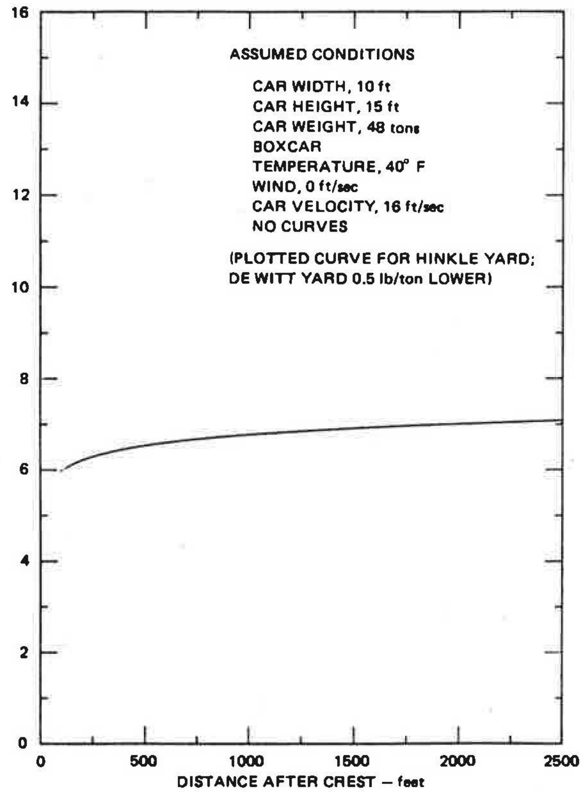
Figure 9. Rolling resistance as a function of distance from crest.



monly held hypothesis that cars incur less resistance farther from the crest.

Presence of Oilers

No significant effect of oilers on rolling resistance was found. The oilers were among the variables confounding the effects of switches and curves, however, so their effect may have been hidden.

CONCLUSIONS

The results of this study have greatly augmented knowledge about rolling resistance, but much more research remains to be conducted. In this study, the experimental setup could not be controlled, and the researchers had to rely on existing PC sensors and their location and accuracy. Thus restricted in the types of data that could be obtained, SRI was restricted in the results that could be obtained. Consequently, the next logical step in furthering knowledge about rolling resistance is to conduct carefully controlled field experiments.

ACKNOWLEDGMENT

The freight-car rollability study was performed by members of the Transportation Operations and Information Systems Center of SRI International for the Department of Transportation's Transportation Systems Center (TSC), Cambridge, Massachusetts. John Hopkins of the TSC was technical monitor for the project. The effort was sponsored by the Office of Freight and Passenger Systems, Federal Railroad Administration, as part of a program managed by William F. Cracker, Jr.

Appreciation is expressed to the following for their cooperation in providing data for the project: the late B. Gallacher (Southern Pacific); M.J. Anderson, J. Conway, and S. Shelton (Union Pacific); J. Wetzel, T. O'Dwyer, and C. Williams (Conrail); W. Butler (Burlington Northern); J.A. Rice (Southern Railway); W.L. Henry (Atchison, Topeka, and Santa Fe); and B.B. Laves (General Railway Signal Company).

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Classification Yard Computer Control Systems

