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PROFILE: Gradient Simulation for Rail Hump Classification Yards

William A. Stock, Masami Sakasita, Carola Elliott, and Peter J. Wong

Designers of rail hump yards traditionally execute a long, tedious manual process to optimally design hump grades and retarder placements. This design process entails checking the velocities and headways of a worst-case sequence of cars to ensure that proper values of these variables can be maintained on the gradient. The computer simulation model PROFILE automatically computes these quantities and thus frees the designer from tedious work and allows him or her to generate and study more design alternatives. The model uses the usual static (velocity-independent) rolling-resistance formulation of car rollability but includes the option of using velocity-dependent rolling resistance. User input requirements and program-generated output are described, and an example of the application of the model to a typical design problem is given.

In rail hump yards, classification is performed by rolling a cut of cars down a grade and switching the cars into various classification tracks. To perform switching properly, sufficient headway between cars must be created and maintained. The principal problems in the design of the hump profile and in the development of an effective speed-control scheme are to ensure that (a) the headway maintained in the switching area [e.g., 15.2 m (50 ft)] is sufficient to throw switches and prevent catch-up in retarders, (b) speed restrictions [e.g., 24.1 km/h (15 miles/h)] at switches and curves are observed, and (c) proper coupling occurs on the class tracks within specified speed limits [e.g., 3.2-9.7 km/h (2-6 miles/h)]. Controlling headway and speeds would not be difficult if all cars had identical characteristics and rolling resistances (or rollability) because the initial time separation established at the crest would result in a uniform and predictable headway between cars.

However, car rollability is not uniform; it varies with weather and type of car and changes during the rolling of a car. Nonetheless, the profile designer must ensure that a large percentage of the cars (e.g., 99.9 percent) are delivered to the bowl tracks in a manner that satisfies the above design constraints. Moreover, because car speed is directly translatable into hump throughput, it is desirable that the fastest car speeds meeting these constraints be used.

Achievement of these aims is usually approached by considering the hardest-rolling (slowest) and easiest-rolling (fastest) cars. Hump grades are usually designed to deliver the hardest-rolling car to the clear point at a specified speed [e.g., 6.4 km/h (4 miles/h)] or to a specified distance into the classification track [e.g., 152.4 m (500 ft)]. The sizing and placement of retarder sections are usually determined by examining a worst-case triplet of a design hardest-rolling car followed by a design easiest-rolling car followed by a design hardest-rolling car traveling to the last switch on the farthest outside track. The retarders are placed where the separation between the two lead cars becomes less than a specified value; the retarder slows down the second car to reestablish proper headway. The length (power) of the retarder is based on the amount of energy that must be removed from the second car in this worst-case situation (of course, railroad policies may require sufficient retarder power to stop any car). At the same time, caution must be exercised to ensure that the second (easiest-rolling) car is not slowed so much that the third (hardest-rolling) car catches it.

The purpose of the PROFILE model is to provide the yard designer with an iterative and interactive computer design tool to perform such an analysis and to ensure that the design constraints are satisfied. The need for some automation of the hump design procedure has long been recognized. The labor and hours involved in plotting velocity head diagrams and converting them to car velocity, integrating velocity of cars to obtain time-distance plots, and finally comparing time-distance plots of cars to obtain headway have severely restricted the number of design alternatives that the yard designer could consider. The PROFILE simulation model is intended to automate this process, and the automation also offers the designer the option of selecting a more advanced model of car rollability (over the usual static-rolling-resistance formulation), if desired. PROFILE does not automate the entire yard design process or replace the designer; it extends the abilities of the designer by permitting him or her to evaluate many more design alternatives in shorter time than is possible in the manual process.

The PROFILE model has been used to support the yard design efforts of the Boston and Maine Corporation (1), the Consolidated Rail Corporation (2), and the Union Pacific Railroad (3).

OVERVIEW OF THE MODEL

PROFILE is a one-track simulation; that is, the user selects one route from the crest to the bowl and simulates only that route in a run. With repeated runs, all routes to the bowl can be simulated, if necessary. The profile gradient along this route is represented as a series of track sections. All parameters are assumed to be constant within a given track section.

Only single-car cuts are modeled, although longer cuts can be approximated as a single car of unusual length.

Within each track section, each car is treated for the purpose of its dynamics as a point mass, the motion of which is assumed to be governed by the following differential equation:

$$d^2X/dt^2 = dV/dt = \alpha + \beta V \qquad (1)$$

$$\alpha = g_e\,[\tan\theta - \mu - C - W - (S/L) - (R/L)] \qquad (1a)$$

$$\beta = g_e\,(-\mu_V - W_V) \qquad (1b)$$

$$g_e = [T/(T + I)]\,g \qquad (1c)$$

where

X = distance from an arbitrary origin (m);
t = time (s);
V = velocity of the car (m/s);
α = sum of all static terms that contribute to the car's acceleration (m/s^2);
β = sum of all velocity-dependent terms that contribute to the car's acceleration (s^{-1});
g_e = effective acceleration of gravity used to account for energy stored in the rotating wheels of the car (m/s^2);
g = acceleration of gravity (m/s^2);
θ = angle of the grade below horizontal;
$\tan\theta$ = grade (downgrades taken positive) (m/m);
μ = static rolling resistance (N/N);
C = curve resistance, if the track section is on a curve (N/N);
W = wind resistance (N/N);
S = velocity head lost in switch, if the track section is a switch (m);
L = length of track section (m);
R = velocity head extracted by retarder (if the track section is a retarder) (m);
μ_V = velocity-dependent resistance coefficient (N/N per m/s);
W_V = velocity-dependent wind resistance coefficient (N/N per m/s);
T = weight of the car (kg); and
I = additional weight of the car to account for the rotation of the wheels (kg).

