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PRELIMINARY THOUGHTS ON SIMULATING THE OPERATIONAL LOGIC OF A CONVENTIONAL RETARDER SYSTEM USING PROFILE

Introduction

This note discusses our preliminary thoughts on incorporating the logic to represent a conventional retarder system into PROFILE. PROFILE is the SRI-developed hump yard profile simulation model and was described in the Appendix to Informal Note #4. Currently, PROFILE does not simulate the logic by which the retarder system determines how much energy should be taken out of each car; the amount of retardation being simply a user input. This note addresses a proposed logic which is felt to be representative of modern state of the art retarder control logics. It should be emphasized that only that part of the logic which is external to the retarder's internal operation is considered here; i.e., the detailed process by which energy is extracted while the car is within the retarder* is not treated in this note. Possible future retarder logics, which, for example, attempt to control for headway in a more direct manner, are also not considered in this note. These will be the subject of future work.

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*Currently, PROFILE assumes that the energy of the car changes linearly with distance within the retarder.

Distribution

7663 Project team and file

Basic Equation

For the purposes of the following discussion, it will be assumed that the rolling resistance of each car is static, i.e., independent of speed. Further, it will be assumed that the rolling resistance of each car, if it varies with distance, varies in the manner of a step function, so that with properly choosen track section boundaries, the rolling resistance will be constant within each track section. Finally, it will be assumed that the gradient in each track section is constant, so that vertical curves can be approximated as a series of short sections of constant grade. All of these assumptions are consistent with PROFILE. Under these assumptions, the following equation can be written between the speeds at any two points, A upstream and B downstream.*

$$V_B^2 = V_A^2 + 2g \sum_{\substack{i \text{ between} \\ A \text{ and } B}} L_i \, (G_i - R_i) \qquad (1)$$

where:

V_B = Speed at downstream point B

V_A = Speed at upstream point A

g = Acceleration of gravity

L_i = Length of track section i

G_i = Grade of track section i

R_i = Resistance of car in track section i

This equation is the basis for the following discussion of retarder logic.

Magic X Retarder Logic

The "Magic X" retarder logic of WABCO will be described here.

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*For convenience, it will be assumed that both A and B are located on track section boundaries. Since artifical track section boundaries can be created to accomplish this, the assumption causes no loss of generality.

This logic is applicable to all but the furthest retarder from the hump; an alternate logic for this last retarder will be described in the next section. The "Magic X" logic to be propounded here is a modification to that "Magic X" logic described in Informal Note #1. It will be assumed that an off-line analysis has established, for the given profile design, satisfactory* retardation values to use in each applicable retarder for each of two cars: A design easy roller and a design hard roller.** From the PROFILE simulation results, or equivalently by application of equation (1), the entry and exit speed for the design cars from each retarder can then be obtained. Graphing the speed of cars within the retarder as a function of distance results in the relation shown in Figure 1. The speeds of the design hard and easy rolling cars within the retarder are shown as the solid lines in the figure. The trajectories of these cars in the velocity distance plane*** can be assumed to determine the "Magic X." Then, given the entry speed $V_{x,in}$ of a car of arbitrary rolling resistance, the exit speed is uniquely determined from this "Magic X" by drawing the straight line shown dashed in Figure 1 which goes from $V_{x,in}$ through the crossing

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* Here, satisfactory is meant to include both speed constraints at critical points (e.g., switches) as well as headway constraints between cars.

** A methodology to do this using PROFILE is given in the Yard Design Project's Working Note #40.

*** Since the speeds of the cars within the retarder are actually linear in the V^2 (speed squared) distance plane (as modelled in PROFILE), one possible modification is to consider the "Magic X" to be defined in this latter plane.

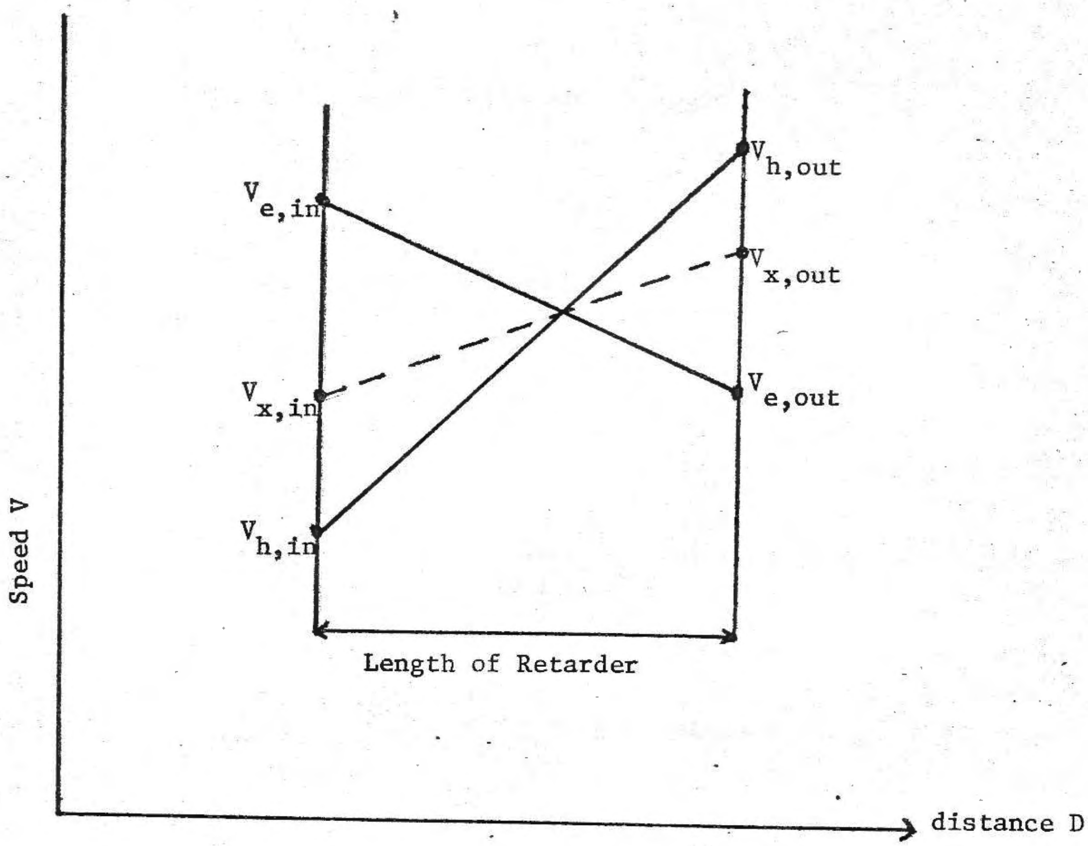
Speed V
V e,in
V x,in
V h,in
V h,out
V x,out
V e,out
Length of Retarder
distance D