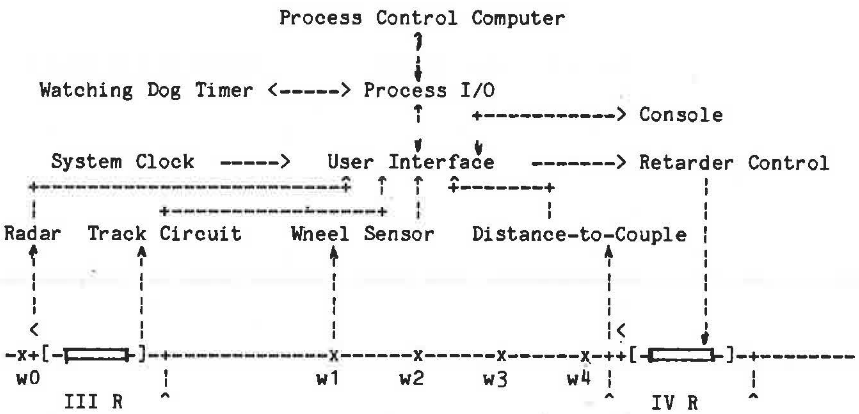
YINGHUA MIN AND LIANLONG YANG

A scheme for classification yard computer control systems (CYCCS) is proposed based on the analysis of experimental data collected from Chinese yard environments. The speed-control system configuration proposed includes a four-level retarder arrangement, various sensors, a process-control computer, and a system redundancy scheme. Much attention is given to measurement of car-rollability data. It is noted that the accuracy of some rollability data collected during past years is unacceptable because of the measurement techniques and the devices for measuring rollability. The primary error sources are analyzed, and some solutions to this problem are also discussed. The strong relationship between rollability and velocity of cars, however, has been widely noticed recently. Based on this idea, a piecewise-linear mathematical model is suggested for target-shooting control systems.

The main operations in a classification yard include receiving inbound trains, classifying cars, and making up outbound trains. According to these operations, a classification hump yard is usually partitioned into receiving yard, classifying yard, and dispatching yard. In a classifying yard, switching and coupling processes are the central activities. As cars roll down the hump grade, retarders slow down the cars to a proper speed so that the free-rolling cars can safely couple with preceding cars on bowl tracks (1). After the switching process had been automated, attention was focused on automatic speed-control systems. The following subjects were considered:

1. Safety: So-called iron shoes are put on bowl tracks in front of the wheels of free-rolling cars to ensure proper coupling of cars. Many workers are needed inside the bowl tracks throughout the classi-

Figure 1. Target speed-control system configuration.



fying yard 24 hr a day to accomplish this heavy and dangerous job. Some injuries occur every year. In addition, freight cars and their contents are frequently damaged. A large percentage of railway accidents occur in classification yards.

2. Efficiency: When these control functions are performed by labor-intensive manual systems, to ensure safety a lower retarder release velocity is preferred to a faster one. In addition, free-rolling cars are usually stopped quite a long way before preceding cars. These two factors consequently result in the so-called free window--a free section between cars on the bowl tracks. When a bowl track does not hold as many cars as planned because of these free windows, the yard engine has to go down the hump to push the cars to couple. This takes about 20 min each time, which is inefficient. The application of classification yard computer control systems (CYCCS) reduces the need for the yard engine and improves the efficiency of the classification operation.

3. Economy: Braking cars with iron shoes causes serious wear and tear to rails. As a result, many rails have to be changed in classification yards every year.

These considerations, in part, show the necessity of CYCCS in China. Therefore, much attention has been given to classification yard automatic control systems, including CYCCS (2). Automatic speed-control systems are emphasized in this paper.

It is more difficult to implement CYCCS in China than in some other countries because of the following reasons:

1. The speed allowed for coupling is restricted to less than 5 km/hr, which is usually called the allowed coupling speed. As is known, the higher the allowed coupling speed, the easier it will be to implement CYCCS, but because of the loading situation and the construction of Chinese freight cars, it is hard to determine whether the allowed coupling speed can be increased.

2. The bowl tracks can be as long as 800 m. This also presents some sophisticated problems in CYCCS.

3. The wide variety in car rolling resistance (rollability) makes implementing CYCCS more difficult, even though the range of rollability variety is not so large as has been reported. There has been some misunderstanding because of the questionable rollability measurement techniques and devices that have been used. This problem will be discussed later.

In the next section the proposed system configuration is presented, including a four-level retarder arrangement, various sensors, a process-control (PC) computer, and a system redundancy scheme. In the third section, measurement of car rollability, which is important and extremely difficult, is discussed in some detail. It is noted that some rollability data collected during past years have been unreliable. The large error in rollability measurement is caused by the measurement techniques and the rollability measurement devices. The primary error sources are analyzed, and some approaches to this problem are discussed. The strong relationship between the rollability and the velocity of cars, however, has been widely noted recently. Based on this idea, a piecewise-linear mathematical model is suggested for target-shooting control systems.

