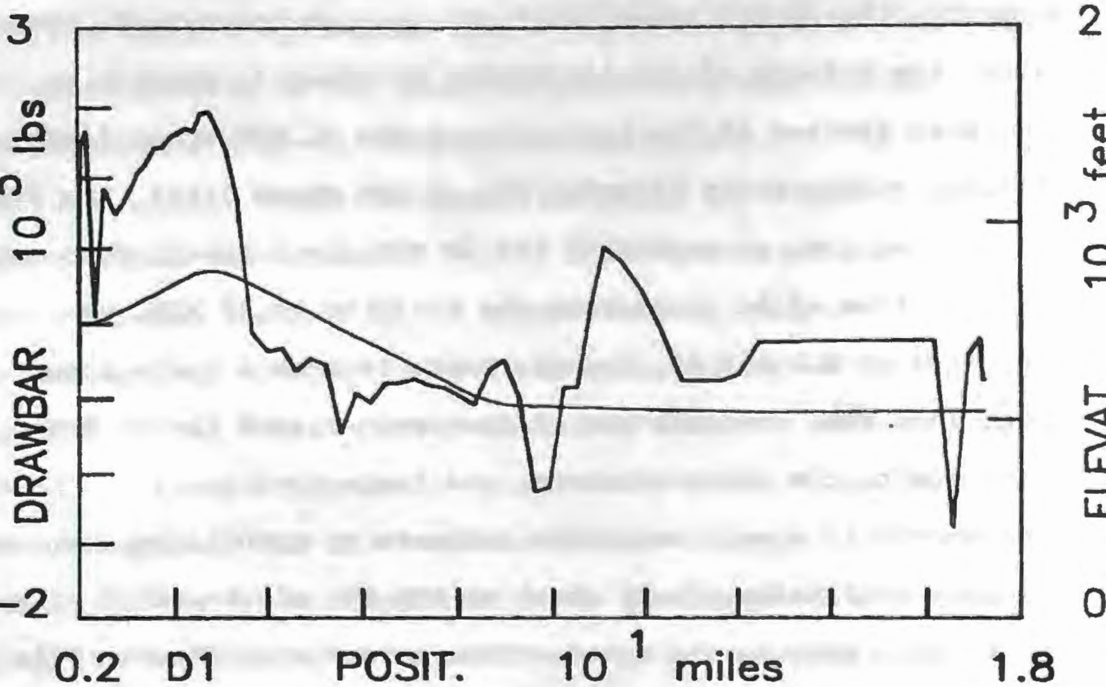


Exhibit 64. Graph for Simulation D1 Showing Drawbar Force and Elevation VS. Track Position for Loaded Train with Autonomous Helper Units Cresting a Hill.

equilibrium speeds for consist D1 are 38 MPH and 49 MPH in notch 3 and notch 4, respectively -- on <u>tangent</u> level track. However, beyond the hill, the track continues to offer significant curve resistance, so that notch 4 is the right choice to maintain a velocity of 40 MPH.

Finally, as the train approaches to within about a mile of the destination, the ATA has the new goal of stopping the train at the track position specified in file D1.STP. Thus, the ATA decelerates the train to a stop with a reduction that starts at 10 PSI and gradually increases to 20 PSI (as shown in Exhibit 61), while trying to maintain the constant approach deceleration of 16 MPH/min specified in file D1.ATA.

To complete the analysis of Simulation D1, consider Exhibit 64, which is a plot of drawbar force and elevation versus track position. As expected, the drawbar force is very large -- about 200 000 lbs -- in "draft" (tension), as the leading locomotives pull the 60 loaded cars up the steep ascending grade, and the drawbar force is large -- about 150 000 lbs -- in "buff" (compression), as the brakes slow the train to a stop at the destination.

7.4.2 Simulation D2: Empty Train with Nonoperating Trailing Locomotives Cresting the Hill in the Opposite Direction

The purpose of Simulation D2 is to show how the ATA handles the empty train as it crests the hill in the opposite direction (the reverse of the track chart in file D1.TRK is in file D2.TRK).

Exhibit 65 is a table showing the input information required to run Simulation D2. The train consist and train operations summary for Simulation D2 is shown in Exhibit 66.

Since the track chart for Simulation D2 (in file D2.TRK) is the reverse of the track chart for Simulation D1 (in file D1.TRK), it has a relatively long upgrade with a maximum of about +2% (at the steepest point) followed by a relatively short downgrade with a minimum of about -2% (at the steepest point).

Exhibit 67 is a plot of velocity and speed limit versus track position and Exhibit 68 is a plot of velocity and elevation versus track position.

The ATA starts the train with the goal of attaining the speed limit of 40 MPH, while trying to maintain the constant departure acceleration of 12 MPH/min specified in file D2.ATA. Thus, the ATA throttles up to accelerate the train up to 40 MPH, and then modulates the throttle setting to maintain 40 MPH on the relatively level stretch of track ahead of the long

INPUT INFORMATION for SIMULATION D2

D2.INI:

Train data file name	D2
Track chart file name	D2
Wind chart file name	NOWIND
File output time interval (sec)	30
Terminal output time interval (sec)	30
Initial heading of leading vehicle (deg)	0
Initial position of leading vehicle (miles,feet)	0 0
Status of vehicle-mounted lubricators	OFF
Status of trackside lubricators	OFF
Effective lubrication distance (feet)	3600
Reduction in rolling resistance (lbs/TON)	0.70

D2.STP:

Final position of leading vehicle (miles,feet)	15 2048
Dwell time for stop 1 (minutes)	1
Locomotive(s) in idle at stop 1?	yes

D2.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	18.0

D2.CMD:

FOLLOW SPEED LIMITS FOR 16 MILES
END SIMULATION

Exhibit 65. Table Showing the Input Information Required to Run Simulation D2.

T E M FUEL and ENERGY REPORT for SIMULATION D2
OPERATIONS SUMMARY

CONSIST D2		
No. Vehicles in Consist	66	
No. Leading Locomotives	2	
No. Cars (and shutdown locos.)	64	
No. Helper Locomotives	0	
Total Train Length	4317	feet
Total Train Power (at the rail)	5333	hp
Total Train Weight	3258	Tons
Weight of Fuel	24	Tons
Weight of Lading	48	Tons
Empty Train Weight	3186	Tons
Maximum Power/Weight	1.64	hp/TON
TRACK D2		
No. Stops	1	
Total Distance Traveled	15 mi 2119	ft
Total Elapsed Time	0 h 40 m 27	s
Over-the-Road Time	0 h 39 m 27	s
Dwell Time	0 h 1 m 0	s
Average Over-the-Road Speed	23	MPH
TOTAL FUEL CONSUMPTION	144	gal
Diesel Fuel/Work	63	gal/Khph

Exhibit 66. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File D2.RPT.

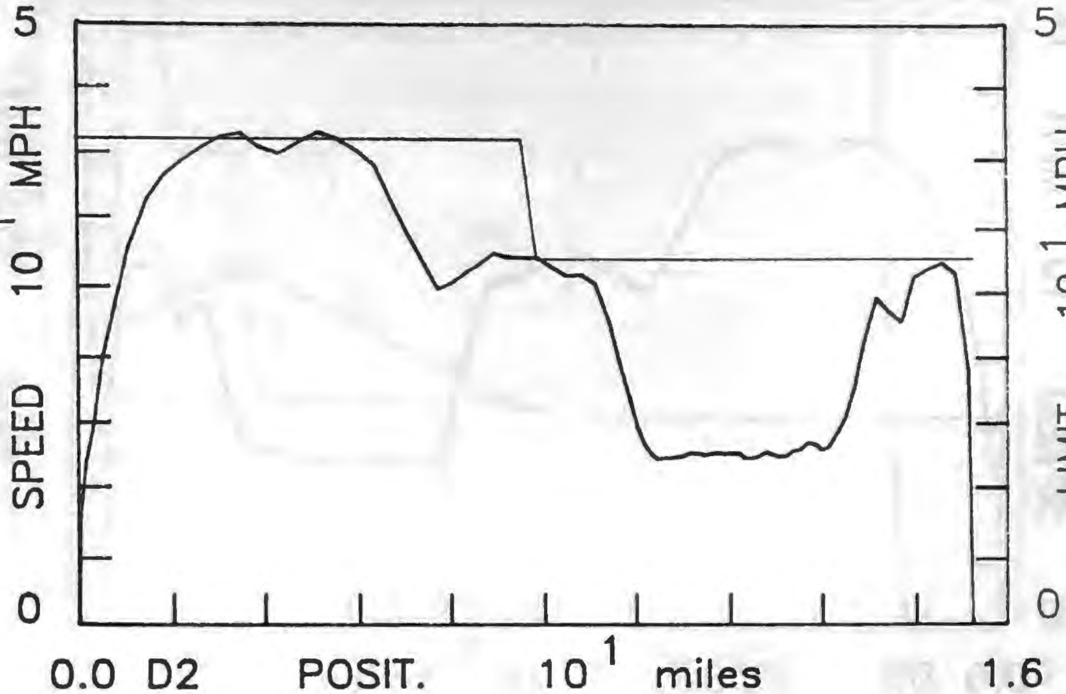


Exhibit 67. Graph for Simulation D2 Showing Velocity and Speed Limit VS. Track Position for Empty Train Cresting the Hill in the Opposite Direction.

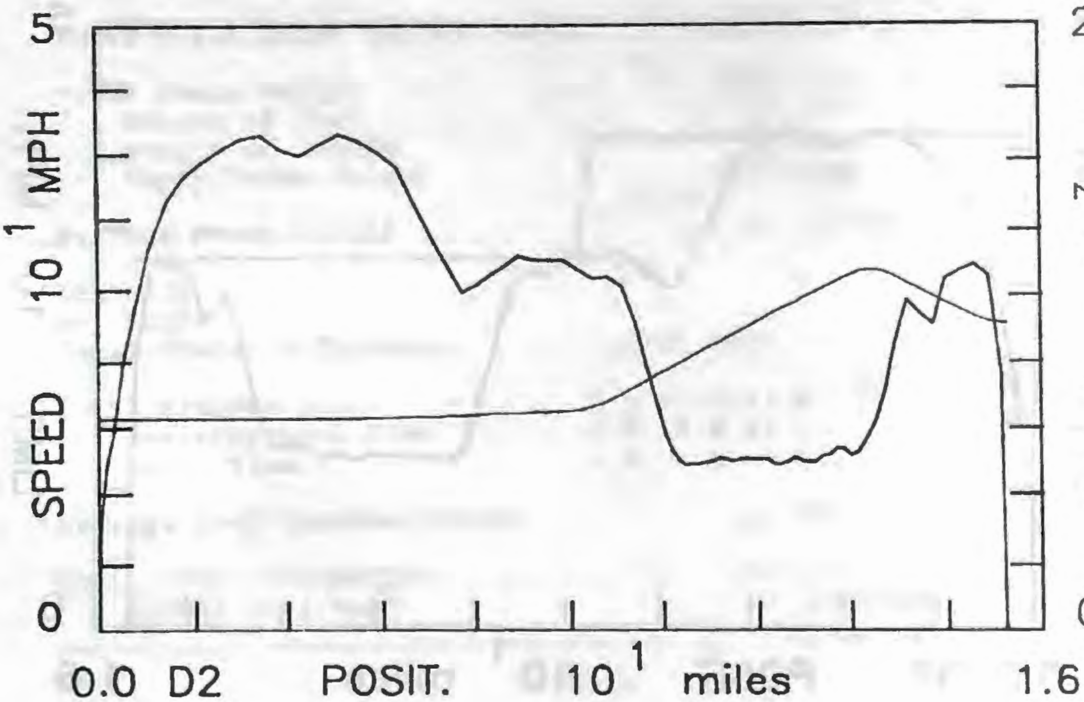


Exhibit 68. Graph for Simulation D2 Showing Velocity and Elevation VS. Track Position for Empty Train Cresting the Hill in the Opposite Direction.

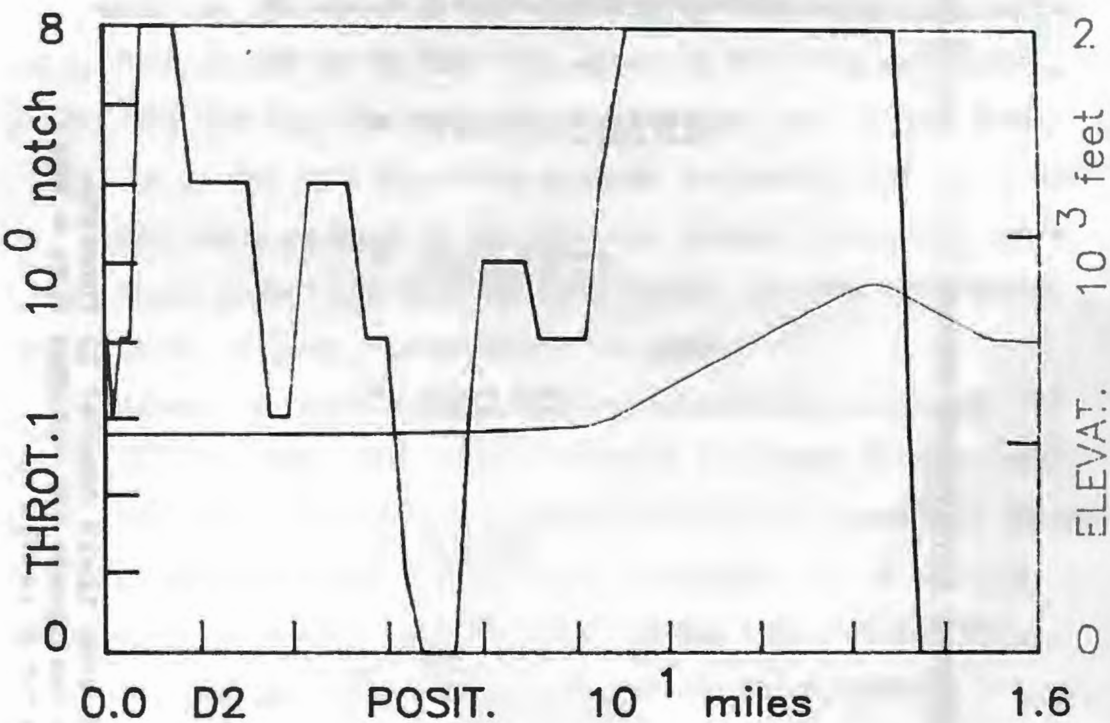


Exhibit 69. Graph for Simulation D2 Showing Throttle Setting and Elevation VS. Track Position for Empty Train Cresting the Hill in the Opposite Direction.