Obviously, in any given track section, not all the terms will be applicable. For example, a conventional retarder and a switch would never be found in the same track section. The various parameters are assumed to be constant within each track section; whenever any parameters change, a new track section must be specified. This happens, for example, in specifying the beginning and end of a retarder. Specification of a new track section is also required whenever the grade changes. Vertical curves are approximated by a series of track sections of constant grade.

The solutions of the differential equations for $\beta \neq 0$ and taking $V = V_0$ and $X = X_0$ at $t = 0$ are

$$V = (\alpha/\beta) + [(\alpha/\beta) + V_0]\,\exp(\beta t) \qquad (2)$$

and

$$X = X_0 - (\alpha/\beta)\,t - (1/\beta)\,[(\alpha/\beta) + V_0]\,[1 - \exp(\beta t)] \qquad (3)$$

For $\beta = 0$ (i.e., only static rolling resistance), the solutions reduce to the well-known case of uniformly accelerated motion (for the above boundary conditions), as follows:

$$V = V_0 + \alpha t \qquad (4)$$

and

$$X = X_0 + V_0 t + (1/2)\,\alpha t^2 \qquad (5)$$

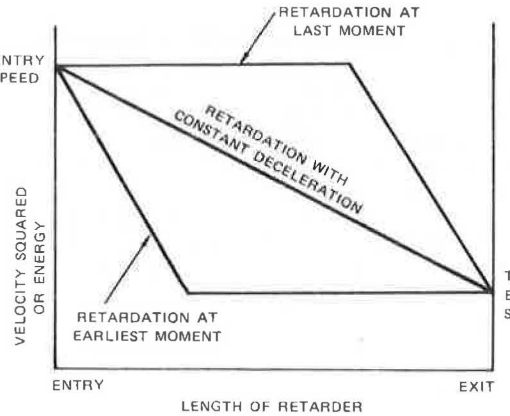
The $\beta = 0$ case is the usual static-rolling-resistance formulation, for which computational techniques based on energy relations are well developed. However, although these energy relations are easily applied to obtain velocity, integrating the velocities over a varying grade to obtain distance-time plots and hence headways between cars can become tedious. Even when a static-rolling-resistance formulation is being used, PROFILE has great utility as a quick means of calculation.

Although wind resistance would usually be handled by a V^2 term, in PROFILE only a V term is used. At the low speeds in a hump yard, the curvature of a V^2 relation should be sufficiently slight that it can be satisfactorily approximated by a linear term.

The retarders treated in the present version of PROFILE are the conventional clasp type, which are usually controlled by a process control computer. Currently, PROFILE does not consider the distributed types of retarders that offer quasicontinuous control through purely mechanical-hydraulic analog logic systems (as offered by certain European vendors). The conventional retarder system is quite complex: The process control computer controls both the overall amount of retardation and the detailed dynamics of car-retarder interactions while the car is within the retarder. Several algorithms are in use to decelerate the car within the retarder. They are all based on achieving a desired exit speed from the retarder. These algorithms can be roughly categorized into three types, as shown in Figure 1 and discussed below:

1. Retardation at the earliest moment—Retardation at the earliest moment is probably the most common algorithm for retarder control (4-6). The retarder closes as soon as the car enters; when the car reaches the exit velocity, either the retarder opens and the car rolls freely for the rest of the length of the retarder or the retarder opens and closes in an attempt to maintain

Figure 1. Retarder deceleration algorithms.



the car at approximately the desired exit speed. This scheme tends to restrict hump throughput because the car travels at minimum average speed for the length of the retarder. It also causes a disproportionate amount of retarder wear to occur near the front.

2. Retardation at the last moment (4)—The algorithm for last-moment retardation is based on a prediction of the rollability of the car and the power of the retarder. The retarder initially remains open when the car enters it. By using the predicted parameters, the retarder is then closed just at the time expected to produce deceleration of the car to the desired exit velocity. This scheme generally permits a high throughput because the car moves at maximum speed throughout the retarder. This algorithm, however, lacks a safety margin for cases in which the car rolls faster than predicted because of errors in predicting rollability, grease on the wheels or rails, or the like. This algorithm also causes a disproportionate amount of retarder wear to occur near the rear of the retarder.

3. Retardation with constant deceleration—Under the constant-deceleration algorithm, the retarder is commanded either to open and close several times (7) or to exert a constant retardation force (5); in either case, the aim is to achieve the desired exit speed with approximately constant deceleration. Some modern commercial retarder systems achieve this ideal at least approximately (8). This scheme maintains better throughput than algorithm 1 and maintains a safety reserve of retarder power that is lacking in algorithm 2. It also causes the retarder to wear approximately uniformly throughout.

In the PROFILE model, the third type of deceleration scheme, constant deceleration, is assumed to apply. Under constant deceleration, energy (i.e., velocity head) is extracted at a uniform rate during the car's transit of the retarder, and the total amount of velocity head extracted within the retarder, when divided by the retarder length, acts simply as an additional resistance term—hence, its appearance in Equation 2.

