Steve

William A. Stock
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PRELIMINARY THOUGHTS ON SIMULATING THE DOWTY SYSTEM USING PROFILE

Introduction

This note describes our preliminary thoughts on modifying the SRI developed hump yard profile simulation, PROFILE,[*] to simulate the Dowty retarder system. This simulation model has the capacity of simulating the roll of individual cars from the hump into the classification track, including the operation of the conventional retarder system.[**] This model is described in Appendix I.

Description of The Dowty System

The Dowty retarder was developed by Dowty Hydraulic Units Ltd. of England. The retarder is actually a series of hydraulic cylinders bolted to the rail. These cylinders may be spread out over most of the course along which the car rolls. The wheel flange depresses a movable piston in each cylinder. If the car speed is below a preset critical speed, the piston moves downward with virtually no resistance. If the car speed is above this critical speed, an internal valve is closed and oil is forced to flow through a small orifice creating resistance to motion (shock absorber principle). The units are available in a variety of critical speeds preset in manufacturing. Very importantly, a modified design can act as a booster retarder. Again, the boost is occasioned by the car being below the preset critical speed. An air compressor system is required to supply the boost.

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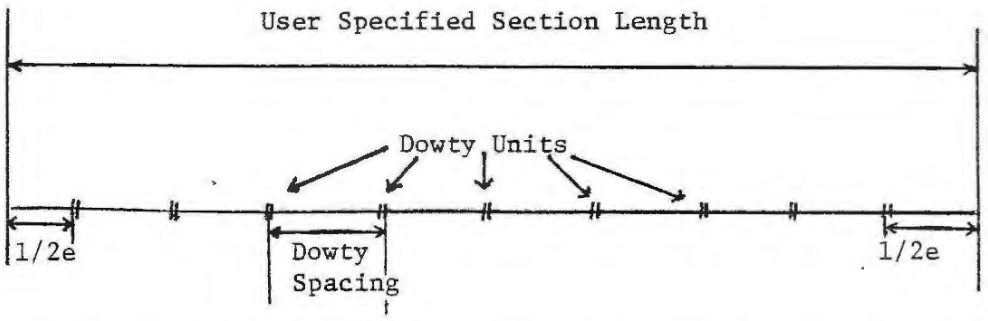
[*] P.J. Wong, C.V. Elliott, R.L. Kiang, M. Sakasita, and W.A. Stock, Railroad Classification Yard Technology - Design Methodology Study, Phase 1 Interim Report, Sept. 1978.

[**] Speed control logics controlling the amount of retardation are not currently included in PROFILE. The user simply inputs the amount of retardation, in feet of head, to be taken out of each car.

Simulation Methodology

The Dowty cylinder will be simulated in a manner analogous to the way switches are already simulated in PROFILE--A short section of track over which a velocity head loss is spread. In the case of the Dowty system, each cylinder will be simulated by a short section of about three inches; a velocity head loss or gain (as applicable) will be given each simulated car as indicated.

This approach will necessitate many (perhaps 1,000) track sections. It is proposed to have the program automatically create the Dowty sections by building them from the thirty or so user-input sections. The user will specify the density or spacing of Dowty units for each user-input track section. The Dowty units will then be placed symmetrically within the user-specified subsection (in real life the spacing of Dowty units will be somewhat irregular). Since the total user-specified section length will not usually be an integer multiple of the Dowty cylinder spacing for that section, any closure error e will be assigned symmetrically 1/2e to the beginning and 1/2e to the end of the user-specified section (see figure 1).



Closure error of e is symmetrically distributed to the two ends of each user-specified suction.

Figure 1 - Assumed Location of Dowty Units Within the User-Specified Section

The actual operation of each Dowty cylinder can be described in simplified terms using the concept of a control speed V_c. Any car hitting a Dowty unit with speed $V \geq V_c$ will receive retardation; any car hitting a Dowty unit with speed $V < V_c$ will either be unaffected (regular unit) or will receive a boost (booster unit).

These concepts are illustrated in Figure 2 which shows retardation as a function of speed for two models. Figure 2a illustrates the simple model described above, and assumes that the amount of boost/retardation, given that they occur, are independent of speed. Figure 2b shows a more complex model in which the boost/retardation received is a function of speed <u>within</u> the boost/retard speed ranges. Also shown in this figure is a slight, residual resistance in the non-retarding speed range of the non-booster retarder, where cars are supposedly unaffected by the unit. Finally, Figure 2b shows that the value and action of the retarder at speed V_c may be only approximate, or the value of V_c itself may be subject to random error. It remains to be determined which level of complexity, as represented in Figure 2, will be modelled in PROFILE.