Consist: D2 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 1.64

%Grade	Notch 1	2	3	4	5	6	7	8
3.0								
2.8								10
2.6								11
2.4							10	12
2.2							11	13
2.0							12	14
1.8						11	13	15
1.6						12	15	17
1.4						13	17	19
1.2					11	15	20	22
1.0				10	13	18	22	25
0.8				12	16	21	26	28
0.6			10	15	19	25	31	34
0.4			13	19	25	31	37	40
0.2		11	18	26	33	38	45	48
0.0	11	18	28	36	42	48	54	57

Exhibit 70. Table Showing Train Consist D2 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

ascending grade, as shown in the graph of Exhibit 69, which is a plot of throttle setting and elevation versus track position. For a short distance, the velocity oscillates slowly about 40 MPH (to within about +1 MPH or -1 MPH), because the speed offset margin specified in file D2.ATA is 0 MPH.

When the ATA detects the approach of the decrease in speed limit from 40 MPH to 30 MPH just ahead of the long ascending grade, the ATA has the new goal of attaining the 30 MPH speed limit. Thus, the ATA throttles down to decelerate the train down to 30 MPH, as indicated in Exhibit 69. Because there is such a large speed error (+10 MPH) at this point, the ATA overreacts, and there is a small "undershoot" in speed.

However, as soon as the leading locomotives encounter the 30 MPH speed limit, they also encounter the start of the long ascending grade. The power of the two leading locomotives (which are the only operating locomotives in consist D2) is quickly overwhelmed by the increasing grade as the train climbs the hill, and the speed begins to decrease. Thus, physical limitations prevent the ATA from reaching its goal -- but (as always) the ATA doesn't stop trying!

In response to the decreasing speed (increasing speed error), which is caused by the increasing grade force as the train climbs the hill, the ATA increases the throttle settings of the leading locomotives to notch 8. But the speed continues to decrease to about 14 MPH as the train encounters the steepest part of the upgrade (about +2.0%).

For consist D2, the speed of 14 MPH on a +2.0% grade could have been predicted by referring to the throttle equilibrium speed table in file D2.TES, which is shown in Exhibit 70. In the table, which is based on the total power of the two leading locomotives (rather than the power of all six locomotives in the consist, since the four trailing locomotives are not in operation), we see that the equilibrium speed at the intersection of the notch 8 column and the +2.0% row is 14 MPH.

Referring again to the graphs in Exhibits 67 and 68: As the train approaches the crest of the hill, the grade decreases. Thus, the speed increases. But the goal of the ATA continues to be the 30 MPH speed limit. Therefore, while the speed error remains large, the ATA holds the two leading locomotives in notch 8.

As the train moves over the crest of the hill, the grade becomes negative. In Exhibit 69, we see that the ATA throttles down slightly ahead of the correct track position to ensure a smooth transition from traction to braking as the train moves over the crest of the hill. Therefore, there is a small "dip" in speed, until more of the train moves over the crest, and the acceleration of gravity increases the speed further.

But, at this point, gravity becomes a driving force, and as

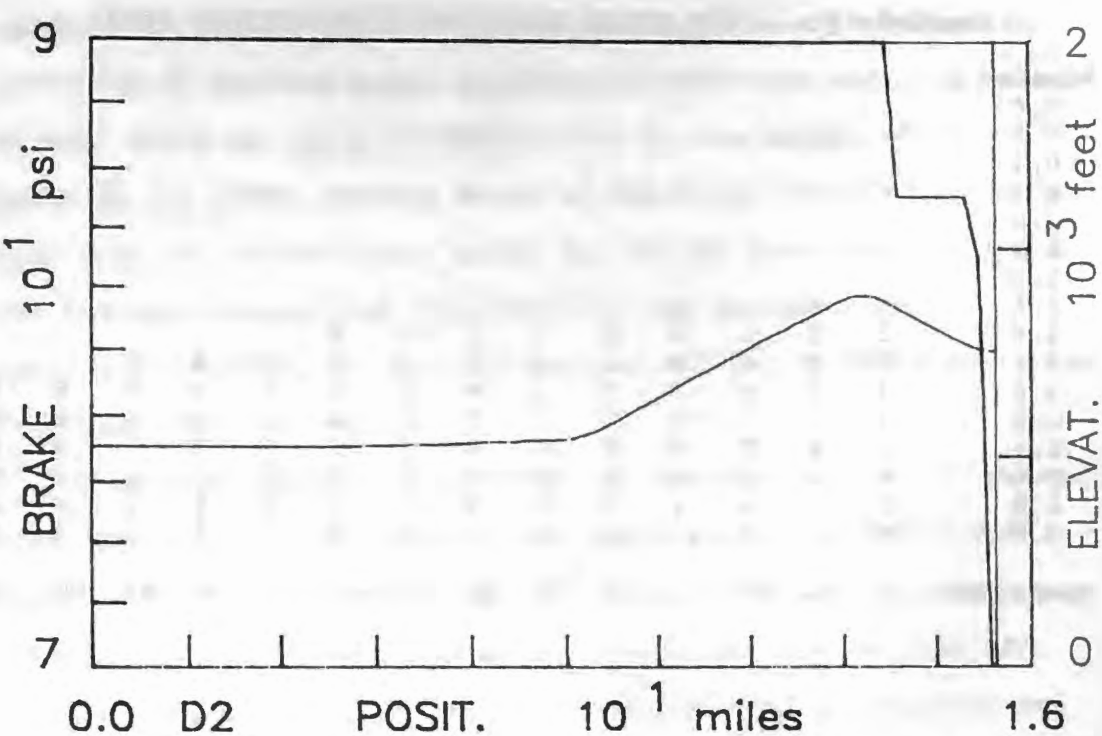


Exhibit 71. Graph for Simulation D2 Showing Automatic Air Brake Pipe Pressure and Elevation VS. Track Position for Empty Train Cresting the Hill in the Opposite Direction.

Consist: D2 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6															
0.8															
1.0															
1.2															
1.4	5	5													
1.6	5	5	5	5	5	5	5	5	5						
1.8	6	6	6	6	6	6	5	5	5	5	5	5			
2.0	7	7	6	6	6	6	6	6	6	6	6	5	5	5	5
2.2	7	7	7	7	7	7	7	7	6	6	6	6	6	6	5
2.4	8	8	8	8	8	8	7	7	7	7	7	7	6	6	6
2.6	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7
2.8	9	9	9	9	9	9	9	9	8	8	8	8	8	8	7
3.0	10	10	10	10	10	9	9	9	9	9	9	9	8	8	8
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 72. Table Showing Train Consist D2 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

shown in the graph of Exhibit 71 (automatic brake pipe pressure and elevation versus track position), the ATA attempts to keep the train from "running away" on the short downgrade (with an average grade of about -1.8%) with a 5 PSI air brake reduction.

For consist D2, the 5 PSI reduction required to maintain a speed of 30 MPH on a -1.8% grade could have been predicted by referring to the air brake equilibrium reduction table in file D2.AER, which is shown in Exhibit 72. In the table, which is based on the total braking force of the sixty empty cars and the four trailing locomotives, which are not in operation (with the two leading locomotives "bailed-off"), we see that the equilibrium setting at the intersection of the 30 MPH column and the -1.8% row is 5 PSI.

Referring again to the graphs in Exhibits 67 and 68: We see that the ATA was able to keep the train under control on the short downgrade with the 5 PSI air brake reduction. However, half-way down the short descending grade, the goal of the ATA changes from maintaining the 30 MPH speed limit to the new goal of stopping the train at the track position specified in file D2.STP. Thus, the ATA decelerates the train to a stop with a reduction that starts at the original 5 PSI (required to maintain 30 MPH on the downgrade) and gradually increases to 20 PSI (as shown in Exhibit 71), while trying to maintain the constant approach deceleration specified in file D2.ATA.

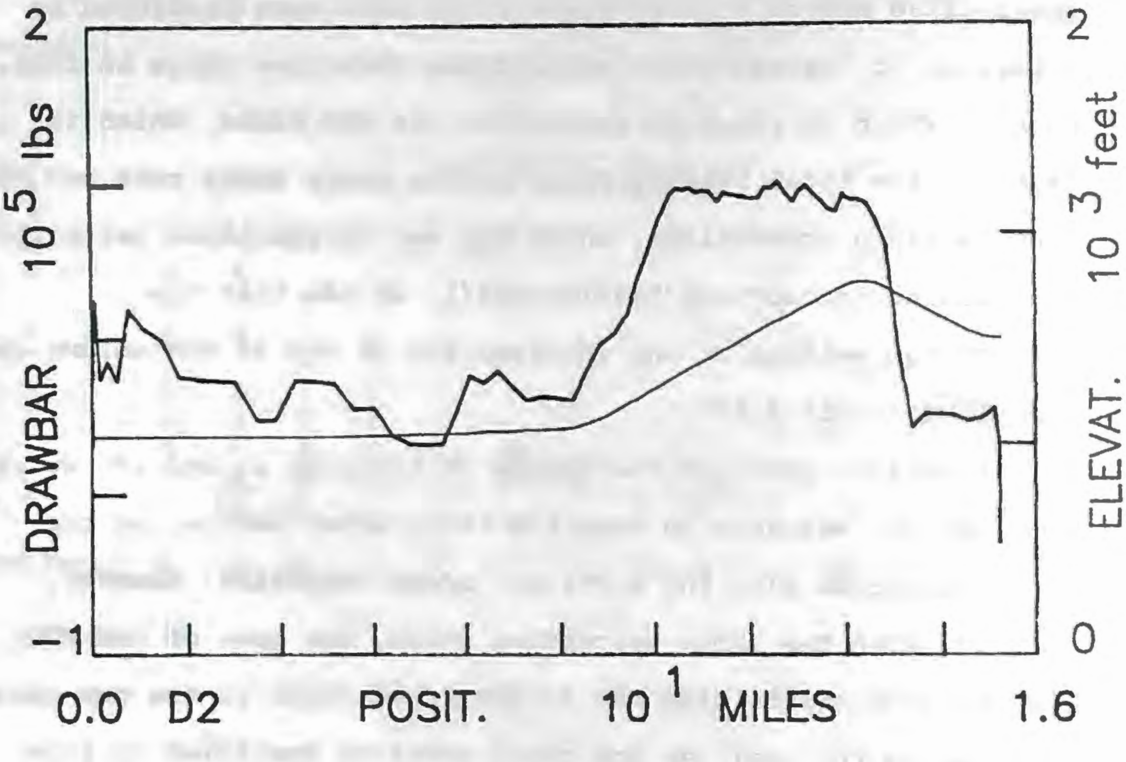


Exhibit 73. Graph for Simulation D2 Showing Drawbar Force and Elevation VS. Track Position for Empty Train Cresting the Hill in the Opposite Direction.

To complete the analysis of Simulation D2, consider Exhibit 73, which is a plot of drawbar force and elevation versus track position. As expected, the drawbar force is large -- about 100 000 lbs -- in "draft" (tension), as the locomotives pull the 60 empty cars up the steep ascending grade, and the drawbar force is fairly large -- about 50 000 lbs -- in "buff" (compression), as the brakes slow the train to a stop at the destination.

7.5 Simulations Demonstrating How TEM Can Be Used to Model a Train Movement with a Change of Consist

The purpose of the next four simulations is to demonstrate how TEM can be used to model a train movement with a change of consist by running back-to-back simulations. The first simulation (E1) involves a train movement from the origin to the foot of a large mountain. A change of consist is made at the foot of the mountain: helper locomotives are added to the end of the train. Without the helper units, the speed would be unacceptably low as the train tried to ascend the steep grade to the top of the mountain.

The second simulation (E2) involves the train movement from the foot of the mountain to the top of the mountain. A change of consist is made at the top of the mountain: the helper locomotives are removed from the end of the train.

The third simulation (E3) involves the train movement (of the original train in Simulation E1) from the top of the mountain down to the destination.

For completeness, the fourth simulation (E4) involves the train movement of the helper locomotives from the top of the mountain back down to the foot of the mountain (where they were added to the train at the end of Simulation E1).

For comparison, these simulations are followed by a fifth simulation (E5), which involves a train movement from origin to destination (with two intermediate stops). For Simulation E5, the helper locomotives (in synchronous operation) are attached to the end of the train for the entire run.

Since the purpose of these simulations is to demonstrate an operational aspect of TEM, rather than to demonstrate the subtle decisions made by the ATA in response to small (but significant) variations in track chart grade, the track chart (in file E.TRK) used in these simulations is fairly simple (compared to the actual track chart from which it was abstracted). Exhibit 74 shows the track profile and speed limit profile for the track chart in file E.TRK. The track chart used in Simulation E4 (file E4.TRK) is merely the reverse of that in file E.TRK.