PROGRAM DESCRIPTION

PROFILE is a time-step simulation written in ANSI standard FORTRAN. Events are assumed to occur either at integral multiples of a predetermined time step Δt or within the time step for certain easily calculated events (such as the entry of a car into a new track section). The time-step method has been selected because of the ease it affords in the calculation of transcendental solutions to differential equations.

The simulation starts by humping the first car at simulation clock time zero. From the length of the cars involved and the hump speed, the hump time for the second car is computed and stored until the simulation clock is equal to that hump time. At the calculated hump time, the second car is humped and put into the system. The hump time for each car is so computed until all cars that the user wishes to put into the system are humped.

Once a car has been humped, movement of cars along the track is accomplished by advancing the simulation clock in increments of Δt. At each time step, the differential Equation 1 is solved for the instantaneous velocities and the distances of cars along the track. Each time a car enters a new track section, the program solves an initial-value problem based on the general solution to the differential equation and the specified configurations of the new track segment. These coefficients are used in subsequent calculations for this car on the track at steps of Δt until the car leaves the track section.

At each time step, the coupler-to-coupler headways between the cars in the system are checked to maintain a safe operating distance between the cars and to avoid mis-switching, catch-up in retarders, and collisions. If headway is insufficient, the program writes a warning message to the output file. If a collision occurs or if a car stalls, the program stops and writes a message to the output file. These messages show the simulation clock time when the catch-up occurred, the distance along the track for each car, and the velocities of the cars at that time. The user can then analyze the output and change retarder placements, the length of the retarder, or any other parameter and start a new computer iteration.

Data on each car are collected at each print interval as specified by the user. For each car, the simulation clock time, instantaneous velocity, velocity head, distance from the hump crest, and distance and time headways from the preceding car are written to and stored in a print buffer. Data in the buffer are written to the output file whenever the simulation stops. If no collision or stall occurs, the simulation stops when the last car has come to the end of the last track section.

Figures 2-4 show sample partial outputs (the program is calibrated in U.S. customary units of measurement).

DESCRIPTION OF INPUT

The first input variables are general: the time step Δt, the hump speed, the data print interval, switches controlling the printing of tables and plots, and the printer width (in characters). To model the occurrence of events accurately, the time step chosen should be sufficiently small but not so small as to cause an inordinate increase in running time (1 s is usually satisfactory). Data output frequency is controlled by the data print interval variable, which should be chosen in integral multiples of the time step but should never be less than the time step.

Next, the following data for the track sections are specified (in U.S. customary units):

1. Length of track section (ft);
2. Grade of track (percent);
3. Rolling resistance, static, easy roller (lbf/ton·f);
4. Rolling resistance, static, hard roller (lbf/ton·f);

5. Rolling resistance, velocity, easy (lbf/ton·f per ft/s);
6. Rolling resistance, velocity, hard (lbf/ton·f per ft/s);
7. If the section is a switch, switch loss, in velocity head (ft);
8. If the section is a retarder, amount of retardation to be given easy-rolling car, in velocity head (ft);
9. If the section is a retarder, amount of retardation to be given hard-rolling car, in velocity head (ft);
10. If the section is a retarder, maximum retardation of the retarder, in velocity head (ft); and
11. Track section alphanumeric identification.

The static and velocity resistances can be specified separately for each track section for the two types of car—easy or hard rolling. Specifying rolling resistances in this manner allows them to vary along the simulated track. If the track segment is a switch or retarder section, additional parameters are required as shown.

Additional data for the cars constitute the final set of information specified to the program. First, the type of car must be specified (easy or hard rolling). Then the car length, in feet; the weight of the car, in tons; and an equivalent rotational weight for the wheels, in tons, must be given. Each car is associated with static (lbf/ton·f) and velocity-dependent (lbf/ton·f per ft/s) wind-resistance terms. These values may vary depending on the type of car (box car, flat car, gondola, etc.).