Figure 1

point of the "Magic X."* Mathematically, the exit speed can be computed from the relation

$$V_{x,out} = V_{e,out} + (V_{h,out} - V_{e,out}) \frac{V_{e,in} - V_{x,in}}{V_{e,in} - V_{h,in}} \qquad (2)$$

where:

$V_{x,out}$ = Let out speed from the retarder of a car of arbitrary rolling resistance, based on the "Magic X".

$V_{e,out}$ = Let out speed from the retarder of the design easy roller.

$V_{h,out}$ = Let out speed from the retarder of the design hard roller.

$V_{x,in}$ = Entry speed to the retarder of a car of arbitrary rolling resistance.

$V_{e,in}$ = Entry speed to the retarder of the design easy roller.

$V_{h,in}$ = Entry speed to the retarder of the design hard roller.

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*If the car is rolling very fast (i.e., the car is a very easy roller), it may be beyond the retarder's capability to decelerate the car sufficiently to achieve the desired let-out speed. In this case, the retarder simply retards to its maximum capability. Similarly, if the car is rolling very slowly (i.e., the car is a very hard roller), it may not be possible to accelerate the car on the grade, even with the retardation completely "off", to the desired let-out speed. Logic will be included in any modelling effort to handle these limiting situations.

Because the parameters of the "Magic X" have been derived from constraints involving both speed control at critical points, as well as headways all through the switching area, the resultant control for an arbitrary car will also, to the extent that the control is derived from these parameters, consider both speed and headway constraints. However, as can be seen from Informal Note #3, the response of the system in terms of headways can indeed be highly non-linear even though the control input is linear. Therefore, an approach such as the "Magic X" that does not consider headways directly will not offer optimal control. Nonetheless, the "Magic X" is typical of modern, state of the art retarder control systems.

Distance to Couple

In the previous section a method for estimating an outlet speed from retarders using the "Magic X" method was described. However, in real world operations there is another constraint to be considered: The coupling speed. Typically, that retarder most downstream from the hump--a group or tangent point retarder--must also control the car to achieve a satisfactory coupling speed.

Designate $V_{c,out}$ as the let out speed from the most downstream retarder which satisfies the coupling speed constraint. This let out speed can be computed by applying equation (1). Rearranging terms and making appropriate name changes for the variables results in an expression for the let out speed necessary to achieve a desired coupling speed:

$$V^2_{c,out} = V^2_{couple} - 2g \sum_{\substack{i \text{ between} \\ \text{last retarder} \\ \text{and coupling} \\ \text{point}}} L_i \,(G_i - R_i) \qquad (3)$$

where:

$V_{c,out}$ = Let out speed from the most downstream retarder necessary to achieve a desired coupling speed.

V_{couple} = Desired coupling speed.

Integrating the "Magic X" with Distance to Couple

If tangent point retarders are used, then the distance to couple let out speed should be used instead of the let out speed computed from "Magic X."* However, when a tangent point retarder is not being used the group retarder must control for headways and speed through the last switches as well as for coupling speed. The let out speeds computed from the two alternate methodologies--the "Magic X" and Distance to Couple--will generally be conflicting. To resolve this conflict, the let out speed from the group retarder, in the absence of a tangent point retarder, will be taken as

$$V_{g,out} = \min(V_{x,out}, V_{c,out})$$

where:

$V_{g,out}$ = Let out speed from the group retarder, in the absence of a tangent point retarder.

This equation simply specifies that whichever criterion--the "Magic X" or the coupling speed-- yields the more restrictive let out speed shall apply.

Concluding Remarks

It is important to note that only the last retarder, because of the distance to couple calculation, requires a measured value of rolling resistance under this logic. Unfortunately, since the last retarder is also the last point upon which control can be exercised over the car, this does not provide opportunity to correct for errors in the control occasioned by the error in measuring a parameter (the rolling resistance) subject to much variability. The effects of errors in measuring this parameter will have to be considered. These will be addressed in later studies.

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*The headway control problem through the switching area is non-existant after the tangent point, and the only speed control required after the tangent point is for coupling.