SYSTEM CONFIGURATION

The CYCCS considered here is essentially a speed-control system. Although the switching-control systems, master retarder, and group retarder control systems are important, they will not be considered in this paper. The discussion will be restricted to speed control, especially to target-shooting control systems. The term "target shooting" refers to the coupling of a free-rolling car with the preceding car at an allowed coupling speed. In the target speed-control system, retarders are employed to accomplish the car speed-control function. Because of the difficulty of implementing CYCCS in China, a four-level retarder arrangement is suggested. In addition to master retarders and group retarders, a tangent retarder, denoted III R, is placed at the beginning of each bowl track. A track retarder, denoted IV R, is placed about 200 m after III R on each bowl track. The target speed-control system configuration is shown in Figure 1.

The system includes the following field inputs:

1. Wheel sensor w0 senses the presence of rolling car wheels and signals the computer to begin a car control task in the real-time operating system (RTOS). From this input, the computer knows how many cars make up a cut. If it is a long cut (more than five cars), the so-called tail control technique has to be used, which means that the retarder is activated after several cars in the cut have passed through it.

2. Track circuits III and IV are closed or open contacts of track relays that indicate whether the track section is occupied by cars.

3. Radars III and IV measure the car's velocity

Figure 2. System-redundancy scheme suggested.

```
        +------> Warning -------+
        |                       |
        |                       v
       CPU  <------------> Yardmaster ---------+
        ^                       |              |
        |                       |              |
        v                       v              |
      PI/O <-----------> Semi-automatic        |
        ^                       |              |
        |                       |              |
        v                       v              |
User Interface ---------> Retarder Control <---+
        ^                       |
        |                       |
        |                       v
   Field Devices            Retarders
```

from its entrance into a track section to its exit. For long cuts of cars, radars indirectly provide information about how many cars have passed through the retarder for the use of real-time control. The PC computer accepts the information and sends retarder control commands to the specified retarder.

4. Wheel sensors w1-w4 measure rollability. When a wheel passes through a wheel sensor, a pulse is generated to signal the computer. From the system clock, the computer times the car's passage, accurate to the millisecond, so that the variation of car velocities can be computed, which indicates the rollability. It is possible to use three wheel sensors instead of four.

5. There are two track circuits on each bowl track to estimate the distance to couple; one is between retarders III and IV, and one is from the retarder IV exit point to the end of the bowl track.

Outputs to fields of the system are to control retarder activity through retarder control units to ensure proper coupling speed. However, there are other units with which the PC computer should also communicate; a console is one. The console is actually an on-line terminal for yardmasters. Yardmasters have higher priority in controlling cars than the computer. They can take back the control power from the computer at any time, so that they can adopt emergency measures. A watchdog timer is employed to supervise the operation of the computer and to process input and output.

If a preceding car is located after retarder IV, retarder IV is basically responsible for the rolling-car control on the bowl track. In some cases, it might be necessary to let retarder III share in the control. If the preceding car is located between retarders III and IV, retarder III is responsible for the rolling-car control.

In order to provide acceptable reliability, many redundant-system schemes have been suggested and adopted. A complete duplicate redundant system is used in the Musashino classification yard in Japan. Two central processing units (CPUs), two input and output processors (PI/Os), and other double critical components run concurrently, but only one of the redundant components has outputs to field devices. There is test equipment in the system to detect failures, and there is also a large relay switching subsystem to switch outputs from the faulty component to the fault-free side.

Although a number of redundant-system schemes can be chosen to provide acceptable reliability, the decision has to be made according to a unified consideration of performance and expense. Three redundant-system schemes are discussed and compared in reports by Min and others (3,4). The results show that the proper redundancy scheme for the situation in China is that shown in Figure 2. Normally, the CPU communicates with the field devices through the PI/O and an interface with the user. If failures occur in the CPU or the PI/O or user interface, the warning system notifies the yardmaster to switch control to a semiautomatic control system, which basically is a hot standby system. If the semiautomatic control system also fails, the yardmaster is able to operate the retarders manually.