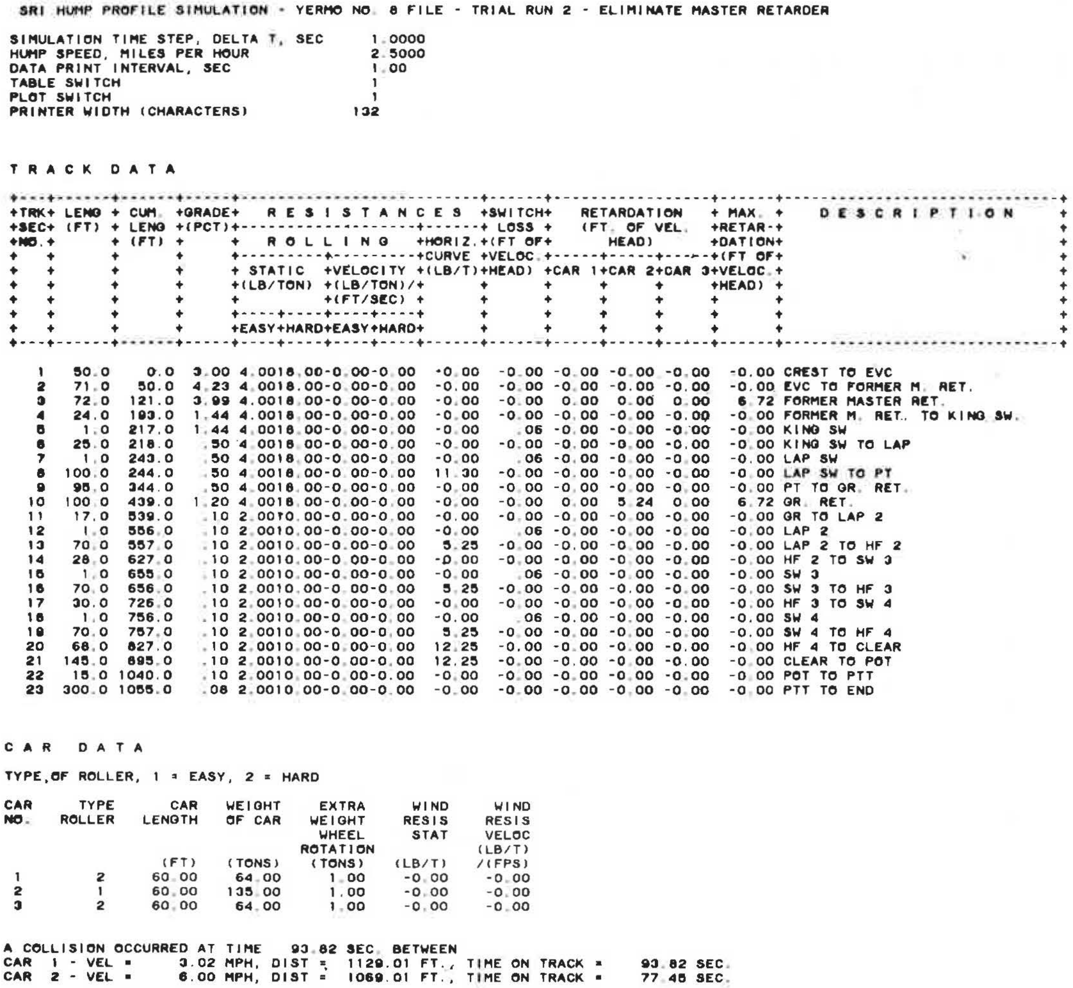
DESCRIPTION OF OUTPUT

The output from PROFILE consists of four parts. The first part is an "echo-back" of the input data (Figure 2), simply a listing of the user's input given for documentation and verification. The second part, which immediately follows the echo-back of car data, lists any special events that might have occurred during the simulation, such as a catch-up of two cars within a retarder, a collision between two cars, or a car stalling. Note that, if no special events occurred, this portion of the output is omitted.

The third part is the numerical output from the simulation proper. This consists of a series of tables, one table for each car. Figure 3 shows an example of a portion of such a table. Each line in a table gives a number of variables that define the status of that particular car at a point in time. The lines are generally printed at uniform increments of simulated time, although whenever a car enters a new track section an additional line is printed. The print increment is specified by the user and is usually on the order of 1 s.

The fourth output section gives optional line printer plots of selected variables. These plots, which include relevant annotation, consist of (a) yard profile versus