Referring to Exhibit 74: The average grades are about +0.3% from 0 to 110 miles, +0.5% from 110 to 120 miles (origin to foot of mountain at 120 miles), +1.2% from 120 to 130 miles, +1.8%

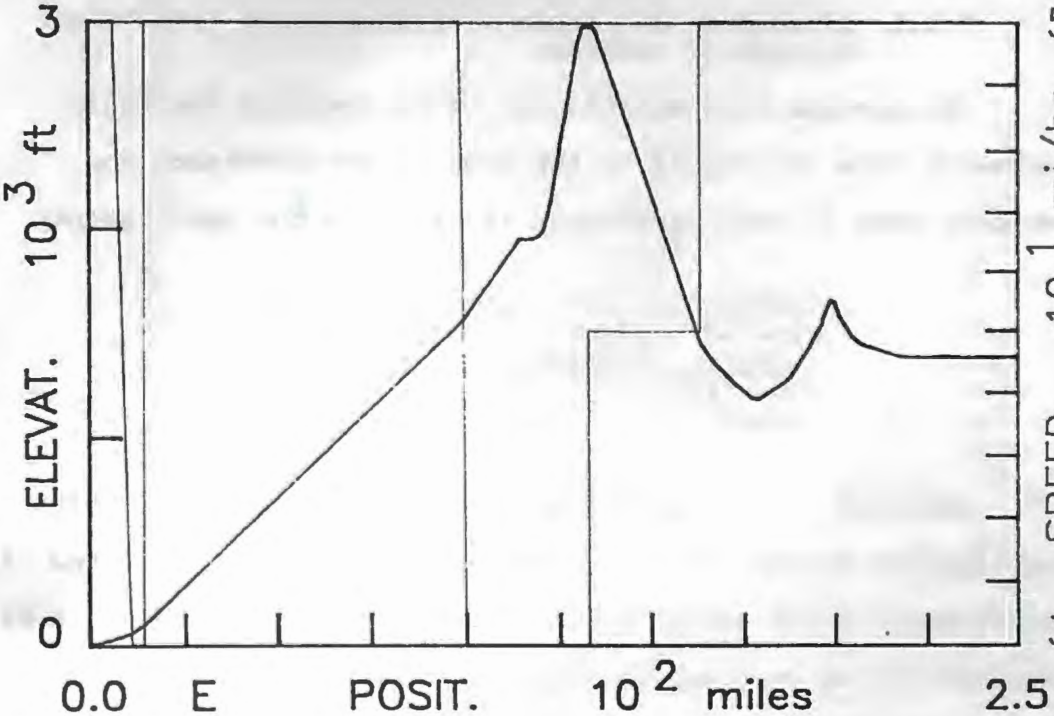


Exhibit 74. Graph Showing the Track Profile and Speed Limit Profile for the Track Chart Data in File E.TRK.

from 130 to 140 miles (foot of mountain to top of mountain at 140 miles), and -1.0% from 140 to 170 miles. The next 80 miles consist of a valley and a large hill, followed by a stretch of level track. The foot of the mountain and the top of the mountain consist of short level stretches of track.

7.5.1 Simulation E1: Train with No Helpers from Origin to Foot of Mountain

The purpose of Simulation E1 is to simulate the train movement from the origin to the foot of the mountain. The consist used in this simulation is given in the table below:

CONSIST for SIMULATION E1 (E1.CON)

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
SD40 (FE)	5	12
GONDOL	60	100

Exhibits 75, 76, and 77 are tables showing the throttle equilibrium speeds, dynamic brake equilibrium settings, and air brake equilibrium reductions for consist E1. From the table of Exhibit 75, we see that the run 8 equilibrium speed for consist E1 is only 14 MPH on a 1.8% grade.

Exhibit 78 is a table showing the input information required to run simulation E1. The train consist and train operations summary for Simulation E1 is shown in Exhibit 79.

Exhibit 80 is a plot of velocity and speed limit versus track position and Exhibit 81 is a plot of velocity and

Consist: E1 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 1.48

%Grade								
3.0								
2.8								
2.6								
2.4								10
2.2							10	12
2.0							11	13
1.8						10	11	14
1.6						11	14	16
1.4						12	16	18
1.2					10	14	19	21
1.0					12	17	22	24
0.8				12	15	20	26	28
0.6				15	19	25	31	35
0.4			13	20	26	33	40	44
0.2		11	20	28	36	43	52	56
0.0	14	25	35	45	53	60	68	72
Notch	1	2	3	4	5	6	7	8

Exhibit 75. Table Showing Train Consist E1 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

Consist: E1 DYNAMIC BRAKE EQUILIBRIUM SETTINGS

%Grade(-)															
0.0															
0.2		3	3	2	1	1	1	1	1	1	1	1	1	1	1
0.4		4	5	4	4	4	4	4	4	4	4	4	4	3	1
0.6		6	5	5	5	4	4	5	5	5	5	5	5	5	5
0.8		7	6	6	5	5	5	5	6	6	6	6	6	7	7
1.0		8	7	6	6	6	6	6	7	7	7	8			
1.2			7	7	7	6	7	7	8						
1.4			7	7	7	7	7								
1.6			8	8	7	8									
1.8															
2.0															
2.2															
2.4															
2.6															
2.8															
3.0															
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 76. Table Showing Train Consist E1 Dynamic Brake Equilibrium Settings for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

Consist: E1 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6															
0.8	6	6	6	6	5	5	5	5	5	5	5				
1.0	7	7	7	7	7	7	7	7	6	6	6	6	6	5	5
1.2	9	9	9	9	9	8	8	8	8	8	8	7	7	7	7
1.4	10	10	10	10	10	10	10	9	9	9	9	9	9	9	8
1.6	12	12	12	12	12	11	11	11	11	11	11	10	10	10	10
1.8	13	13	13	13	13	13	13	13	13	12	12	12	12	12	11
2.0	15	15	15	15	15	14	14	14	14	14	14	14	13	13	13
2.2	16	16	16	16	16	16	16	16	16	15	15	15	15	15	14
2.4	18	18	18	18	18	18	17	17	17	17	17	17	16	16	16
2.6	19	19	19	19	19	19	19	19	19	18	18	18	18	18	17
2.8	21	21	21	21	21	21	20	20	20	20	20	20	19	19	19
3.0	23	22	22	22	22	22	22	22	22	22	21	21	21	21	20
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 77. Table Showing Train Consist E1 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

INPUT INFORMATION for SIMULATION E1

E1.INI:		
Train data file name	E1	
Track chart file name	E	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
E1.STP:		
Final position of leading vehicle (miles,feet)	120	0
Dwell time for stop 1 (minutes)	30	
Locomotive(s) in idle at stop 1?	yes	
E1.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	
E1.CMD:		
FOLLOW SPEED LIMITS FOR 121 MILES		
END SIMULATION		

Exhibit 78. Table Showing the Input Information Required to Run Simulation E1.

T E M FUEL and ENERGY REPORT for SIMULATION E1
OPERATIONS SUMMARY

CONSIST E1		
No. Vehicles in Consist	65	
No. Leading Locomotives	5	
No. Cars (and shutdown locos.)	60	
No. Helper Locomotives	0	
Total Train Length	4252	feet
Total Train Power (at the rail)	13333	hp
Total Train Weight	9035	Tons
Weight of Fuel	60	Tons
Weight of Lading	6000	Tons
Empty Train Weight	2975	Tons
Maximum Power/Weight	1.48	hp/TON
TRACK E		
No. Stops	1	
Total Distance Traveled	120 mi 88	ft
Total Elapsed Time	3 h 21 m 32	s
Over-the-Road Time	2 h 51 m 18	s
Dwell Time	0 h 30 m 14	s
Average Over-the-Road Speed	42	MPH
TOTAL FUEL CONSUMPTION	1977	gal
Diesel Fuel/Work	62	gal/Khph

Exhibit 79. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File E1.RPT.

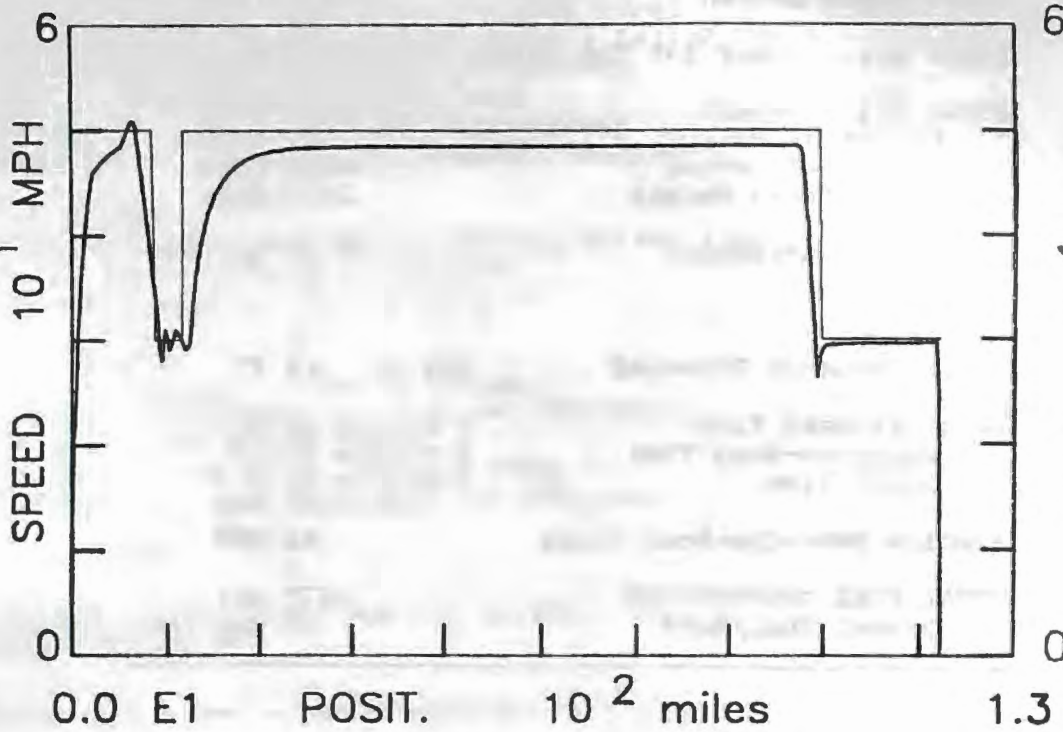


Exhibit 80. Graph for Simulation E1 Showing Velocity and Speed Limit VS. Track Position for a Train Moving from Origin to Foot of Mountain.

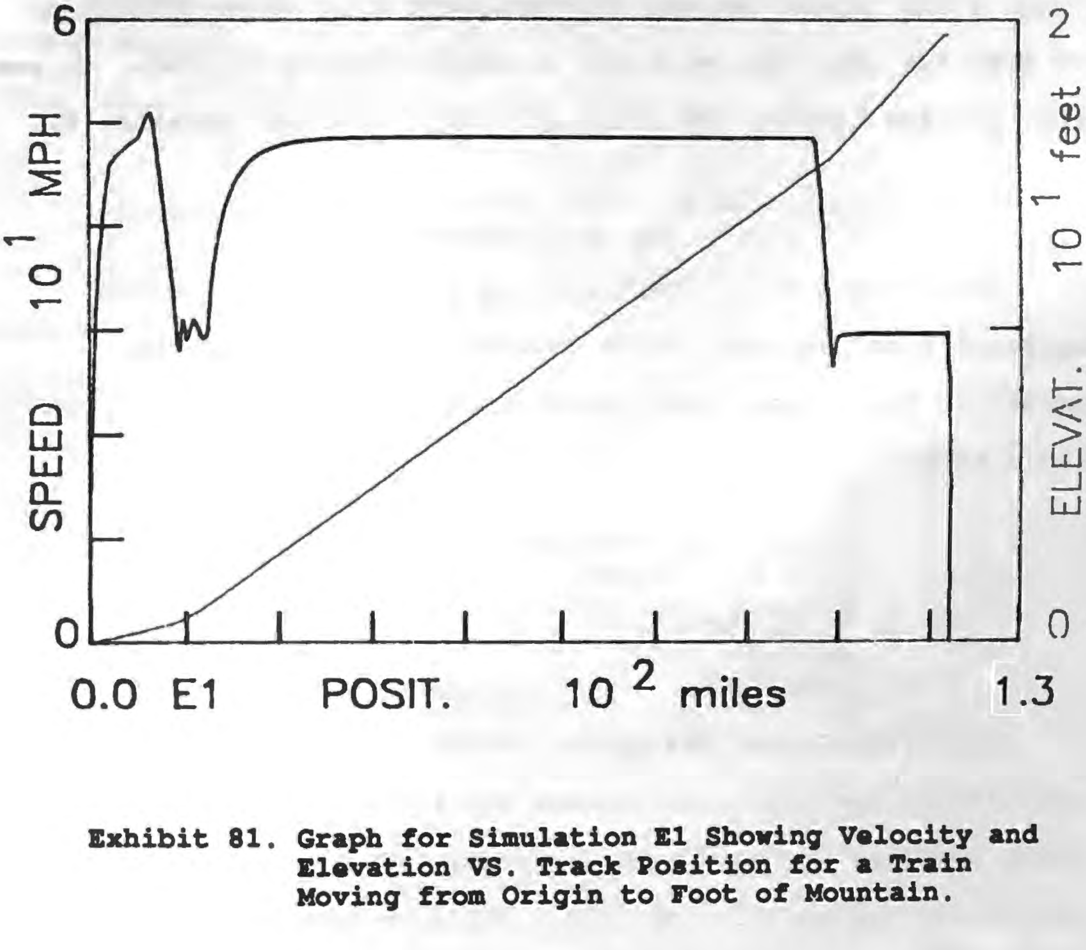


Exhibit 81. Graph for Simulation E1 Showing Velocity and Elevation VS. Track Position for a Train Moving from Origin to Foot of Mountain.

elevation versus track position.