ROLLABILITY MEASUREMENT

An understanding of rollability (car rolling resistance) is critical in the design and operation of railway hump yards. Rollability is measured in two ways: off line or on line. Off-line measurement determines rollability of specific cars in specific environments. The data collected are used by engineers to design hump height and classification-track grades and to determine the placement, length, and capacity of retarders. On-line rollability measurement is needed in CYCCS as a real-time measurement for the purpose of automatic control (5). The importance of information on rollability is widely recognized, but the difficulty of rollability measurement has not been well appreciated. In this section, some rollability measurement techniques are discussed from the point of view of error analysis. Important aspects in gathering correct data for the use of yard design and CYCCS design are pointed out.

Basic Formula for Computing Rollability

The rollability of a cut of cars is usually determined by measuring the velocity of the cars at two points. The traditional formula is as follows:

$$R = [G - (V_2^2 - V_1^2)]/2\underline{g}\,L * 10^{-3} \qquad (1)$$

where

R = measured rollability (kg/ton),
G = grade (%),
V_1 = car speed at upstream point 1 (m/sec),
V_2 = car speed at downstream point 2 (m/sec),
L = distance from point 1 to point 2 (m), and
$\underline{g}$ = conversion acceleration of gravity (m/sec²).

Each variable to be measured in Equation 1 is subject to an error called the absolute error, denoted ΔV_2, ΔV_1, $\Delta \underline{g}$, ΔL, and ΔG, respectively; thus, the rollability (R) to be computed must be subject to an error ΔR. The relative error δR is defined as $\Delta R/R$. Similarly, δV and δL are defined as $\Delta V/V$ and $\Delta L/L$, respectively. For simplicity of expression, $\Delta \underline{g}$ and ΔG are ignored and the approximate expression of δR is obtained by using the total differential formula. That is,

$$\delta(R - G) = (V_1^2 \delta V_1 - V_2^2 \delta V_2)/[\underline{g}\,L(R - G) * 10^{-3}] - \delta L \qquad (2)$$

Suppose that $\Delta V_2 = \Delta V_1 = \Delta V$ and $\delta L = 0$, $\underline{g} \doteq 10$. In the worst case, ΔV_1 might be positive and ΔV_2 might be negative, or vice versa. Hence,

$$|\Delta (R - G)| \leqslant 2V^2 \delta V/L * 10^{-2} \qquad (3)$$

Determining Rollability by Using Radar

One way to determine rollability is to use radar to measure the velocity of cars at two points as implemented in the Musashino CYCCS in Japan. Radar measures the velocity by sending out a beam of radio waves and receiving the reflection of those waves from the moving car by using the principle of Doppler frequency shift. Every 50 msec, the number

Figure 3. Determining rollability by using radar.

```
Radar ---> 8-bit Counter ---> CPU
                 ↑
                 |
         reset every 50 ms
```

Figure 4. Field situation.

```
1.2% III R                  IV R
-----[====]------------[====]---
          |<----200m---->|
```

Figure 5. Determining rollability by using four wheel sensors.

```
     |<------- L ------>|
     |                  |
 |<--d-->|          |<--d-->|
-X---+---X----------X---+---X--
 w1  1   w2         w3  2   w4
```

Figure 6. Determining rollability by using three wheel sensors.

```
  |    t1    |    t2    |
  |          |          |
  |<-- L -->|<-- L -->|
--X----+----X----+----X--
  w1   1    w2   2    w3
```

of Doppler pulses is sent to the CPU through an 8-bit counter, as shown in Figure 3. The CPU resets the counter every 50 msec. Some typical data are as follows: There are 70 pulses/sec for a car speed of 1 m/sec. Suppose that the rollability is measured at a car speed of about 3 m/sec, i.e., 210 pulses/sec, which is equal to 10 pulses/50 msec. Unavoidably the error of the counter is ±1 pulse. Hence, the relative error of V is $\delta V = 1/10$. The rollability is measured on a track with a grade of 1.2 percent between the tangent retarder III R and the track retarder IV R (L = 200 m), as shown in Figure 4. From Equation 3 the following equation may be obtained:

$$\Delta R = V^2 \delta V \tag{4}$$

If the preceding values are substituted into Equation 4, the result is $\Delta R = 0.9$ kg/ton, which is much larger than desired.