Figure 2. Echo-back and collision information for trial run 2 of Yermo Yard.



```
 SRI HUMP PROFILE SIMULATION - YERMO NO. 8 FILE - TRIAL RUN 2 - ELIMINATE MASTER RETARDER

SIMULATION TIME STEP, DELTA T, SEC      1.0000
HUMP SPEED, MILES PER HOUR              2.5000
DATA PRINT INTERVAL, SEC                1.00
TABLE SWITCH                            1
PLOT SWITCH                             1
PRINTER WIDTH (CHARACTERS)            132


T R A C K   D A T A

+---+------+------+-----+--------------------+------+-----------------+-----+----------------------------+
+TRK+ LENG + CUM. +GRADE+  R E S I S T A N C E S +SWITCH+  RETARDATION   + MAX. +    D E S C R I P T I O N   +
+SEC+ (FT) + LENG +(PCT)+--------------+------+ LOSS +  (FT. OF VEL.   +RETAR-+                            +
+NO.+      + (FT) +     +  R O L L I N G +HORIZ.+(FT OF+      HEAD)      +DATION+                            +
+   +      +      +     +---------+---------+CURVE +VELOC.+-----+-----+-----+(FT OF+                            +
+   +      +      +     + STATIC  +VELOCITY +(LB/T)+HEAD) +CAR 1+CAR 2+CAR 3+VELOC.+                            +
+   +      +      +     +(LB/TON) +(LB/TON)/+      +      +     +     +     +HEAD) +                            +
+   +      +      +     +         +(FT/SEC) +      +      +     +     +     +      +                            +
+   +      +      +     +----+----+----+----+      +      +     +     +     +      +                            +
+   +      +      +     +EASY+HARD+EASY+HARD+      +      +     +     +     +      +                            +
+---+------+------+-----+----+----+----+----+------+------+-----+-----+-----+------+----------------------------+

  1    50.0    0.0 3.00 4.0018.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 CREST TO EVC
  2    71.0   50.0 4.23 4.0018.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 EVC TO FORMER M. RET.
  3    72.0  121.0 3.99 4.0018.00-0.00-0.00  -0.00  -0.00  0.00  0.00  0.00   6.72 FORMER MASTER RET.
  4    24.0  193.0 1.44 4.0018.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 FORMER M. RET. TO KING SW.
  5     1.0  217.0 1.44 4.0018.00-0.00-0.00  -0.00    .06 -0.00 -0.00 -0.00  -0.00 KING SW
  6    25.0  218.0  .50 4.0018.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 KING SW TO LAP
  7     1.0  243.0  .50 4.0018.00-0.00-0.00  -0.00    .06 -0.00 -0.00 -0.00  -0.00 LAP SW
  8   100.0  244.0  .50 4.0018.00-0.00-0.00  11.30  -0.00 -0.00 -0.00 -0.00  -0.00 LAP SW TO PT
  9    95.0  344.0  .50 4.0018.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 PT TO GR. RET.
 10   100.0  439.0 1.20 4.0018.00-0.00-0.00  -0.00  -0.00  0.00  5.24  0.00   6.72 GR. RET.
 11    17.0  539.0  .10 2.0010.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 GR TO LAP 2
 12     1.0  556.0  .10 2.0010.00-0.00-0.00  -0.00    .06 -0.00 -0.00 -0.00  -0.00 LAP 2
 13    70.0  557.0  .10 2.0010.00-0.00-0.00   5.25  -0.00 -0.00 -0.00 -0.00  -0.00 LAP 2 TO HF 2
 14    28.0  627.0  .10 2.0010.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 HF 2 TO SW 3
 15     1.0  655.0  .10 2.0010.00-0.00-0.00  -0.00    .06 -0.00 -0.00 -0.00  -0.00 SW 3
 16    70.0  656.0  .10 2.0010.00-0.00-0.00   5.25  -0.00 -0.00 -0.00 -0.00  -0.00 SW 3 TO HF 3
 17    30.0  726.0  .10 2.0010.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 HF 3 TO SW 4
 18     1.0  756.0  .10 2.0010.00-0.00-0.00  -0.00    .06 -0.00 -0.00 -0.00  -0.00 SW 4
 19    70.0  757.0  .10 2.0010.00-0.00-0.00   5.25  -0.00 -0.00 -0.00 -0.00  -0.00 SW 4 TO HF 4
 20    68.0  827.0  .10 2.0010.00-0.00-0.00  12.25  -0.00 -0.00 -0.00 -0.00  -0.00 HF 4 TO CLEAR
 21   145.0  895.0  .10 2.0010.00-0.00-0.00  12.25  -0.00 -0.00 -0.00 -0.00  -0.00 CLEAR TO POT
 22    15.0 1040.0  .10 2.0010.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 POT TO PTT
 23   300.0 1055.0  .08 2.0010.00-0.00-0.00  -0.00  -0.00 -0.00 -0.00 -0.00  -0.00 PTT TO END


C A R   D A T A

TYPE,OF ROLLER, 1 = EASY, 2 = HARD

CAR     TYPE      CAR    WEIGHT     EXTRA      WIND      WIND
NO.    ROLLER   LENGTH   OF CAR    WEIGHT     RESIS     RESIS
                                    WHEEL      STAT     VELOC
                                  ROTATION             (LB/T)
                  (FT)   (TONS)    (TONS)    (LB/T)   /(FPS)
 1         2     60.00    64.00      1.00     -0.00     -0.00
 2         1     60.00   135.00      1.00     -0.00     -0.00
 3         2     60.00    64.00      1.00     -0.00     -0.00

A COLLISION OCCURRED AT TIME   93.82 SEC. BETWEEN
CAR  1 - VEL =      3.02 MPH, DIST =  1129.01 FT., TIME ON TRACK =     93.82 SEC.
CAR  2 - VEL =      6.00 MPH, DIST =  1069.01 FT., TIME ON TRACK =     77.46 SEC.
```

Figure 3. Example of car history table: partial output of car 2 (easy roller) for trial run 2 of Yermo Yard.