Interpolating the values in the table of Exhibit 75, we find that the equilibrium speed of consist E1 in notch 8 on a 0.3% grade is 48 MPH, and that the equilibrium speed in notch 6 on a 0.5% grade is 29 MPH. Since the respective speed limits on track E are 50 MPH (except for the short slow speed stretch at 30 MPH) for the 0.3% grade and 30 MPH for the 0.5% grade, we see that the ATA handled the train perfectly in train movement E1.

7.5.2 Simulation E2: Train with Helpers from Foot of Mountain to Top of Mountain

The purpose of Simulation E2 is to simulate the train movement from the foot of the mountain to the top of the mountain. The consist used in this simulation is given in the table below:

CONSIST for SIMULATION E2 (E2.CON)

Type of Vehicle	Number of These		Fuel/Lading Each (TONs)
SD40 (FE)	5		12
GONDOL	60		100
SD40 (FE)	3	(helpers)	12

Exhibits 82, 83, and 84 are tables showing the throttle equilibrium speeds, dynamic brake equilibrium settings, and air brake equilibrium reductions for consist E2. From the table of Exhibit 82, we see that the run 8 equilibrium speed for consist E2 is 22 MPH on a 1.8% grade. Since the speed limit (see Exhibit 74) on this grade is 30 MPH, 22 MPH is much more acceptable than the 14 MPH, which is attainable with consist E1.

Exhibit 85 is a table showing the input information required to run simulation E2. The train consist and train operations summary for Simulation E2 is shown in Exhibit 86.

Exhibit 87 is a plot of velocity and speed limit versus track position and Exhibit 88 is a plot of velocity and elevation versus track position. From these Exhibits, we see that the ATA handled the train very well in train movement E2.

7.5.3 Simulation E3: Train with No Helpers from Top of Mountain to Destination

The purpose of Simulation E3 is to simulate the train movement of consist E1 from the top of the mountain to the final destination.

Exhibit 89 is a table showing the input information required to run simulation E3. The train consist and train operations summary for Simulation E3 is shown in Exhibit 90.

Exhibit 91 is a plot of velocity and speed limit versus track position and Exhibit 92 is a plot of velocity and elevation versus track position. From these Exhibits, we see that the ATA handled the train perfectly in train movement E3.

The total elapsed time (simulated time) for Simulations E1, E2, and E3 is 6 hours, 59 minutes and 18 seconds (including dwell time); the total fuel consumption for Simulations E1, E2, and E3 is 3463 gallons.

Consist: E2 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 2.20

%Grade								
3.0							11	13
2.8							12	14
2.6						10	13	15
2.4						11	14	16
2.2						12	16	18
2.0						13	17	20
1.8					11	15	19	22
1.6					12	17	21	24
1.4				10	13	19	24	26
1.2				12	16	21	27	30
1.0				14	18	25	31	35
0.8			11	17	22	30	36	41
0.6			14	21	28	35	44	49
0.4		11	19	28	36	44	54	59
0.2		16	27	39	48	57	66	72
0.0	18	31	44	55	65	73	82	87
Notch	1	2	3	4	5	6	7	8

Exhibit 82. Table Showing Train Consist E2 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

Consist: E2 DYNAMIC BRAKE EQUILIBRIUM SETTINGS

%Grade(-)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
0.0															
0.2		2	2	1	1	1	1	1	1	1	1	1	1	1	1
0.4		4	4	4	4	3	3	3	4	4	3	3	3	2	1
0.6		5	5	5	4	4	4	4	4	4	4	4	4	4	4
0.8		5	5	5	5	4	4	5	5	5	5	5	5	5	5
1.0		6	6	6	5	5	5	5	5	6	6	6	6	6	7
1.2		7	6	6	6	5	5	6	6	6	7	7	7	8	8
1.4		8	7	6	6	6	6	6	7	7	8				
1.6			7	7	7	6	6	7	7						
1.8			7	7	7	7	7	8							
2.0			7	7	7	7	7								
2.2			8	7	7	7									
2.4					7	8									
2.6															
2.8															
3.0															

Speed(mph) shown in column headings.

Exhibit 83. Table Showing Train Consist E2 Dynamic Brake Equilibrium Settings for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

Consist: E2 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6	5	5													
0.8	6	6	6	6	6	6	6	5	5	5	5	5	5		
1.0	8	8	8	8	7	7	7	7	7	7	7	6	6	6	6
1.2	9	9	9	9	9	9	9	9	9	8	8	8	8	8	7
1.4	11	11	11	11	11	11	10	10	10	10	10	10	9	9	9
1.6	13	13	13	12	12	12	12	12	12	12	11	11	11	11	11
1.8	14	14	14	14	14	14	14	14	13	13	13	13	13	12	12
2.0	16	16	16	16	16	16	15	15	15	15	15	15	14	14	14
2.2	18	18	17	17	17	17	17	17	17	17	16	16	16	16	15
2.4	19	19	19	19	19	19	19	19	18	18	18	18	18	17	17
2.6	21	21	21	21	21	20	20	20	20	20	20	19	19	19	19
2.8	23	22	22	22	22	22	22	22	22	21	21	21	21	21	20
3.0	24	24	24	24	24	24	24	23	23	23	23	23	22	22	22
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 84. Table Showing Train Consist E2 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

INPUT INFORMATION for SIMULATION E2

E2.INI:		
Train data file name	E2	
Track chart file name	E	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	120	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
E2.STP:		
Final position of leading vehicle (miles,feet)	140	0
Dwell time for stop 1 (minutes)	30	
Locomotive(s) in idle at stop 1?	yes	
E2.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	

E2.CMD:

START HELPERS WITH RUN 0 IN SYNCHRONOUS OPERATION
FOLLOW SPEED LIMITS FOR 20 MILES
END SIMULATION

Exhibit 85. Table Showing the Input Information Required to Run Simulation E2.

T E M FUEL and ENERGY REPORT for SIMULATION E2
OPERATIONS SUMMARY

CONSIST E2		
No. Vehicles in Consist	68	
No. Leading Locomotives	5	
No. Cars (and shutdown locos.)	60	
No. Helper Locomotives	3	
Total Train Length	4464	feet
Total Train Power (at the rail)	21333	hp
Total Train Weight	9704	Tons
Weight of Fuel	96	Tons
Weight of Lading	6000	Tons
Empty Train Weight	3608	Tons
Maximum Power/Weight	2.20	hp/TON
TRACK E		
No. Stops	1	
Total Distance Traveled	19 mi 5030	ft
Total Elapsed Time	1 h 18 m 45	s
Over-the-Road Time	0 h 48 m 32	s
Dwell Time	0 h 30 m 13	s
Average Over-the-Road Speed	25	MPH
TOTAL FUEL CONSUMPTION	777	gal
Diesel Fuel/Work	63	gal/Khph

Exhibit 86. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File E2.RPT.

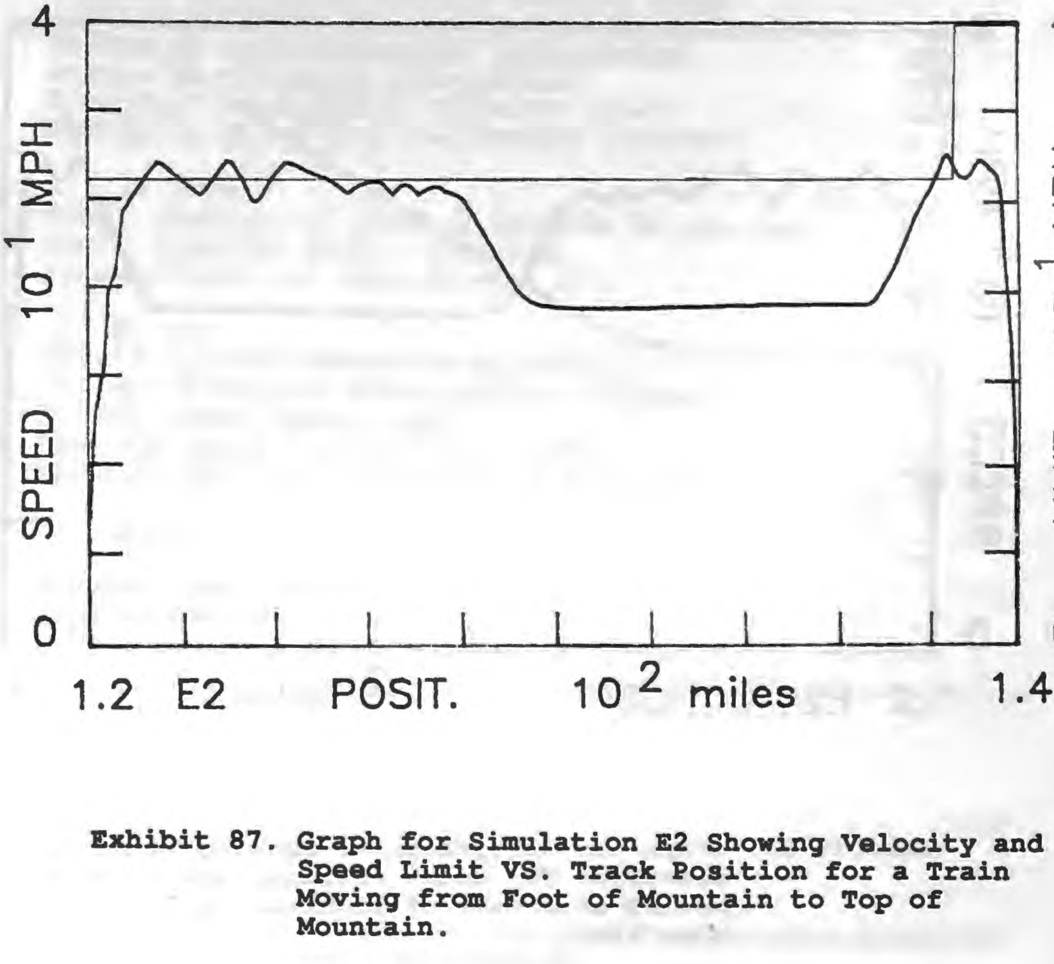


Exhibit 87. **Graph for Simulation E2 Showing Velocity and Speed Limit VS. Track Position for a Train Moving from Foot of Mountain to Top of Mountain.**

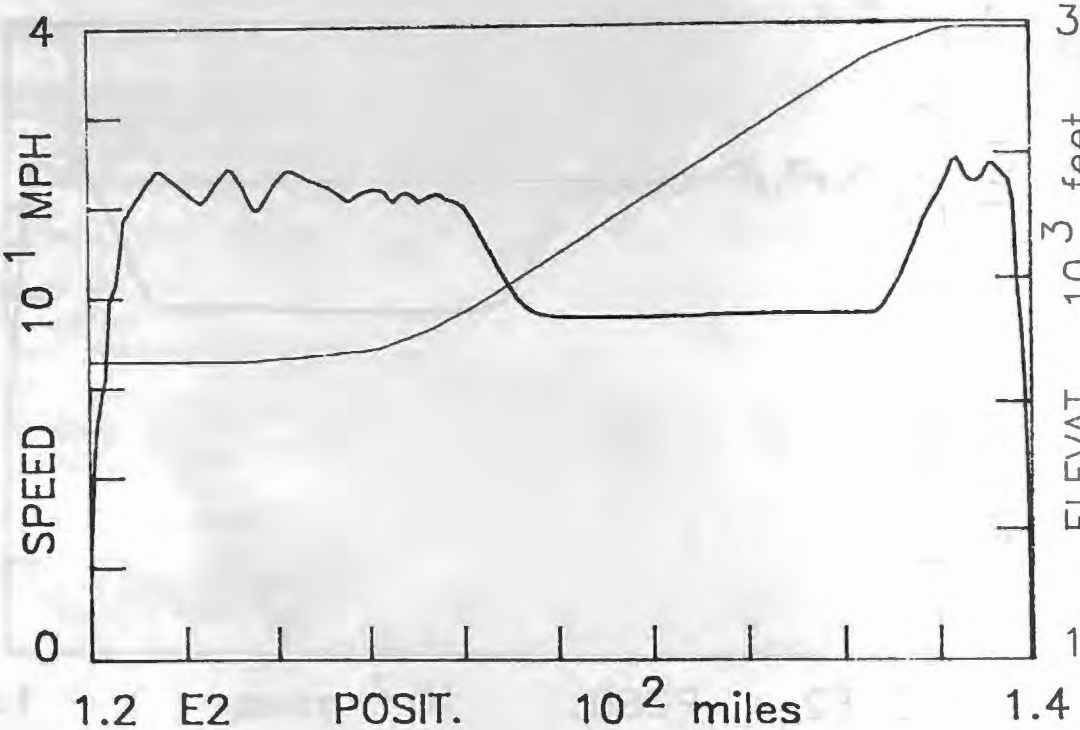


Exhibit 88. Graph for Simulation E2 Showing Velocity and Elevation VS. Track Position for a Train Moving from Foot of Mountain to Top of Mountain.

INPUT INFORMATION for SIMULATION E3

E3.INI:

Train data file name	E1	
Track chart file name	E	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	140	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	

E3.STP:

Final position of leading vehicle (miles,feet)	240	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	

E3.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

E3.CMD:

FOLLOW SPEED LIMITS FOR 100 MILES
END SIMULATION

Exhibit 89. Table Showing the Input Information Required to Run Simulation E3.

T E M FUEL and ENERGY REPORT for SIMULATION E3
OPERATIONS SUMMARY

CONSIST E1	
No. Vehicles in Consist	65
No. Leading Locomotives	5
No. Cars (and shutdown locos.)	60
No. Helper Locomotives	0
Total Train Length	4252 feet
Total Train Power (at the rail)	13333 hp
Total Train Weight	9035 Tons
Weight of Fuel	60 Tons
Weight of Lading	6000 Tons
Empty Train Weight	2975 Tons
Maximum Power/Weight	1.48 hp/TON
TRACK E	
No. Stops	1
Total Distance Traveled	99 mi 5051 ft
Total Elapsed Time	2 h 19 m 1 s
Over-the-Road Time	2 h 17 m 47 s
Dwell Time	0 h 1 m 14 s
Average Over-the-Road Speed	44 MPH
TOTAL FUEL CONSUMPTION	709 gal
Diesel Fuel/Work	73 gal/Khph

Exhibit 90. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File E3.RPT.