According to Dowty literature,* the amount of boost/retardation energy added/subtracted is independent of the car's weight. Hence, the head added/subtracted will be inversely proportional to the car's weight. Table 1* gives typical specifications for the parameters of the Dowty system.

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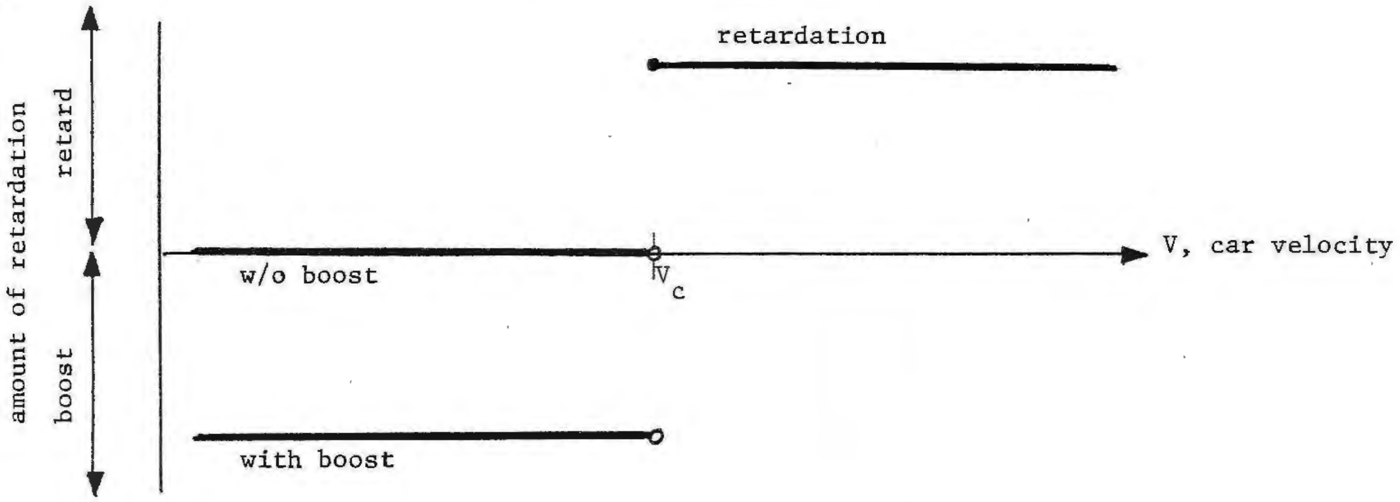
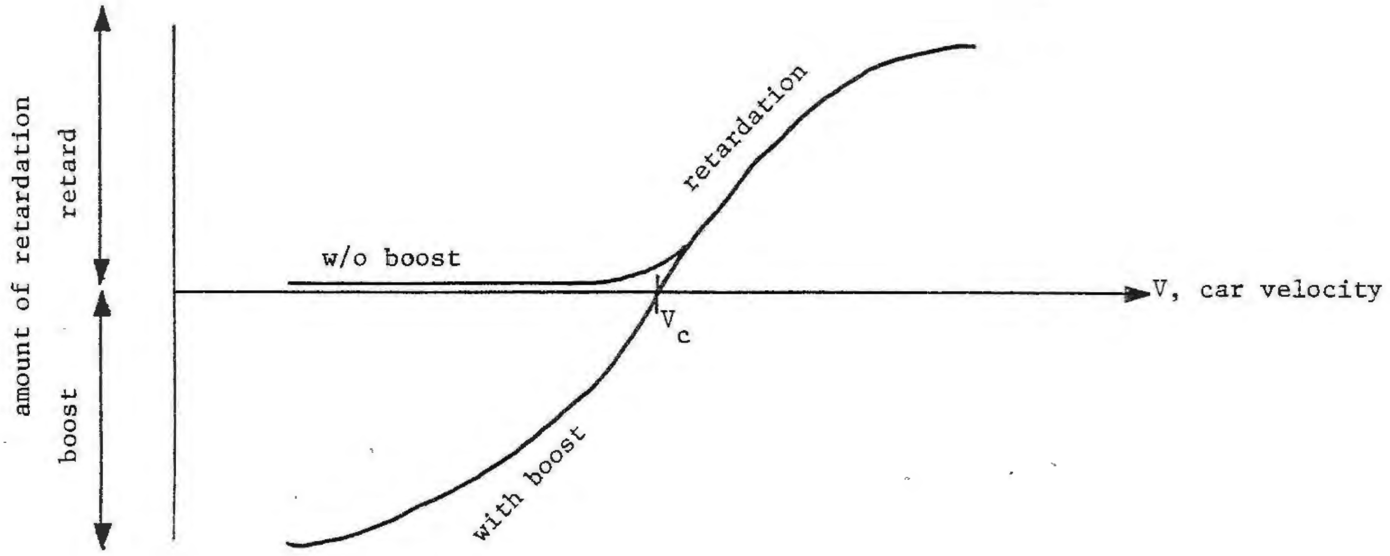
*Dowty Hydraulic Units Ltd, "High Duty Hydraulic Retarders", promotional pamphlet DHU/268/2/1000/TY, Sept. 1977, and
Dowty Hydraulic Units Ltd., "High Duty Oleo Retarder with Temperature Sensitive Capsule 300730-01-26 to 300730-21-29 -- Maintenance Instructions" DHUR 1/1 undated.