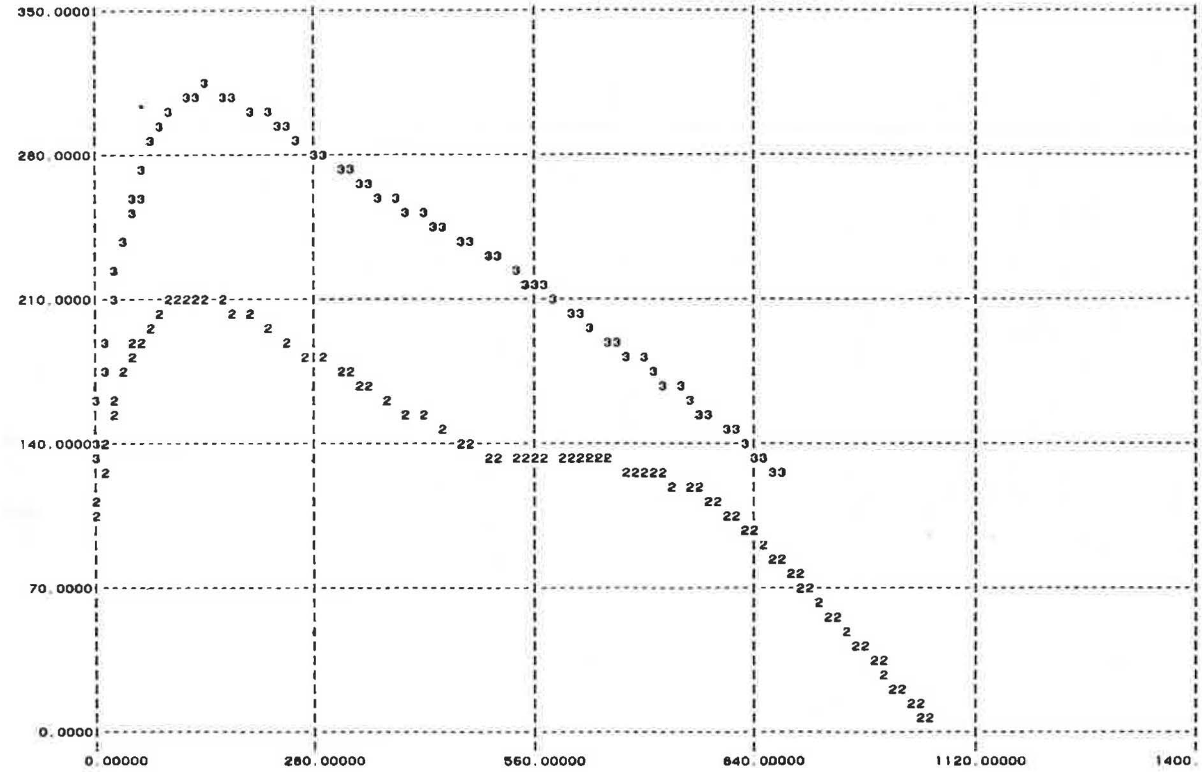
```
CAR NO.   2

                                      DISTANCE      TIME
                          DISTANCE    HEADWAY      HEADWAY     INSTAN-     INSTAN-
CAR TRAVEL     SYSTEM      ALONG      BETWEEN      BETWEEN     TANEOUS     TANEOUS     VELOCITY    TRACK
   TIME         TIME       TRACK      PREC CAR     PREC CAR    VELOCITY    VELOCITY     HEAD       SECTION
  (SEC)        (SEC)       (FT)        (FT)         (SEC)     (FT/SEC)     (MPH)        (FT)       NUMBER     TRACK SECTION DESCRIPTION

    0.000      16.364       0.000     102.770       7.382       3.667       2.500        .210      0/ 1      ****TRACK SECTION BOUNDARY****
     .636      17.000       2.515     111.691       7.772       4.236       2.888        .281      1         CREST TO EVC
    1.636      18.000       7.198     125.778       8.328       5.131       3.499        .412      1         CREST TO EVC
    2.636      19.000      12.777     139.547       8.823       6.026       4.109        .568      1         CREST TO EVC
    3.636      20.000      19.250     152.447       9.266       6.921       4.719        .749      1         CREST TO EVC
    4.636      21.000      26.619     164.261       9.663       7.816       5.329        .956      1         CREST TO EVC
    5.636      22.000      34.883     174.850      10.022       8.711       5.939       1.187      1         CREST TO EVC
    6.636      23.000      44.041     184.238      10.347       9.606       6.550       1.443      1         CREST TO EVC
    7.240      23.603      50.000     189.322      10.530      10.146       6.918       1.610      1/ 2      ****TRACK SECTION BOUNDARY****
    7.636      24.000      54.126     192.394      10.642      10.657       7.266       1.777      2         EVC TO FORMER M. RET.
    8.636      25.000      65.427     199.028      10.892      11.945       8.145       2.232      2         EVC TO FORMER M. RET.
    9.636      26.000      78.016     204.087      11.097      13.234       9.023       2.740      2         EVC TO FORMER M. RET.
   10.636      27.000      91.894     207.583      11.263      14.522       9.901       3.299      2         EVC TO FORMER M. RET.
   11.636      28.000     107.060     209.683      11.395      15.810      10.779       3.910      2         EVC TO FORMER M. RET.
   12.469      28.852     121.000     210.356      11.484      16.908      11.528       4.472      2/ 3      ****TRACK SECTION BOUNDARY****
   12.636      29.000     123.513     210.369      11.498      17.087      11.651       4.567      3         FORMER MASTER RET.
   13.636      30.000     141.206     209.688      11.574      18.299      12.477       5.238      3         FORMER MASTER RET.
   14.636      31.000     160.111     207.669      11.599      19.510      13.302       5.955      3         FORMER MASTER RET.
   15.636      32.000     180.227     204.324      11.557      20.722      14.128       6.717      3         FORMER MASTER RET.
   16.242      32.606     193.000     201.725      11.494      21.456      14.629       7.201      3/ 4      ****TRACK SECTION BOUNDARY****
   16.636      33.000     201.491     199.877      11.439      21.612      14.735       7.306      4         FORMER M. RET. TO KING SW.
   17.349      33.713     217.000     196.445      11.323      21.895      14.928       7.499      4/ 5      ****TRACK SECTION BOUNDARY****
   17.395      33.759     218.000     196.189      11.315      21.825      14.881       7.451      5/ 6      ****TRACK SECTION BOUNDARY****
   17.636      34.000     223.269     195.010      11.272      21.848      14.896       7.467      6         KING SW TO LAP
   18.538      34.901     243.000     190.603      11.096      21.935      14.955       7.526      6/ 7      ****TRACK SECTION BOUNDARY****
   18.583      34.947     244.000     190.381      11.086      21.851      14.899       7.469      7/ 8      ****TRACK SECTION BOUNDARY****
   18.636      35.000     245.158     190.127      11.075      21.847      14.896       7.466      8         LAP SW TO PT
   19.636      36.000     266.962     185.424      10.859      21.762      14.838       7.408      8         LAP SW TO PT
   20.636      37.000     288.682     180.901      10.622      21.677      14.780       7.351      8         LAP SW TO PT
   21.636      38.000     310.317     176.535      10.373      21.593      14.722       7.293      8         LAP SW TO PT
   22.636      39.000     331.858     172.104      10.118      21.508      14.665       7.236      8         LAP SW TO PT
   23.201      39.565     344.000     169.520       9.971      21.460      14.632       7.204      8/ 9      ****TRACK SECTION BOUNDARY****
   23.636      40.000     353.351     167.483       9.855      21.502      14.660       7.232      9         PT TO GR. RET.
   24.636      41.000     374.900     162.586       9.576      21.598      14.726       7.297      9         PT TO GR. RET.
   25.636      42.000     396.546     157.381       9.286      21.694      14.791       7.362      9         PT TO GR. RET.
   26.636      43.000     418.288     151.873       8.999      21.790      14.857       7.427      9         PT TO GR. RET.
   27.585      43.949     439.000     146.418       8.731      21.881      14.919       7.489      9/10      ****TRACK SECTION BOUNDARY****
   27.636      44.000     440.124     146.116       8.717      21.811      14.871       7.442     10         GR. RET.
   28.636      45.000     461.257     140.879       8.484      20.456      13.947       6.546     10         GR. RET.
   29.636      46.000     481.035     136.734       8.337      19.100      13.023       5.707     10         GR. RET.
   30.636      47.000     499.458     133.733       8.266      17.745      12.099       4.926     10         GR. RET.
   31.636      48.000     516.525     131.878       8.257      16.390      11.175       4.202     10         GR. RET.
   32.636      49.000     532.237     131.168       8.317      15.035      10.251       3.536     10         GR. RET.
   33.096      49.459     539.000     131.229       8.368      14.412       9.827       3.249     10/11      ****TRACK SECTION BOUNDARY****
   33.636      50.000     546.793     131.433       8.435      14.412       9.827       3.249     11         GR TO LAP 2
   34.275      50.639     556.000     131.627       8.512      14.412       9.827       3.249     11/12      ****TRACK SECTION BOUNDARY****
   34.345      50.709     557.000     131.649       8.520      14.279       9.736       3.189     12/13      ****TRACK SECTION BOUNDARY****
   34.636      51.000     561.158     131.760       8.556      14.256       9.719       3.179     13         LAP 2 TO HF 2
```