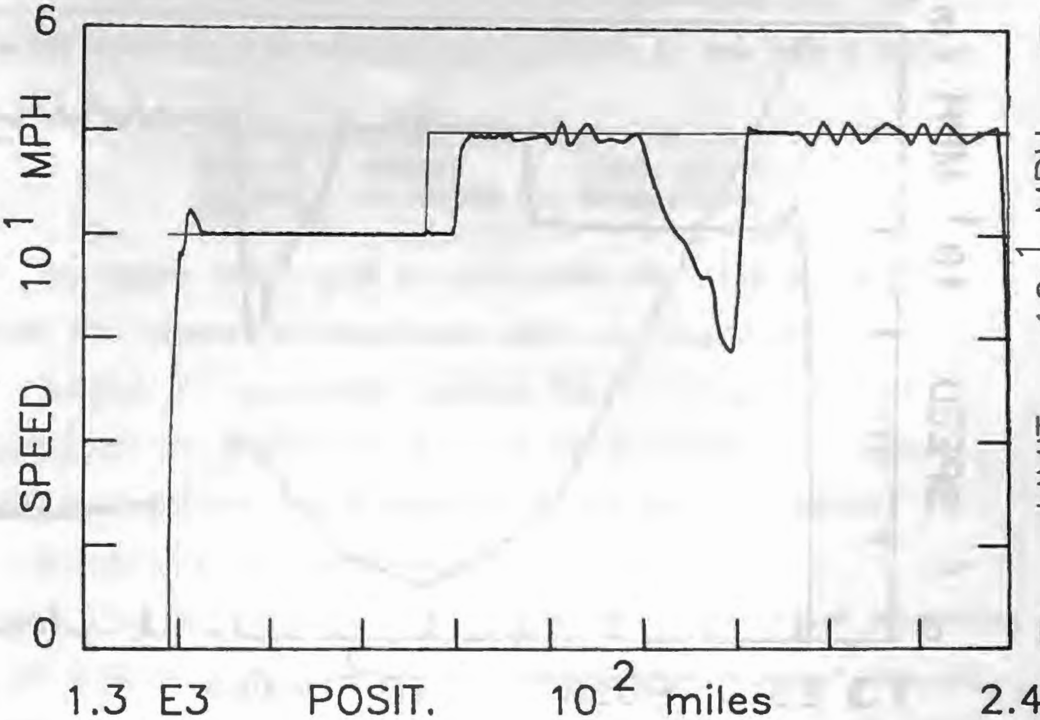


Exhibit 91. Graph for Simulation E3 Showing Velocity and Speed Limit VS. Track Position for a Train Moving from Top of Mountain to Destination.

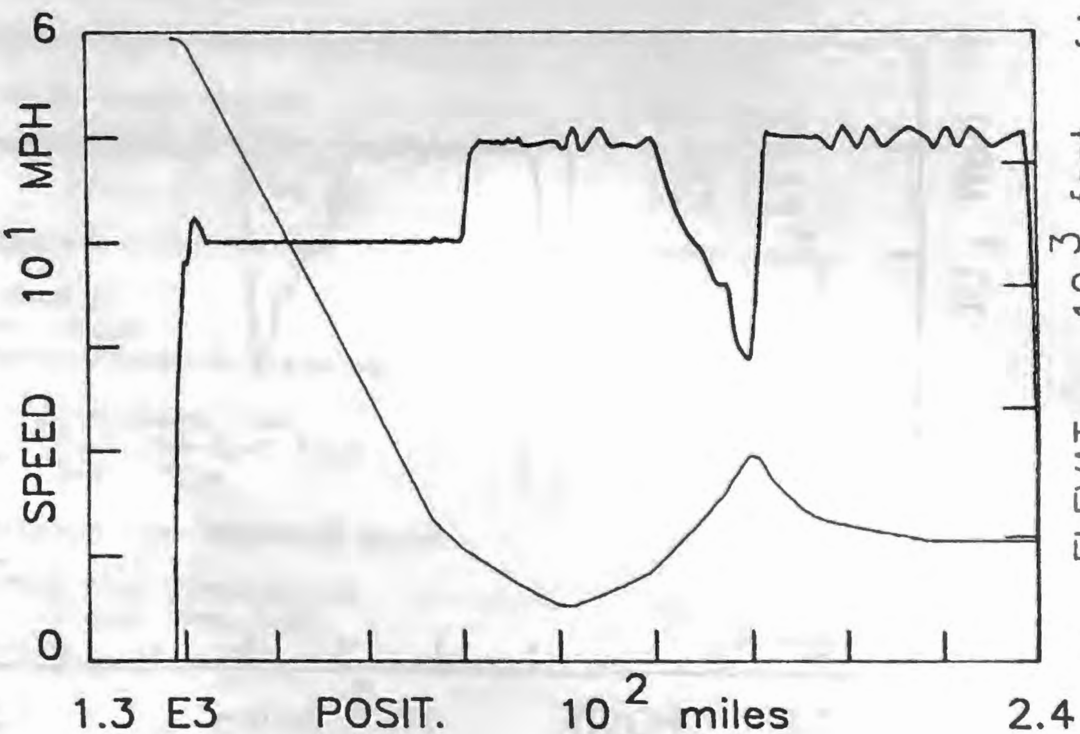


Exhibit 92. **Graph for Simulation E3 Showing Velocity and Elevation VS. Track Position for a Train Moving from Top of Mountain to Destination.**

7.5.4 Simulation E4: Helpers Return from Top of Mountain to Foot of Mountain

The purpose of Simulation E4 is to simulate the train movement of consist E4 (the helper locomotives) from the top of the mountain back down to the foot of the mountain (where they were added to the train at the end of Simulation E1). The consist used in this simulation is given in the table below:

CONSIST for SIMULATION E4 (E4.CON)

Type of Vehicle	Number of These	Fuel/Lading Each (TONs)
SD40 (FE)	3	12

The track chart used in Simulation E4 (file E4.TRK) is merely the reverse of the track chart in file E.TRK.

Exhibit 93 is a table showing the input information required to run simulation E4. The train consist and train operations summary for Simulation E4 is shown in Exhibit 94.

Exhibit 95 is a plot of velocity and speed limit versus elapsed time and Exhibit 96 is a plot of velocity and elevation versus elapsed time. From these Exhibits, we see that the ATA did not handle the train very well in Simulation E4. We will return to this simulation in the next chapter.

Finally, from the table in Exhibit 94, we see that the fuel consumption for the return of the helpers (32 gallons) is negligible compared to the total fuel consumption for train movements E1, E2, and E3 (3463 gallons).

INPUT INFORMATION for SIMULATION E4

E4.INI:	
Train data file name	E4
Track chart file name	E4
Wind chart file name	NOWIND
File output time interval (sec)	30
Terminal output time interval (sec)	30
Initial heading of leading vehicle (deg)	0
Initial position of leading vehicle (miles,feet)	110 0
Status of vehicle-mounted lubricators	OFF
Status of trackside lubricators	OFF
Effective lubrication distance (feet)	3600
Reduction in rolling resistance (lbs/TON)	0.70
E4.STP:	
Final position of leading vehicle (miles,feet)	130 0
Dwell time for stop 1 (minutes)	1
Locomotive(s) in idle at stop 1?	yes
E4.ATA:	
Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

E4.CMD:

FOLLOW SPEED LIMITS FOR 21 MILES
END SIMULATION

Exhibit 93. Table Showing the Input Information Required to Run Simulation E4.

T E M FUEL and ENERGY REPORT for SIMULATION E4
OPERATIONS SUMMARY

CONSIST E4		
No. Vehicles in Consist	3	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	0	
No. Helper Locomotives	2	
Total Train Length	211	feet
Total Train Power (at the rail)	8000	hp
Total Train Weight	669	Tons
Weight of Fuel	36	Tons
Weight of Lading	0	Tons
Empty Train Weight	633	Tons
Maximum Power/Weight	11.96	hp/TON
TRACK E4		
No. Stops	1	
Total Distance Traveled	20 mi 291	ft
Total Elapsed Time	0 h 41 m 45	s
Over-the-Road Time	0 h 40 m 34	s
Dwell Time	0 h 1 m 11	s
Average Over-the-Road Speed	30	MPH
TOTAL FUEL CONSUMPTION	32	gal
Diesel Fuel/Work	647	gal/Khph

Exhibit 94. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File E4.RPT.

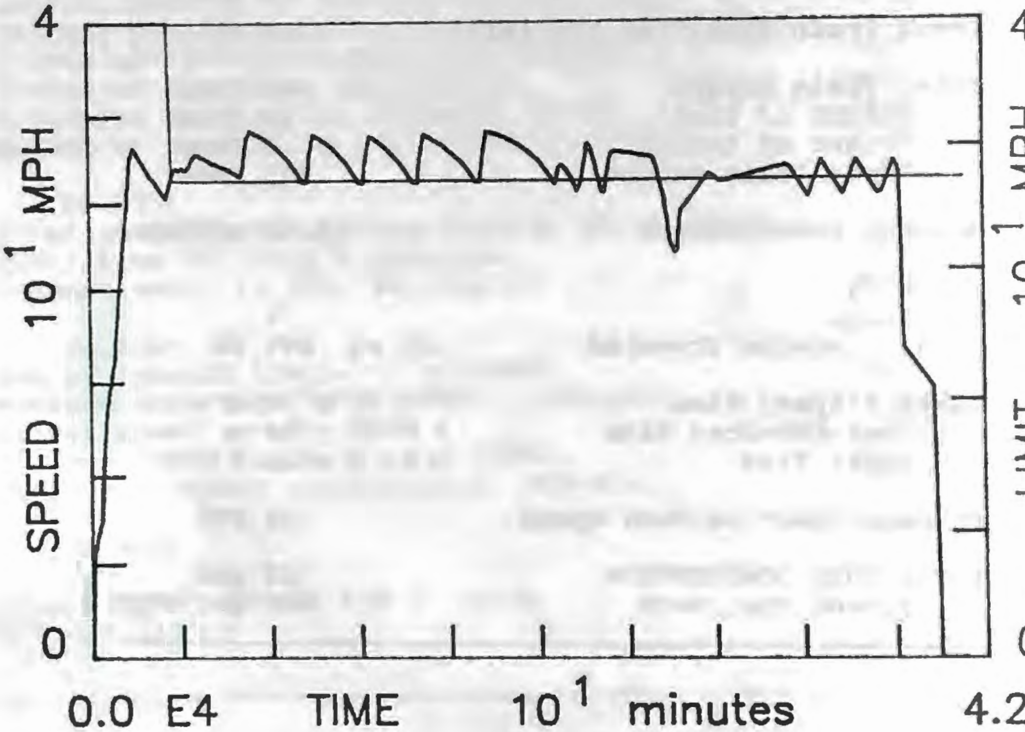


Exhibit 95. Graph for Simulation E4 Showing Velocity and Speed Limit VS. Elapsed Time for Helpers Moving from Top of Mountain to Foot of Mountain.

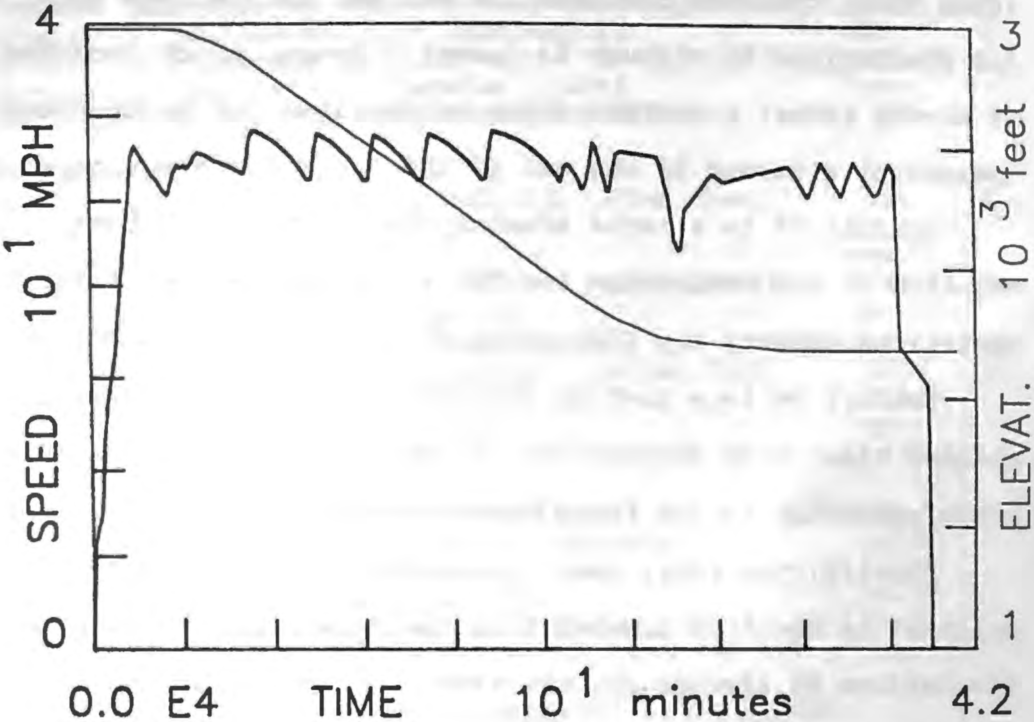


Exhibit 96. Graph for Simulation E4 Showing Velocity and Elevation VS. Elapsed Time for Helpers Moving from Top of Mountain to Foot of Mountain.