(a) Simple Model



(b) More Complex Model

Figure 2 - Two Alternate Models of the Effect of a Dowty Cylinder on a Moving Car

TABLE I

TYPICAL DOWTY SYSTEM PARAMETER VALUES

	Non Booster Retarder Cylinder	Booster Retarder Cylinder
Range of control speeds, V_c, available	0 to 11.2 mph	0 to 7.8 mph
Typical retarding energy* for $V \geq V_c$	.28 ft.tons**	.28 ft.tons
Typical residual retardation (non-boost retarder) or boost* (booster retarder)	.012 ft.ton*** (residual)	.43 ft.tons (boost)

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* For car velocity 3.4 mph.

** Not given in literature - value given for booster retarder assumed.

*** Computed from maximum stroke of 3.25 in. x non-retarding depression force of 85 lb. (actual force range 70 to 100 lb.).

APPENDIX I

PROFILE A HUMP YARD PROFILE SIMULATION PROGRAM

Introduction

This appendix describes the SRI-developed PROFILE[*] simulation model developed for a companion project dealing with railroad yard design.[**] This appendix has been excerpted from a syllabus written for the other project. This syllabus was prepared for a yard design workshop held at Conrail on October 30, 1978.

PROFILE is a computer simulation program designed to aid in selecting the proper hump yard profile for a freight classification yard. The program is to serve as a tool not only for new hump yard designs but also for improving and modernizing existing classification yards. It is to aid the designer in determining the placement and length of of retarder sections in the hump and switching areas. With it the designer can test car performance on various gradient designs. For instance, he can design the yard profile so that:

- Cars with a maximum rolling resistance travel beyond the clearance point under adverse weather conditions.
- Cars with average rolling resistnace travel to the far end of the yard.
- Maximum humping speed is obtained.
- Acceptable coupling speeds are obtained.
- Car catch-ups are avoided.

PROFILE is a time-step simulation in FORTRAN. It can be run in either a batch or time-sharing environment.

The remainder of the appendix is devoted to an overview of the PROFILE simulation model. First a discussion of the mathematical formulation of the model is given. Next, its implementation as a computer program is described. Finally, the inputs and outputs of the model are described.

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[*] "PROFILE" is sometimes also referred to as "PROFYL."

[**] Railroad Classification Yard Technology--Design Methodology Study.

Mathematical Formulation

Two basic equations of physics are used to simulate hump throughput and switching operations aided by retarders. They are the equation of gravity motion of an object and equation of conservation of energy. These equations are used to describe the motion of cars along normal track sections and retarder sections respectively.