Figure 4. Distance headway versus distance for trial run 2 of Yermo Yard.

PLOT OF HEADWAY IN FEET (DOWN) VS. DISTANCE IN FEET (ACROSS)



```
PLOT LEGEND -
 HEADWAY    PLOTTED
 BT. CARS     NO.

 1 AND 2      2
 2 AND 3      3
```

distance, (b) speeds of all cars versus distance, and (c) distance headways between all cars versus distance (Figure 4).

APPLICATION OF THE MODEL

The sample application problem described in this section is based on a modified specification for the Union Pacific Railroad's Yermo Yard in southern California. The hump profile design requires several levels of decision making on cost- and performance-related matters. The considerations on cost and performance would be reflected in the retarder types to be used, hump-crest height, humping speed, impact speed, and number of mis-switched cars. After having determined the type of retarder and retarder configuration to be adopted, the designer must iteratively examine both the horizontal and vertical design to arrive at a final design that satisfies the specified goal.

The application problem discussed here is only one stage of the process of hump profile design in which a given profile design is evaluated and modified to a better design through iterations of PROFILE runs.

The design, as used in trial run 1 (not shown in the figures) in this example, has a master retarder of 28.3 m (93 ft) and three group retarders of 30.5 m (100 ft). Each group retarder leads to 10 classification tracks. The distance between the hump crest and the tangent point of the outermost track is 323.4 m (1061 ft).

The runs for this design were based on the simulation of a conventional hard/easy/hard-rolling triplet of cars. A worst-case condition was assumed: Since the easy-rolling car is going to a nearly full-class track, it must be retarded to a low target speed by the tangent point [9.6 km/h (6 miles/h)]; meanwhile, since the hard-rolling car must penetrate as far as possible an adjacent empty-class track, its retardation is minimal.

The objective of the study was to test the feasibility of the design by examining the following design requirements:

1. The hump speed is at least 4.0 km/h (2.5 miles/h), 3.67 cars/min.
2. The hard roller must not stall before the tangent point.
3. The maximum speed of the easy roller at the tangent point is 9.6 km/h (6 miles/h).
4. The maximum speed of a car in the switch segments is 24 km/h (15 miles/h).
5. The coupler-to-coupler headway is at least 15.2 m (50 ft) at each switch.
6. There is never more than one car in the same retarder at any time.
7. No catch-ups should occur before the clearance point of each track.

The major assumptions used in the design process were the following:

1. Only static rolling resistances apply.
2. The hard roller has a rolling resistance of 9 N/kN (18 lbf/ton·f) between the hump crest and the exit from the group retarders and 9 N/kN (10 lbf/ton·f) thereafter.
3. The easy roller has a rolling resistance of 2 N/kN (4 lbf/ton·f) between the hump crest and the exit from the group retarder and 1 N/kN (2 lbf/ton·f) thereafter.
4. The velocity head loss attributable to each switch is 0.018 m (0.06 ft) when the car travels along the curved track and is assumed to be zero if a car travels on the straight track. This value is constant for all turnout numbers.
5. The velocity head loss attributable to a curved section of track is 0.012 m (0.04 ft) per degree of deflection angle.
6. The average car length is 18.3 m (60 ft).
7. The average car weight is 58 Mg (64 tons) for the hard roller and 122 Mg (135 tons) for the easy roller.
8. The extra weight of the car attributable to wheel rotation is 0.91 Mg (1 ton).
9. The wind resistance is zero.