7.5.5 Simulation E5: Train with Helpers from Origin to Destination

The purpose of Simulation E5 is to compare the total fuel consumption for Simulations E1 through E4 (3495 gallons) to the fuel consumption required to move the same amount of lading (6000 TONs) the same distance (240 miles) in the same total time for Simulations E1 through E3 (about 7 hours, which includes two 30 minute stops) with the helper locomotives (in synchronous operation) attached to the end of the train for the entire run.

Exhibit 97 is a table showing the input information required to run simulation E5. The train consist and train operations summary for Simulation E5 is shown in Exhibit 98.

Exhibit 99 is a plot of velocity and speed limit versus elapsed time. From Exhibit 99, we see that the ATA handled the train perfectly in the three train movements of Simulation E5.

Finally, the total fuel consumption for Simulation E5 (3678 gallons) is about 5% greater than the total fuel consumption for Simulations E1 through E4. Therefore, in this case, it is more fuel-efficient to move the 6000 TONs of lading with a change of consist for the second train movement.

INPUT INFORMATION for SIMULATION E5

E5.INI:		
Train data file name	E2	
Track chart file name	E	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	0	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
E5.STP:		
Final position of leading vehicle (miles,feet)	120	0
Dwell time for stop 1 (minutes)	30	
locomotive(s) in idle at stop 1?	yes	
Final position of leading vehicle (miles,feet)	140	0
Dwell time for stop 2 (minutes)	30	
Locomotive(s) in idle at stop 2?	yes	
Final position of leading vehicle (miles,feet)	240	0
Dwell time for stop 3 (minutes)	1	
Locomotive(s) in idle at stop 3?	yes	
E5.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	

E5.CMD:

START HELPERS WITH RUN 0 IN SYNCHRONOUS OPERATION
FOLLOW SPEED LIMITS FOR 120 MILES
START HELPERS WITH RUN 0 IN SYNCHRONOUS OPERATION
FOLLOW SPEED LIMITS FOR 20 MILES
START HELPERS WITH RUN 0 IN SYNCHRONOUS OPERATION
FOLLOW SPEED LIMITS FOR 100 MILES
END SIMULATION

Exhibit 97. Table Showing the Input Information Required to Run Simulation E5.

T E M FUEL and ENERGY REPORT for SIMULATION E5
OPERATIONS SUMMARY

CONSIST E2	
No. Vehicles in Consist	68
No. Leading Locomotives	5
No. Cars (and shutdown locos.)	60
No. Helper Locomotives	3
Total Train Length	4464 feet
Total Train Power (at the rail)	21333 hp
Total Train Weight	9704 Tons
Weight of Fuel	96 Tons
Weight of Lading	6000 Tons
Empty Train Weight	3608 Tons
Maximum Power/Weight	2.20 hp/TON
TRACK E	
No. Stops	3
Total Distance Traveled	239 mi 4810 ft
Total Elapsed Time	6 h 50 m 48 s
Over-the-Road Time	5 h 48 m 13 s
Dwell Time	1 h 2 m 35 s
Average Over-the-Road Speed	41 MPH
TOTAL FUEL CONSUMPTION	3678 gal
Diesel Fuel/Work	63 gal/Khph

Exhibit 98. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File E5.RPT.

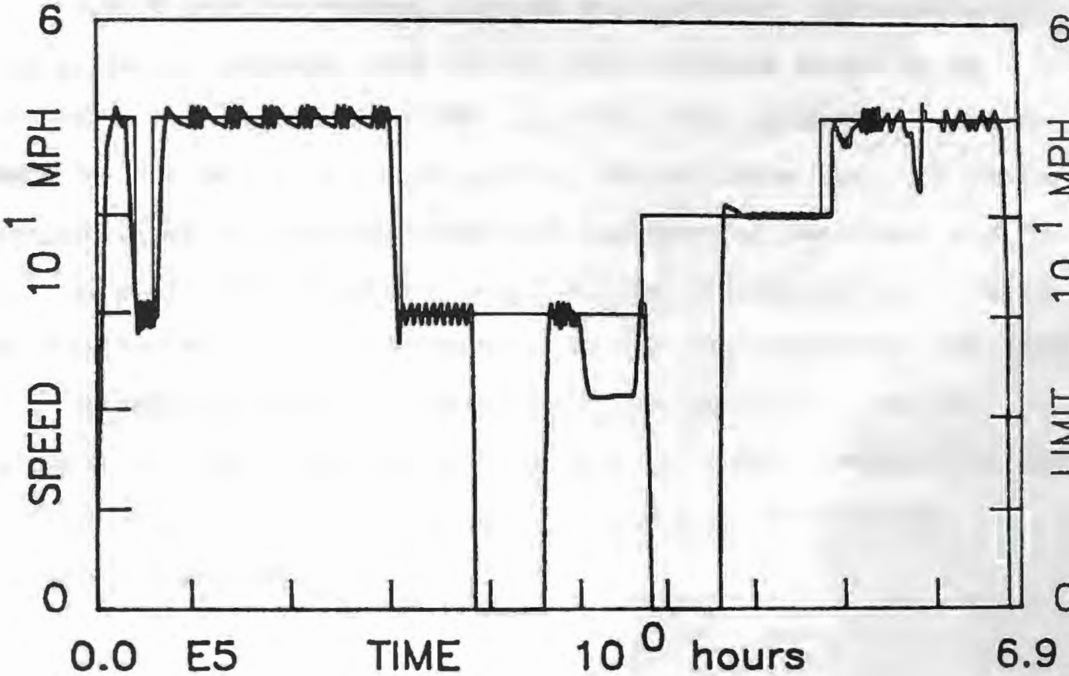


Exhibit 99. Graph for Simulation E5 Showing Velocity and Speed Limit VS. Elapsed Time for a Train Moving from Origin to Destination.

8.0 MANUAL CONTROL OF TRAIN ENERGY MODEL SIMULATIONS

The purpose of this chapter is to demonstrate, through an example simulation, how TEM English-language commands, along with the various TEM computer terminal displays, can be used to operate a TEM simulation under manual control (or a combination of manual and ATA control).

There may be various reasons for running a TEM simulation under manual control. One of the major reasons would be to re-run a simulation in which: (1) the train-handling decisions made by the ATA were unacceptable (in the sense that the train handling had an adverse effect on the desired results); and (2) the unacceptable decisions could not be effectively over-ruled by adjustments to the parameters in the corresponding .ATA file.

Before going on to the example simulation, it may be helpful for the reader to review the TEM command structure, the stored command (.CMD) file, and the various TEM computer terminal displays.

8.1 TEM Commands

8.1.1 TEM Command Structure

There are two types of TEM master commands: 1) train control commands that correspond to actual control settings in the leading locomotive consist in the train, and 2) simulation operation commands. All master commands consist of four numbers:

1. MODE of control or operation.
   For helper commands (MODE 9, as defined below), the first number serves only as an indicator that the following three numbers correspond to helper commands.

2. SETTING appropriate for the specified mode.
   For helper commands, the second number is the MODE.

3. RANGE of command.
   This can be: a time interval that must elapse,
   a distance that must be covered, or
   a speed that must be attained
   before the command is completed.

   For helper commands, the third number is the SETTING.

4. METHOD of specifying the range:
   For master commands:
   "1" indicates a time in minutes (MINutes)
   "2" indicates a time in seconds (SEConds)
   "3" indicates a distance in miles (MILes or MI_)
   "4" indicates a distance in feet (FEEt or FT_)
   "5" indicates a speed in MPH (MPH)

   For helper commands (which have no RANGE):
   "7" indicates synchronous helper control (SYNchronous)
   "8" indicates autonomous helper control (AUTonomous)

A TEM helper command consists of four numbers:

1. "9" (HELper)
   This number serves only as an indicator that the following three numbers correspond to helper commands.

2. HELPER MODE of control:
   "1" indicates throttle control (RUN)
   "2" indicates dynamic brake control (DYNamic)

3. HELPER SETTING for the specified mode.
   The appropriate settings are the same as those for MODE 1 and MODE 2.

4. HELPER METHOD of implementing control:
   "7" indicates synchronous control (SYNchronous)
   "8" indicates autonomous control (AUTonomous)

T E M ENGLISH COMMAND MODE KEY GROUPS

Command MODE	Special SETTING	Key Letter GROUP	Key Letter ALTERNATIVES		Key WORD
Throttle:					
1		RUN	run	Run	RUN
1	-1	SHU	shu	Shu	SHUTDOWN
Dynamic Brake:					
2		DYN	dyn	Dyn	DYNAMIC
Automatic Air Brake:					
3		RED	red	Red	REDUCTION
3	-1	REL	rel	Rel	RELEASE
Independent Air Brake:					
4		IND	ind	Ind	INDEPENDENT
4	-1	BAI	bai	Bai	BAILOFF
ATA Command Control:					
6		CON	con	Con	CONSTANT
6	-1	LIM	lim	Lim	LIMIT
Manual Control:					
7	1	MAN	man	Man	MANUAL
Track Chart Display:					
8		DIS	dis	Dis	DISPLAY
Helper Control:					
9		HEL	hel	Hel	HELPER
End Simulation:					
0		END	end	End	END

Exhibit 100. Table Showing TEM English Command MODE Key Letter Groups and Key Words.

T E M ENGLISH COMMAND METHOD KEY GROUPS

Command METHOD	Key Letter GROUP	Key Letter ALTERNATIVES	Key WORD
A time interval that must elapse:			
1	MIN	min	MINUTE
2	SEC	sec	SECOND
A distance that must be covered:			
3	MIL	mil MI_ mi_	MILE
4	FEE	fee FT_ ft_	FEET
A speed that must be attained:			
5	MPH	mph	MPH
Type of helper control:			
7	SYN	syn	SYNCHRONOUS
8	AUT	aut	AUTONOMOUS

Exhibit 101.Table Showing TEM English Command METHOD Key Letter Groups and Key Words.

For convenience, Exhibits 15 and 16 are reproduced in this chapter as Exhibits 100 and 101. The TEM English-language command MODE three-letter key groups and the corresponding key words are summarized in the table shown in Exhibit 100. The TEM English-language command METHOD three-letter key groups and the corresponding key words are summarized in the table shown in Exhibit 101.

8.1.2 MACRO Commands

Assuming that the train is being operated manually in a TEM simulation, there are four situations in which the repetition of similar commands could be very tedious for the user:

1. MODE 1:
   A) Throttling up from one run notch setting to another, where the higher notch is more than one greater than the lower notch.
   B) Throttling down from one run notch setting to another, where the difference is more than one notch.

2. MODE 2:
   A) Increasing the dynamic brake from one setting to another, where the higher setting is more than one increment (say .5) greater than the lower setting.
   B) Decreasing the dynamic brake from one setting to another, where the difference is more than one increment.

Under these four circumstances, MODE 1 (RUN) and MODE 2 (DYN) commands act as MACRO commands; that is, they automatically generate a string of similar commands that are implemented by the simulation program and stored in the .CMD file. The MACRO commands generate the following commands for the corresponding situations listed above:

1. MODE 1:
   A) One "RUN M" generates a "RUN n 2 SEC" command for each run notch from n = L + 1 to n = M, where L is the lowest (current) setting and M is the highest (specified) setting.
   B) One "RUN L" generates a "RUN n 2 SEC" command for each run notch from n = M - 1 to n = L, where M is the highest (current) setting and L is the lowest (specified) setting.

2. MODE 2:
   A) One "DYN M" generates a "DYN n 1 SEC" command for each dynamic setting from n = L + .5 to n = M, where L is the lowest (current) setting and M is the highest (specified) setting (in .5 increments).
   B) One "DYN L" generates a "DYN n 1 SEC" command for each dynamic setting from n = M - .5 to n = L, where M is the highest (current) setting and L is the lowest (specified) setting (in .5 decrements).

8.2 Stored Command File (.CMD)

The .CMD file contains a set of TEM train control and simulation control commands. Each line (one for each command) of the .CMD file consists of four numbers:

TEM Master Command:

1 MODE of control or operation.
2 SETTING appropriate for the specified mode.
3 RANGE of command.
4 METHOD of specifying the range.

TEM Helper Command:

1 "9" (This number serves only as an indicator.)
2 HELPER MODE of control.
3 HELPER SETTING for the specified mode.
4 HELPER METHOD of implementing control.

If a simulation is to be run entirely by manual control (user supplied train control settings from the terminal) or by a combination of manual and ATA control, then to start the process of building a stored command file, the first and only command in the .CMD file (which can be set up by running PRE Function 9) for input to the simulation could be:

MANUAL TRAIN HANDLING (7 1 0 0)

While the simulation is running in manual mode, the program automatically writes the user supplied commands (from the terminal) to the .CMD file (following the MANUAL command). Thus, when the simulation is finished and the program is terminated, the user has a complete record of his or her train handling decisions (including the decision to use ATA).

If the user wants to use this .CMD file as a stored command file for another simulation, then the MANUAL command in the output .CMD file must be deleted (using the PC editor). However, a final MANUAL command can be added to the new input .CMD file, so that the process of building up stored commands (for example, by trial and error) can continue indefinitely.