The equation of gravity motion contains two friction terms: static friction and viscous friction. In particular, the equation of motion of a freight car rolling down a grade of angle σ is assumed to be

$$\overset{\circ}{V} = \sin \sigma g - \mu g - KgV \tag{1}$$

For very small σ this equation can be written

$$\overset{\circ}{V} = \tan\sigma g - \mu g - KgV \tag{2}$$

where $\overset{\circ}{V}$ = car acceleration (ft/s^2)

$\tan \sigma$ = grade

μ = coefficient of static friction (dimensionless)

K = coefficient of viscous friction (ft/s)$^{-1}$

V = car velocity (ft/s)

$g = 32.2$ ft/s^2

The model uses this equation to simulate the gravity motion of a freight car along any part of track that is not a retarder section.

Retarder sections follow the law of conservation of energy. We assume the following equation:

$$mgH = 1/2mV_2^{\,2} - 1/2mV_1^{\,2} \tag{3}$$

or

$$H = \frac{V_2^{\,2} - V_1^{\,2}}{2g} \tag{4}$$

or

$$V_2^{\,2} = V_1^{\,2} + 2gH \tag{5}$$

If h is the velocity head extracted per foot of working length of the retarder and L the length of the retarder, we define

$$V_{in} = \text{entry velocity of car, and} \tag{6}$$

$$H = hL \tag{7}$$

Then, we have that the minimum achievable exit velocity (i.e., the maximum velocity head which may be removed):

$$V^2_{out\ min} = V_{in}^{\,2} + 2ghL \tag{8}$$

Program Description

PROFYL is a time-step simulation. This means that events are assumed to take place at integral multiples of a predetermined time step, Δt. The time-step method has been selected because of the ease afforded in solving transcendental and other solutions to differential equations.

The program first will read operational constants such as the hump speed and the car separation minimum. This is followed by reading the data of the track configurations.

The simulation starts with humping the first car at simulation time zero. From the length of the humped car and the hump speed, the hump time for the next car is computed and stored until the simulation clock is equal to that hump time or greater. At this time a new car gets humped and put into the system. Again the hump time for the next car is computed and so on 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 linear differential equation (2) is solved for the instantaneous velocities and the distances of cars along the track. To simulate rolling resistance more accurately, several terms have been added to equation (2) to make it look as follows in the simulation program:

$$\overset{\circ}{V} = \left[\frac{W}{W + I}\right]\left[Gg - R_s g - R_{ws} g - R_c g - R_{ss} g - (R_v g + R_{wv} g)V\right] \qquad (9)$$

where

$\overset{\circ}{V}$ = Acceleration of car (ft/s^2)

G = Grade ($G = \tan\sigma$, $\tan\sigma \doteq \sin\sigma$ for small values of σ)

W = Weight of car (tons)

I = Enhanced weight to allow for the rotational energy of the wheels (tons)

V = Velocity of car (ft/s)

R_c = Planar curve resistance

R_s = Static resistance

R_{ss} = Static switch resistance

R_v = Velocity resistance (ft/s)$^{-1}$

R_{ws} = Static wind resistance

R_{wv} = Velocity wind resistance (ft/s)$^{-1}$

In addition, each time a car enters a new track segment, the program solves an initial-value problem based on the general solution to the differential equation and the specific configurations of the new track segment. These coefficients will be used in subsequent calculations of this particular car on this track at steps of Δt until the car enters a new track.

Cars that enter retarder sections follow different rules. First, the amount of retardation to be given the car is specified as a user input. We assume that the deceleration is linear in V^2. This way we can write the equation for V in the following form:

$$V^2 = b + mx \tag{10}$$

or

$$V = \sqrt{b + mx} \tag{11}$$

Integrating (11) with respect to t and computing values for b and m, it can be shown that the car moves under a law of uniformly accelerated motion within the retarder. Thus, we can find the distance of the car along the retarder section at any increment of time, Δt.

At each time step, the distances between the cars in the system are checked. This is done to maintain a safe operating distance between them and to avoid misswitching or catch-ups. If a catch-up occurs, the program will stop and write a message to this effect to the output file. The message will show the simulation clock time at which the catch-up occurred, the distance along the track for each car and their velocities at this time. The user may then analyze the output and make changes to retarder placements, length of the retarder or any other parameter and start a new computer iteration.

Data on each car are collected at each print interval determined by the data print variable. For each car the instantaneous velocity, the distance along the total track and the separation distance from the preceding car in addition to the simulation clock time are written to and stored in a print buffer. Data in the buffer will be written to the output file whenever the simulation comes to a stop. The simulation comes to a stop if a catch-up occurs or when the first car has come to the end of the last track segment.