A general interactive and iterative design procedure was used here to select an example design. The steps in this procedure are the following:

1. Select the configuration and type of retarder and the method of retardation.
2. Determine the car-speed constraints at the tangent point and at other points along the track.
3. Design a trial horizontal layout.
4. Determine the hump height from steps 2 and 3.
5. Select the trial grades along the track.
6. Run PROFILE.
7. Examine the output. If the result is satisfactory, go to step 8. If the result shows speed violations, go back to step 3. If the result contains catch-up problems, go first to step 5. If the catch-up problem cannot be solved by changing grades, go to step 3.
8. Determine whether any segment, especially the retarder segment, is excessively long; if so, go to step 3. Otherwise, the design is complete.

It should be noted that other procedures not shown here have been developed to enable the PROFILE user to select a hump speed and a retarder control policy.

The example discussed here illustrates one step of the interactive and iterative design procedure presented above. The objective in trial run 2, the partial output of which is shown in Figures 2-4, was to try to eliminate the master retarder. This change necessitated shortening the distance between the hump crest and the first switch by 6.4 m (21 ft), which shortened the distance to the tangent point to 317.0 m (1040 ft). A comparison between the collision-related output for trial run 1 (not shown) and the same information for trial run 2 (Figure 2) revealed that the collision point decreased from 398.1 to 334.0 m (1306-1099 ft) from the hump crest. Since the latter value is still well past the clearance point (in fact, past the tangent point), the design of trial run 2 satisfies the design requirements. Examination of other performance measures output by the model, as shown partially in Figures 2-4, reveals that all other design requirements are also met by the design of trial run 2. Under the assumptions used in this example, the design changes effected between trial runs 1 and 2 demonstrate a considerable cost reduction and point up the advantage of having the PROFILE model available to try such "what if" experiments.

Figure 3 shows a part of the output for car 2 (the easy roller). All of the necessary data related to the movements of car 2 are included in this table.

From the plot of speeds of the cars as a function of distance (not shown) or data such as those in Figure 3, it has been determined that the easy roller in trial run 2 attains a maximum speed of slightly less than 24 km/h (15 miles/h). This satisfies the maximum-speed constraint in the switching area. It can also be verified that the easy roller satisfies the 9.6-km/h (6-mile/h) speed constraint at the tangent point and that the unretarded hard roller satisfies both speed constraints.

Figure 4 shows a plot of distance headway between successive cars. The number 2 indicates the headway between cars 1 and 2, and 3 indicates the headway between cars 2 and 3. Figures 3 and 4 show that sufficient headway exists between cars to detect individual cars and to throw the switch in all switch segments.

FURTHER WORK AND CONCLUSIONS

Further work is in progress to enhance the interactive capability of the PROFILE program. Specifically, simplifying the user input procedures and increasing the amount of graphical output are being considered. In addition, more work is required to characterize and quantify the nature of car rollability. Freight-car rolling behavior, which is essentially an input to PROFILE, is a critical determinant of the final profile design.

This paper has shown that PROFILE can be used to eliminate the tedious manual process of evaluating hump profile designs by using scale drawings. In addition, PROFILE gives a precise prediction of catch-up problems between cars. The program allows the yard designer to evaluate many more design alternatives than it was previously possible to evaluate, thus ensuring production of the most cost-effective design.

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Conflicts Between Urban Areas and Railroads: A Status Report

Richard G. McGinnis

The development of conflicts between urban areas and railroads in the United States is examined, and the nature and magnitude of the current problems and present and past efforts to resolve them are described. Many American cities developed primarily as a result of the railroads, but changes in urban activities and transportation operations have altered somewhat the relation between the cities and railroads. Continuing expansion of urbanized areas and increases in vehicle travel have intensified the conflict. Cities have reacted by pushing for elimination of railroad-highway grade crossings and, in some cases, for consolidation, relocation, and/or removal of railroad tracks from the center city. Many city planners see the railroads as a hindrance to rejuvenation efforts. In some cities, underutilized railroad properties are in strategic locations that could be important in urban redevelopment plans. High-volume rail lines that pass through congested downtown areas can cause massive traffic jams and delays unless crossings are grade separated. Railroad-highway grade crossings pose safety problems to the motorist and restrict mobility, which is particularly important for emergency vehicles. In addition, the slow train speeds mandated by local municipalities, frequent grade crossings, and large numbers of trespassers are not compatible with efficient railroad operation. But new rail routes are difficult to locate and expensive to build, and there are many implementation problems involved in other, less expensive solutions, such as consolidation or abandonment.

Conflicts between U.S. railroads and urban communities have existed, to varying degrees, ever since railroad operations began in 1830. Initially, most of the concerns about urban railroads had to do with safety. Safety problems included dangers associated with grade crossings, runaway trains, and derailments. However, since train speeds through towns were relatively slow and vehicle traffic crossing tracks was of low volume, the safety of rail operations in urban areas