8.3 TEM Simulation Terminal Displays

8.3.1 Simulation Dynamics Display

While a TEM simulation is in progress, a constantly changing display, the simulation dynamics display, appears on the computer terminal. The interval between display changes is nominally equal to the terminal output time interval (simulated time) specified in the .INI file. However, the solution of the equation of motion may not be available at precisely those time intervals. In that case, the solution nearest to the nominal interval is displayed on the terminal. The display includes the following information:

- Train control settings:
  - Leading locomotive throttle (indicated as "run")
  - Helper locomotive throttle (following "/")
  - Leading locomotive dynamic (one-tenth resolution)
  - Helper locomotive dynamic (following "/")
  - Automatic air brake reduction (indicated as "psi")
- Elapsed simulated train time:
  - Hours (indicated as "h")
  - Minutes (indicated as "m")
  - Seconds (indicated as "s")
- Track position of leading vehicle:
  - Miles (indicated as "mi")
  - Feet (indicated as "ft")
- Velocity of train (MPH):
  - Actual speed
  - Current speed limit (following "/")
- Acceleration of train (mph/min)
- Drawbar force (lbs)
- Track data:
  - Milepost number
  - Elevation (indicated as "ft")
  - Direction with respect to initial heading (indicated as "deg")

NOTE: If a place name (at one of the specified positions on the track chart) is close to the current track position of the leading vehicle in the train, the place name appears on the terminal display, instead of the three items of track data (milepost number, elevation, and direction).

8.3.2 Manual Command Prompt / Control Status Display

If a TEM simulation is being run in manual mode, and the program requires a new command from the user, a manual command prompt, which incorporates a control status display, appears immediately below the simulation dynamics display (or the track chart display, if the previous command was DISPLAY). The control status display contains the following information (on one line):

Throttle setting for:	(indicated as "1)thl ")
Leading locomotive consist	(followed by "/")
Helper locomotives	(followed by "*", if there are any helpers)
Dynamic brake setting for:	(indicated as "2)dyn ")
Leading locomotive consist	(followed by "/")
Helper locomotives	(followed by "*", if there are any helpers)
Automatic brake pipe pressure:	(indicated as "3) air " and given in PSI)
Independent brake pressure:	(indicated as "4) ind " and given in PSI)

When the master command prompt appears, there are four audible "beeps," indicating that the program requires four items of information: the MODE, SETTING, RANGE, and METHOD numbers of the TEM master command. However, as we have seen, the user can enter a TEM English-language command, instead. In general, the syntax of a TEM English-language command has the same form as a TEM four-number command.

8.3.3 Track Chart Display

During a simulation under manual control, the user can command TEM to display the track profile on which the train is positioned and immediately ahead of the train to any specified "look-ahead" distance (consistent with the contents of the track buffer at the time) by using the MODE 8 (DISPLAY) command.

> NOTE: This display is not a true graphics display; it is a "character display". The advantage of this type of display is that it can be used on a mainframe or PC computer terminal without any special graphics capabilities.
>
> A DISPLAY command is not written to the .CMD file.

8.4 Simulations Demonstrating How TEM Can Be Used with Manual and Stored Command Control

8.4.1 Simulation E4 Revisited: Train Handling Problems With The Helper Consist

While the ATA controls "regular" trains very well (as is evident from the example simulation results in the previous chapter), it does not control locomotive consists (trains consisting solely of locomotives) very well. Referring to Exhibits 95 and 96: We see that the ATA did not handle the train very well in Simulation E4. In that case, the "train" consisted of three SD40 locomotives only (with a maximum power to weight ratio of 11.96 hp/TON). Exhibits 102, 103, and 104 are tables showing the throttle equilibrium speeds, dynamic brake equilibrium settings, and air brake equilibrium reductions for consist E4. From the values in these tables, we can see that it would be very easy to over-control such a "train."

Consist: E4 THROTTLE EQUILIBRIUM SPEEDS (mph) max.hp/TON: 11.96

%Grade								
3.0			18	27	37	47	60	67
2.8		10	19	29	39	49	63	71
2.6		11	20	31	42	53	67	75
2.4		12	22	33	45	56	71	79
2.2		13	23	36	48	60	76	84
2.0		14	25	39	52	65	81	90
1.8		15	28	42	56	70	87	96
1.6		16	31	46	61	75	93	>100
1.4		18	34	51	67	82	100	>100
1.2	11	23	39	57	74	89	>100	>100
1.0	12	27	44	64	82	97	>100	>100
0.8	15	32	51	72	91	>100	>100	>100
0.6	19	38	60	82	100	>100	>100	>100
0.4	25	48	71	93	>100	>100	>100	>100
0.2	35	61	84	>100	>100	>100	>100	>100
0.0	52	77	99	>100	>100	>100	>100	>100
Notch	1	2	3	4	5	6	7	8

Exhibit 102. Table Showing Train Consist E4 Throttle Equilibrium Speeds for Notches 1 to 8 and Grades from 0 to 3%.

Consist: E4 DYNAMIC BRAKE EQUILIBRIUM SETTINGS

%Grade(-)														
0.0														
0.2		1	1	1	1	1	1	1	1	1	1	1	1	1	[illegible]
0.4		2	2	1	1	1	1	1	1	1	1	1	1	1	[illegible]
0.6		2	2	2	1	1	1	1	1	1	1	2	2	2	[illegible]
0.8		3	3	2	2	1	2	2	2	2	2	3	3	3	[illegible]
1.0		4	4	3	2	2	2	3	3	3	3	4	4	4	[illegible]
1.2		4	4	4	3	3	3	3	3	4	4	4	4	4	[illegible]
1.4		4	4	4	4	3	3	4	4	4	4	4	4	4	[illegible]
1.6		4	4	4	4	3	4	4	4	4	4	4	4	4	[illegible]
1.8		4	4	4	4	4	4	4	4	4	4	4	4	4	[illegible]
2.0		4	4	4	4	4	4	4	4	4	4	4	4	5	[illegible]
2.2		4	4	4	4	4	4	4	4	4	4	5	5	5	[illegible]
2.4		4	5	4	4	4	4	4	4	4	5	5	5	5	[illegible]
2.6		5	5	4	4	4	4	4	4	5	5	5	5	5	[illegible]
2.8		5	5	5	4	4	4	4	4	5	5	5	5	5	[illegible]
3.0		5	5	5	4	4	4	4	5	5	5	5	5	5	[illegible]
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	7

Exhibit 103. Table Showing Train Consist E4 Dynamic Brake Equilibrium Settings for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

Consist: E4 AIR BRAKE EQUILIBRIUM REDUCTIONS (psi)

%Grade(-)															
0.0															
0.2															
0.4															
0.6															
0.8	5	5	5	5	5	5	5	5							
1.0	7	6	6	6	6	6	6	6	6	6	5	5	5	5	5
1.2	8	8	8	8	8	7	7	7	7	7	7	7	6	6	6
1.4	9	9	9	9	9	9	9	9	8	8	8	8	8	8	7
1.6	11	10	10	10	10	10	10	10	10	10	9	9	9	9	9
1.8	12	12	12	12	12	11	11	11	11	11	11	11	11	11	10
2.0	13	13	13	13	13	13	13	13	12	12	12	12	12	12	11
2.2	15	14	14	14	14	14	14	14	14	14	13	13	13	13	13
2.4	16	16	16	16	16	15	15	15	15	15	15	15	14	14	14
2.6	17	17	17	17	17	17	17	17	16	16	16	16	16	16	15
2.8	19	18	18	18	18	18	18	18	18	18	17	17	17	17	17
3.0	20	20	20	20	20	19	19	19	19	19	19	19	18	18	18
Speed(mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70

Exhibit 104. Table Showing Train Consist E4 Air Brake Equilibrium Reductions for Grades from 0 to -3% and Equilibrium Speeds from 0 to 70 MPH.

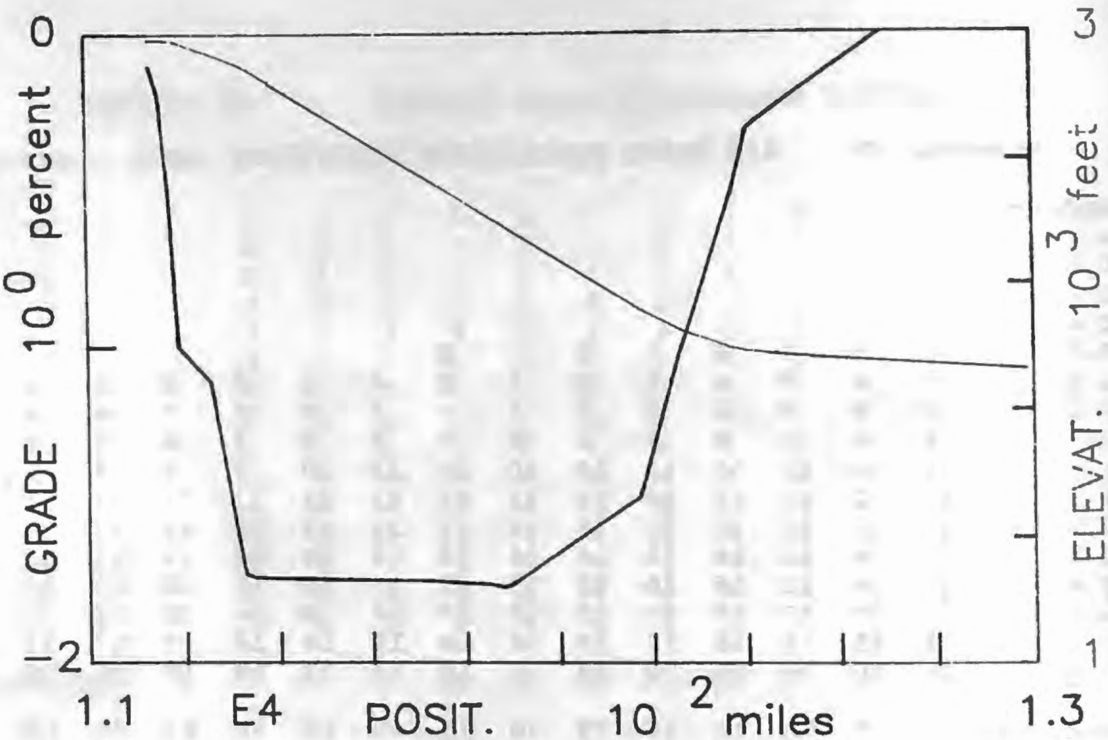


Exhibit 105.Graph Showing the Grade Profile and Elevation Profile for the Track Chart Data in File E4.TRK from Track Position 110 Miles to Track Position 130 Miles.

8.4.2 Simulation M1: Manual Control of Helper Consist from Top of Mountain to Foot of Mountain

The purpose of Simulation M1 is to operate locomotive consist E4 (in file E4.CON) on track E4 (in file E4.TRK) from the top of the mountain to the foot of the mountain by entering English language commands at the computer keyboard.

Exhibit 105 shows the grade profile and elevation profile for the track chart in file E4.TRK from track position 110 miles to track position 130 miles. For this stretch of track, the speed limit is 30 MPH, and the average grade is about -1.4%. This Exhibit, along with Exhibits 102, 103, and 104 are helpful in planning a train-handling strategy for running the helper consist under manual control.

For example, the throttle equilibrium speed table in Exhibit 102 shows that a throttle setting of notch 1 will be more than sufficient to start the consist and bring the speed up to 30 MPH; and the dynamic brake equilibrium setting table in Exhibit 103 shows that a dynamic brake setting of about 3 is required to maintain 30 MPH on a -1.4% grade.

Essentially, the train-handling strategy for Simulation M1 is to: (1) start the consist with the throttle in notch 1 (then throttle down when the speed reaches 30 MPH), (2) hold the dynamic brake close to setting 3 (perhaps with some modulation) until the consist reaches the foot of the mountain (then "coast"

INPUT INFORMATION for SIMULATION M1

M1.INI:		
Train data file name	E4	
Track chart file name	E4	
Wind chart file name	NOWIND	
File output time interval (sec)	1	
Terminal output time interval (sec)	1	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	110	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	
M1.STP:		
Final position of leading vehicle (miles,feet)	130	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	
M1.ATA:		
Use of dynamic brakes is allowed?	yes	
Average departure acceleration (MPH/min)	12.0	
Offset speed margin (MPH)	0.0	
Maximum speed limit allowed (MPH)	100.0	
Average approach deceleration (MPH/min)	16.0	
M1.CMD:		
MANUAL TRAIN HANDLING		

Exhibit 106. Table Showing the Input Information Required to Run Simulation M1.

INPUT COMMANDS for SIMULATION M1

	English Command	Key Letter Command	Four-Number Command (M1.CMD)			
1	SET THROTTLE TO RUN 1 AND HOLD UNTIL SPEED REACHES 30 MPH	RUN 1 30 MPH	1	1.0	30.00	5
2	THROTTLE DOWN TO RUN 0	RUN 0	1	0.0	0.00	1
3	HOLD RUN 0 FOR 45 SECONDS	RUN 0 45 SEC	1	0.0	45.00	2
4	HOLD RUN 0 UNTIL SPEED REACHES 30 MPH	RUN 0 30 MPH	1	0.0	30.00	5
5	INCREASE DYNAMIC BRAKE SETTING TO 1.0 *	DYN 1.0	2	0.5	1.00	2
			2	1.0	1.00	2
6	HOLD DYNAMIC 1.0 UNTIL SPEED REACHES 30 MPH	DYN 1.0 30 MPH	2	1.0	30.00	5
7	HOLD DYNAMIC 1.0 FOR 12 SEC	DYN 1.0 12 SEC	2	1.0	12.00	2
8	INCREASE DYNAMIC BRAKE SETTING TO 2.0 *	DYN 2.0	2	1.5	1.00	2
			2	2.0	1.00	2
9	HOLD DYNAMIC 2.0 FOR 18 SEC	DYN 2.0 18 SEC	2	2.0	18.00	2
10	HOLD DYNAMIC 2.0 FOR 30 SEC	DYN 2.0 30 SEC	2	2.0	30.00	2
11	HOLD DYNAMIC 2.0 FOR 2 MIN	DYN 2.0 2 MIN	2	2.0	2.00	1
12	INCREASE DYNAMIC BRAKE SETTING TO 3.0 *	DYN 3.0	2	2.5	1.00	2
			2	3.0	1.00	2
13	HOLD DYNAMIC 3.0 FOR 1 MIN	DYN 3.0 1 MIN	2	3.0	1.00	1

* This is a MACRO Command

Exhibit 107.Table Showing TEM English Commands Used to Control Train in Simulation M1.