Description of Input

A complete list of input variables and their formats is given in Table 1. On card type 1, the time step (Δt), the hump speed, the minimum car separation and the data print interval must be given. To model event occurrences accurately, the time step should be chosen sufficiently small but not too small as to cause an inordinate increase in running time. The car separation minumum should not be less than one car length. Data output is controlled by the data-print-interval variable. This variable should be chosen in integral multiples of the time step but never less than the time step.

Card type 2 contains data for track sections. The entire profile is input to the model as a series of track sections. All parameters are assumed to be constant within a given track section. The static and velocity resistances depend on the type of car, easy roller or hard roller. These resistances are entered on card type 2 in their appropriate data fields. Length of track and percent of grade are also entered on this card. If the track segment is a retarder section, additional parameters are required.

PROFYL INPUT

CARD TYPE 1: GENERAL INPUT PARAMETERS

TIME STEP, DELTA T, SEC.
HUMP SPEED, FEET PER SECOND
DATA PRINT INTERVAL (IN SEC)
TABLE SWITCH
PLOT SWITCH
PRINTER WIDTH (CHARACTERS)

CARD TYPE 2: TRACK SECTION DESCRIPTIONS

LENGTH OF TRACK SECTION, FT.
GRADE OF TRACK, PERCENT
ROLLING RESISTANCE, STATIC, EASY (LB/TON)
ROLLING RESISTANCE, STATIC, HARD (LB/TON)
ROLLING RESISTANCE, VELOCITY, EASY (LB/TON)/(FT/SEC)
HORIZONTAL CURVE RESISTANCE (LB/TON)
SWITCH RESISTANCE, STATIC (LB/TON)
AMOUNT OF RETARDATION TO BE GIVEN FIRST CAR (FEET OF HEAD)
AMOUNT OF RETARDATION TO BE GIVEN SECOND CAR (FEED OF HEAD)
AMOUNT OF RETARDATION TO BE GIVEN THIRD CAR (FEET OF HEAD)
MAXIMUM CAPABILITY OF THE RETARDER (FEET OF HEAD)
TRACK SECTION ALPHA NUMERIC IDENTIFICATION

CARD TYPE 3: CAR DESCRIPTIONS

TYPE OF ROLLER, 1 = EASY, 2 = HARD
CAR LENGTH, FT.
WEIGHT OF CAR (TONS)
EQUIVALENT ROTATIONAL WEIGHT OF ALL THE WHEELS (TONS)
WIND RESISTANCE, STATIC (LB/TON)
WIND RESISTANCE, VELOCITY (LB/TON)/(FT/SEC)

TABLE 1

They are the retardation in feet of head to be given each car and the retardation factor. The retardation factor is the extracted velocity head of equation (7) and is measured per foot of working length of the retarder. A set of two cards is required for each track segment. The set of all track cards must be followed by two blank cards. The program allows for a maximum of fifty segments.

Data for cars are entered on card type 3. First, the type of car must be specified: 1 = easy-rolling car, 2 = hard-rolling car. Then the car length, the weight of the car and an equivalent rotational weight for the wheels must be given. Each car is associated with wind resistance terms. They are the static and the velocity wind resistances. These values may vary depending on the type of car (box car, flat car, gondola, etc.). One card must be supplied for each car.

Description of Output

The output from PROFYL consists of three parts. First, an "echo-back" of the input data is given. This is simply a listing of the user's input given for documentation and verification.

Next, the numerical output from the simulation proper is given. This consists of a series of tables, one table for each car. Each line in a table gives a number of variables defining the status of that particular car at a point in time. The lines are printed at uniform increments of simulated time. The print increment is given by the user and is usually on the order of one second. Each line contains:

- The time in seconds relative to the time the first car went over the hump .
- The time in seconds relative to the time the car in question went over the hump.
- The distance in feet of the car along the track relative to the hump crest.
- Headways, both in distance and time, between the car in question and the preceeding car.
- The instantaneous velocity of the car, both in miles per hour and in feet per second.
- The instantaneous velocity head of the car in feet.
- The section number and user description of the track section the car is currently in.

The third and last output section gives optional line printer plots of selected variables. These plots, which include relevant annotation, consist of:

- A plot of the yard profile versus distance.
- A plot of speeds of all cars versus distance.
- A plot of distance headways between all cars versus distance.

Distribution

7663 Project team and file