Determining Rollability by Using Four Wheel Sensors

Determining rollability by using four wheel sensors is quite common and has been done for a long time. Much confidence is placed in the data collected by this methodology. Nevertheless, it is not necessarily accurate if some important factors are not carefully taken into account. The placement of wheel sensors is shown in Figure 5. If t_1 and t_2 represent the length of time that it takes cars to pass through [w1,w2] and [w3,w4], respectively, speeds V_1 and V_2 are obtained by $V_1 = d/t_1$ and $V_2 = d/t_2$, where d is the distance between w1 and w2 or w3 and w4. The relative error in the speed is $\delta V = \delta d - \delta t$. Then

$$|\delta V| \leq |\delta d| + |\delta t| \tag{5}$$

Suppose that $G = 0$, $d = 5$ m, $L = 50$ m, $\Delta d = 1$ cm, $\Delta t = 6.8$ msec, and $v \doteq 4$ m/sec. Thus, $t \doteq 1200$ msec, $\delta t = \Delta t/t = 0.0056$, $\delta d = \Delta d/d = 0.002$, and from Equation 5 $|\delta V| \leq 0.0076$. From Equation 3

$$\Delta R = 4V^2 \delta V \tag{6}$$

If the preceding values are substituted into Equation 6, the result is $|\Delta R| \leq 0.49$ (kg/ton). But in practice, the situation may be even worse than this.

Determining Rollability by Using Three Wheel Sensors

A revised approach to measuring rollability is to use three wheel sensors instead of four (6,7). This approach computes rollability by using the following equation:

$$R = [G - (2L/g)(t_1 - t_2)]/[t_1 t_2 (t_1 + t_2) * 10^{-3}] \tag{7}$$

where

- L = distance from w1 to w2 or from w2 to w3 (m),
- t_1 = passage time from w1 to w2 (sec), and
- t_2 = passage time from w2 to w3 (sec).

The other terms are as defined for Equation 1. These parameters are shown in Figure 6. Compare these parameters with Equation 1 and note that $V_1 = L/t_1$, $V_2 = L/t_2$, and $(V_1 + V_2)/2 = 2L/(t_1 + t_2)$. Substituting them into Equation 7 produces

$$\begin{aligned} R &= G - (2L/g)\,[(V_2 + V_1)/2]\,[(V_2 - V_1)/L]\,(1/2L * 10^{-3}) \\ &= [G - (V_2^2 - V_1^2)]/2g\,L * 10^{-3} \end{aligned}$$

which is exactly the same as Equation 1. Therefore, Equation 3 also holds for this approach. In the Sotteville Yard, G = 0 and L = 10 m. From Equation 3

$$\Delta R = 20V^2 \delta V \tag{8}$$

Suppose that $V \doteq 4$ m/sec and $\Delta L = 0$; then from Equation 5, $\delta V = \delta t$, and thus $\Delta R = 320\delta t$.

In order to reach an accuracy of $\Delta R = 0.1$ kg/ton, $\delta t \leq 0.031$ percent is required; i.e., $\Delta t \leq 0.78$ msec. It is difficult to achieve such accuracy in passage-time measurement in classification yard environments. This problem will be discussed in the next section.