INPUT COMMANDS for SIMULATION M1 (continued)

	English Command	Key Letter Command	Four-Number Command (M1.CMD)			
14	SET DYNAMIC BRAKE TO 3.2 FOR 1 SECOND	DYN 3.2 1 SEC	2	3.2	1.00	2
15	HOLD DYNAMIC 3.2 UNTIL SPEED REACHES 28 MPH	DYN 3.2 28 MPH	2	3.2	28.00	5
16	SET DYNAMIC BRAKE TO 3.0 FOR 1 SECOND	DYN 3.0 1 SEC	2	3.0	1.00	2
17	HOLD DYNAMIC 3.0 UNTIL SPEED REACHES 30 MPH	DYN 3.0 30 MPH	2	3.0	30.00	5

NOTE: Commands 14 through 17 form a cycle of commands; the cycle is repeated 20 times, so that the next command is #94.

	English Command	Key Letter Command	Four-Number Command (M1.CMD)			
94	SET DYNAMIC BRAKE TO 3.2 FOR 1 SECOND	DYN 3.2 1 SEC	2	3.2	1.00	2
95	HOLD DYNAMIC 3.2 UNTIL SPEED REACHES 28 MPH	DYN 3.2 28 MPH	2	3.2	28.00	5
96	SET DYNAMIC BRAKE TO 3.0 FOR 1 SECOND	DYN 3.0 1 SEC	2	3.0	1.00	2
97	HOLD DYNAMIC 3.0 UNTIL SPEED REACHES 26 MPH	DYN 3.0 26 MPH	2	3.0	26.00	5
98	DECREASE DYNAMIC BRAKE SETTING TO 2.0 *	DYN 2.0	2	2.5	1.00	2
			2	2.0	1.00	2
99	HOLD DYNAMIC 2.0 UNTIL SPEED REACHES 30 MPH	DYN 2.0 30 MPH	2	2.0	30.00	5

* This is a MACRO Command

INPUT COMMANDS for SIMULATION M1 (continued)

	English Command	Key Letter Command	Four-Number Command (M1.CMD)
100	HOLD DYNAMIC 2.0 FOR 38 SEC	DYN 2.0 38 SEC	2 2.0 38.00 2
101	HOLD DYNAMIC 2.0 UNTIL SPEED REACHES 26 MPH	DYN 2.0 26 MPH	2 2.0 26.00 5
102	DECREASE DYNAMIC BRAKE SETTING TO 1.0 *	DYN 1.0	2 1.5 1.00 2 2 1.0 1.00 2
103	HOLD DYNAMIC 1.0 FOR 58 SEC	DYN 1.0 58 SEC	2 1.0 58.00 2
104	HOLD DYNAMIC 1.0 UNTIL SPEED REACHES 26 MPH	DYN 1.0 26 MPH	2 1.0 26.00 5
105	SET DYNAMIC BRAKE TO 0.5 FOR 1 SECOND	DYN 0.5 1 SEC	2 0.5 1.00 2
106	HOLD DYNAMIC 0.5 FOR 24 SEC	DYN 0.5 24 SEC	2 0.5 24.00 2
107	SET DYNAMIC BRAKE TO 0.0 FOR 1 SECOND	DYN 0.0 1 SEC	2 0.0 1.00 2
108	HOLD DYNAMIC 0.0 FOR 19 SEC	DYN 0.0 19 SEC	2 0.0 19.00 2
109	HOLD RUN 0 FOR 6 MIN (COAST)	RUN 0 6 MIN	1 0.0 6.00 1
110	HOLD RUN 0 UNTIL SPEED REACHES 26 MPH	RUN 0 26 MPH	1 0.0 26.00 5
111	THROTTLE UP TO RUN 1 FOR 2 SEC	RUN 1 2 SEC	1 1.0 2.00 2
112	HOLD RUN 1 UNTIL SPEED REACHES 30 MPH	RUN 1 30 MPH	1 1.0 30.00 5

* This is a MACRO Command

INPUT COMMANDS for SIMULATION M1 (continued)

	English Command	Key Letter Command	Four-Number Command (M1.CMI		
113	THROTTLE DOWN TO RUN 0 FOR 2 SEC	RUN 0 2 SEC	1	0.0	2.00
114	HOLD RUN 0 FOR 4 MIN (COAST)	RUN 0 4 MIN	1	0.0	4.00
115	SET INDEPENDENT BRAKE TO 12 PSI FOR 1 SEC	IMD 12 1 SEC	4	12.0	1.00
116	HOLD INDEPENDENT AT 12 PSI FOR 2 MIN	IND 12 2 MIN	4	12.0	2.00
117	END SIMULATION	END	0	0.0	0.00

* This is a MACRO Command

T E M FUEL and ENERGY REPORT for SIMULATION M1
OPERATIONS SUMMARY

CONSIST E4		
No. Vehicles in Consist	3	
No. Leading Locomotives	1	
No. Cars (and shutdown locos.)	0	
No. Helper Locomotives	2	*
Total Train Length	211	feet
Total Train Power (at the rail)	8000	hp
Total Train Weight	669	Tons
Weight of Fuel	36	Tons
Weight of Lading	0	Tons
Empty Train Weight	633	Tons
Maximum Power/Weight	11.96	hp/TON
TRACK E4		
No. Stops	1	
Total Distance Traveled	20 mi 15	ft
Total Elapsed Time	0 h 44 m 55	s
Over-the-Road Time	0 h 44 m 6	s
Dwell Time	0 h 0 m 49	s
Average Over-the-Road Speed	27	MPH
TOTAL FUEL CONSUMPTION	32	gal
Diesel Fuel/Work	1004	gal/Khph

* Although the .RPT file shows these locomotives as "helpers", the simulator program treats them as part of the leading locomotive consist.

Exhibit 108. Table Showing Train Consist and Train Operations Summary as It Appears in Disk File M1.RPT.

in idle as much as possible), and (3) stop the consist with the independent brake.

Exhibit 106 is a table showing the input information required to run simulation M1 and Exhibit 107 is a table (continued over four pages) showing the TEM English-language commands used to obtain the final results in Simulation M1. (The numbers on the left-hand side of the table are for reference only.) For each English-language command, Exhibit 107 shows the corresponding simplified key group command and the four-number form of the command. The four-number command is the form actually stored in the .CMD file.

Finally, Exhibit 108 shows the train consist and train operations summary for Simulation M1.

8.4.3 Simulation M2: Stored Command Control of Helper Consist from Top of Mountain to Foot of Mountain

In the first chapter of this manual, it was stated that TEM commands can originate from three sources:

The User (manual train handling)
The ATA (Automatic Train-handling Algorithm)
The Stored Command File (preprogrammed train handling)

In this chapter, we have seen an example of manual train handling in Simulation M1, and in the previous chapter, we saw many examples of ATA train handling.

INPUT INFORMATION for SIMULATION M2

M2.INI:

Train data file name	E4	
Track chart file name	E4	
Wind chart file name	NOWIND	
File output time interval (sec)	30	
Terminal output time interval (sec)	30	
Initial heading of leading vehicle (deg)	0	
Initial position of leading vehicle (miles,feet)	110	0
Status of vehicle-mounted lubricators	OFF	
Status of trackside lubricators	OFF	
Effective lubrication distance (feet)	3600	
Reduction in rolling resistance (lbs/TON)	0.70	

M2.STP:

Final position of leading vehicle (miles,feet)	130	0
Dwell time for stop 1 (minutes)	1	
Locomotive(s) in idle at stop 1?	yes	

M2.ATA:

Use of dynamic brakes is allowed?	yes
Average departure acceleration (MPH/min)	12.0
Offset speed margin (MPH)	0.0
Maximum speed limit allowed (MPH)	100.0
Average approach deceleration (MPH/min)	16.0

M2.CMD:

See Exhibit 110.

Exhibit 109. Table Showing the Input Information Required to Run Simulation M2.

STORED COMMANDS in FILE M2.CMD

1	1.0	30.00	5	2	3.2	1.00	2
1	0.0	0.00	1	2	3.2	28.00	5
1	0.0	45.00	2	2	3.0	1.00	2
1	0.0	30.00	5	2	3.0	26.00	5
2	0.5	1.00	2	2	2.5	1.00	2
2	1.0	1.00	2	2	2.0	1.00	2
2	1.0	30.00	5	2	2.0	30.00	5
2	1.0	12.00	2	2	2.0	38.00	2
2	1.5	1.00	2	2	2.0	26.00	5
2	2.0	1.00	2	2	1.5	1.00	2
2	2.0	18.00	2	2	1.0	1.00	2
2	2.0	30.00	2	2	1.0	58.00	2
2	2.0	2.00	1	2	1.0	26.00	5
2	2.5	1.00	2	2	0.5	1.00	2
2	3.0	1.00	2	2	0.5	24.00	2
2	3.0	1.00	1	2	0.0	1.00	2
....				2	0.0	19.00	2
: 2	3.2	1.00	2 :	1	0.0	6.00	1
: 2	3.2	28.00	5 :	1	0.0	26.00	5
: 2	3.0	1.00	2 :	1	1.0	2.00	2
: 2	3.0	30.00	5 :	1	1.0	30.00	5
:...................:				1	0.0	2.00	2
NOTE: Enclosed cycle				1	0.0	4.00	1
of four commands is				4	12.0	1.00	2
repeated 20 times.				4	12.0	2.00	1
				0	0.0	0.00	0

Exhibit 110. Table Showing the Stored Commands in File M2.CMD Required to Run Simulation M2.

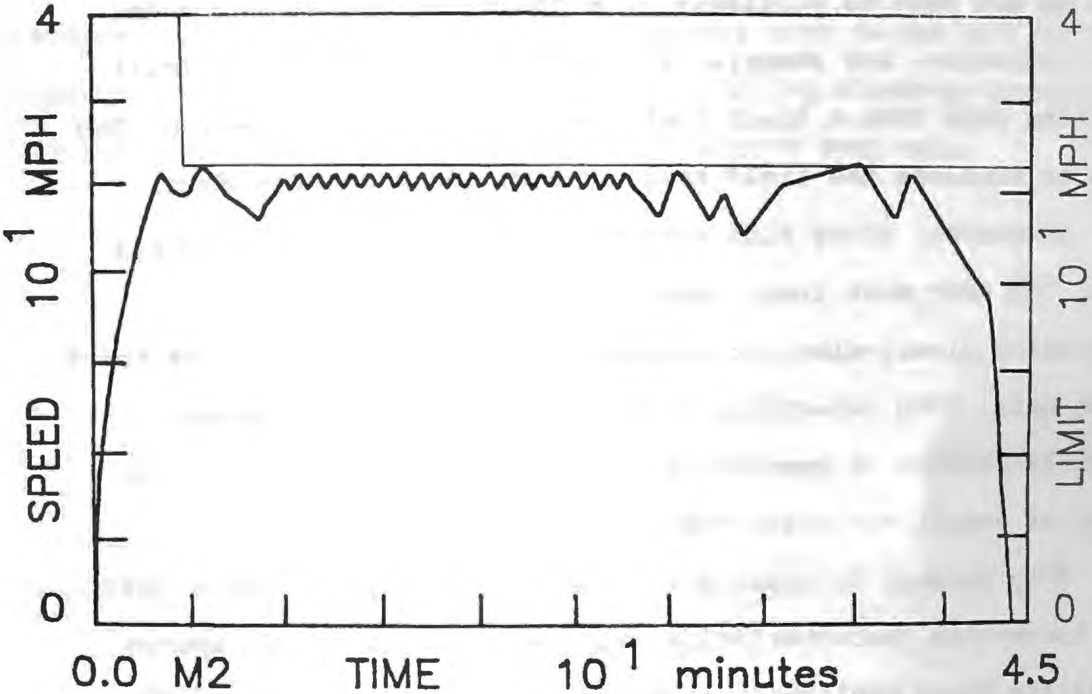


Exhibit 111. Graph for Simulation M2 Showing Velocity and Speed Limit VS. Elapsed Time for Helper Consist Moving from Top of Mountain to Foot of Mountain.

The purpose of Simulation M2 is to demonstrate that a TEM simulation can be run from a preprogrammed set of instructions in the stored command file. In this case, we will use the commands that were generated by running Simulation M1 in manual mode.

However, the preprogrammed commands in the stored command file do not need to originate in a prior, manually-controlled TEM simulation. For example, if the user has sufficient train handling data from a field test, he or she can construct a .CMD file to simulate the field test with the Train Energy Model.

Of course, along with reasonably accurate train handling data, the user must input reasonably accurate train data (including diesel-electric locomotive characteristics) and track chart data. With reasonably accurate data, the Train Energy Model is capable of generating very realistic results (on the level of detail for which TEM was developed).

With respect to input data, the user should be aware that the locomotive characteristics supplied with the Train Energy Model are those published by the locomotive manufacturer. The actual characteristics of the locomotives on the user's railroad may differ from the ideal characteristics supplied by the manufacturer. If the differences are significant, the user may need to construct customized .PAR, .THL, and .DYN files for the locomotives on his or her railroad (assuming that the necessary data is available).

Exhibit 109 is a table showing the input information required to run Simulation M2 and Exhibit 110 is a table showing the stored commands (in four-number form) in file M2.CMD. Note that there are no MANUAL (7 1 0 0) commands in file M2.CMD.

Exhibit 111 is a plot of velocity and speed limit versus elapsed time for Simulation M2. Comparing this to Exhibit 95 for Simulation E4, we see that the train-handling strategy (embodied in the commands given in Exhibit 110) worked very well.