Error in Passage Time

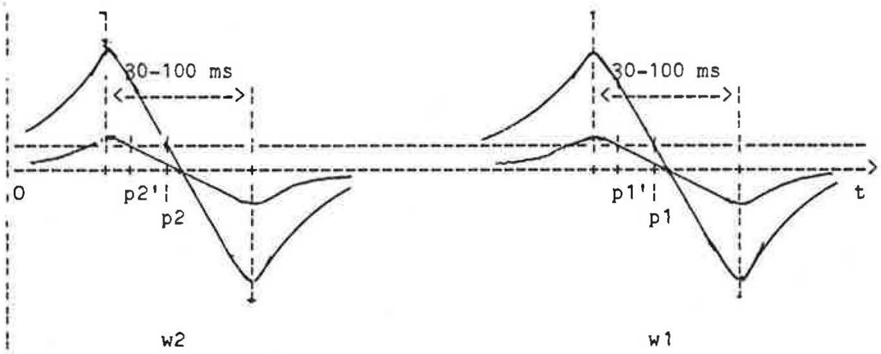
In order to obtain an R of acceptable accuracy, it is critical to decrease errors in the time it takes cars to pass through pairs of wheel sensors. Passage time is measured as shown in Figure 7. An external clock sends pulses of high enough frequency to the counter. After wheel sensor pulses w1 and w2 have been shaped, shaped pulses p1 and p2 are obtained. Counting starts at p1 and stops at p2. The number of pulses counted corresponds to the passage time from w1 to w2. Much attention has been given to the clock frequency for improving the accuracy of the passage time (t). The clock frequency was even taken to be as high as 1 or 10 MHz. Unfortunately, this is not in the focus of the problem.

As is known, a wheel sensor sets up a magnetic field in a section of rail. When a wheel passes, it changes the field, including a current in a nearby coil, which produces a wheel sensor pulse that is sent to a shaper. Figure 8 shows the wheel sensor pulses (w1 and w2) and the shaped pulses. Shaped pulses p1 or p2 correspond to large wheel sensor pulses, and shaped pulses p1' or p2' correspond to small wheel sensor pulses. Wheel sensor pulse heights are different because of the physical in-

Figure 7. Measuring passage time.

```
                                    External Clock
                                          |
                                          |
     w1                  p1               v            p2                 w2
  ------> Shaper  --------> Counter <-------- Shaper <------
                                          |
                                          |
                                          v
                                         CPU
```

Figure 8. Wheel sensor pulses.



stallation positions and features of the wheel sensors. Experiments show that the difference can be so large that the height of a large pulse can be three to four times that of a small one. If w1 and w2 are large, the passage time (p1, p2) is obtained; if w1 and w2 are small, the passage time (p1', p2'), which has almost the same length as (p1, p2), is obtained. But if w1 is large and w2 is small, the passage time (p1, p2') is obtained, resulting in an error Δt = p2 - p2'. If w1 is small and w2 is large, the time error Δt = p1' - p1, which is negative. Analysis indicates that Δt = 6.8 msec is common. This is the main reason for errors in rollability measurement. Therefore, the problem is how to make shaped pulses p1 and p2 correspond to fixed physical positions on the track. To solve this problem a zero cross-switch circuit instead of a magnitude-discriminator circuit is applied to get the shaped pulses at the moment the wheel sensor pulses go through zero. But the zero cross-switch circuit should be carefully designed to suppress noise (8, pp. 145-150).

For on-line rollability measurement, the same problem exists. In addition, if the CPU receives shaped wheel sensor pulses by an interrupt mode, the interrupt waiting time and response time have to be considered. No more than 3 to 5 msec of interruption-masked time of the CPU is allowed. This is an additional requirement for CYCCS software and the RTOS. Unfortunately, this requirement is not generally satisfied and efforts to achieve it have to be made in the software. In a CYCCS in China, after hardware and software had been carefully designed and coordinated, the rollabilities of the same car measured by its four pairs of wheels were only approximate. The difference among them was about 0.1 kg/ton, which was the error in rollability measurement [see paper by Min (5)].

Remarks on Rollability Measurement

The preceding analysis allows us to suspect the precision of existing data on car rollability because of unreliable measurement techniques. The data were employed to come to many conclusions that did not agree with practice. For instance, the range of rollability variety was said to be 0.5 to 5 kg/ton, even 10 kg/ton, which would mean a hump height of 5 m or so. Too high a hump causes problems and waste. Actually the range of rollability variety is not so large as the preceding estimate. Many cars continue to run at a speed of 3 to 5 m/sec until the ends of bowl tracks if no control is taken. It was occasionally found that some cars run freely down the hump and stop at a point about 100 m from the tangent retarders. This, however, is often due to improper positioning of car bleed brakes or other trouble with the cars. Therefore, this is a yard operation problem and should be solved by the servicing crew. It should not be taken into account in designs of hump height and CYCCS.

By applying Equation 3, some ways can be found to improve the accuracy in rollability measurement as discussed previously. On the other hand, the obtainable accuracy is limited because of the randomness in the car speed-decreasing rate. However, it is not necessary to pursue excessive accuracy of rollability for the purpose of yard control and design.

MATHEMATICAL MODEL FOR CONTROL

As mentioned earlier, suppose that a preceding car is located after IV R, and a rolling car is approaching. Before the rolling car enters a IV R, the CYCCS has to compute a correct exit speed from the retarder IV R according to the measured and given parameters, such as rollability, distance to couple, and so on. This is why a mathematical model for control is needed.

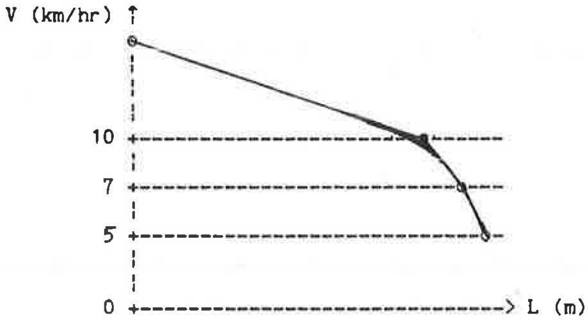
At the beginning of the research, the motion of a freight car rolling down a grade was analyzed and described by the concepts of classical mechanics. The exit speed from a retarder is calculated by the following equation:

$$V_e^2 = V_c^2 + 2\underline{g}L(R - G) * 10^{-3} \tag{9}$$

where

V_e = exit speed from the retarder (m/sec),
V_c = allowed coupling speed (m/sec),
$\underline{g}$ = conversion acceleration of gravity (m/sec^2),
L = distance to couple (m),

Figure 9. V-L curves.



R = rollability (kg/ton), and
G = grade (%).

Experiments show that V_e computed by Equation 9 in general is too large, which means that when a rolling car leaves the retarder at speed V_e, it will couple with the preceding car at a speed higher than V_C. On the other hand, theoretical analysis indicates that Equation 9 is equivalent to the proposition that R is a constant. Hence, as has been widely noted recently, R is not a constant. A strong relationship exists between rollability and velocity of rolling cars. In order to find the relationship, a series of field experiments was performed. In some 800-m-long bowl tracks, many wheel sensors were installed to measure velocity of rolling cars at many different points. Many velocity-distance curves were then obtained. The shape of these curves is shown in Figure 9, where L = 0 corresponds to the exit point of tangent retarder III R.

A piecewise-linear function is a good approximation of the V-L curves. It can be separated into the following components:

1. When V > 10 km/hr (for a free-rolling car, V cannot be higher than about 25 km/hr), the curve is close to a straight line with slope a. Therefore we have

$$\delta V/dL = a = \text{constant} \tag{10}$$

The acceleration of cars (A) is

$$A = dV/dt = (dV/dL) * (dL/dt) = aV$$

On the other hand, the following formula can be found in a report by Wong and others (7):

$$R = G - (A/g) \tag{11}$$

Hence, we have

$$R = G - (a/g)V \tag{12}$$

which reveals the relationship between R and V. Note that slope a is usually negative, so R increases with V. Also note that slope a has its physical meaning, that is, the decrease of velocity in distance passed of unit length. Parameter a plays an important role in this mathematical model and is called the speed-decreasing rate.

2. When 7 km/hr < V $\leq$ 10 km/hr, the V-L curve is close to a straight line with slope k_1a. Experience shows that k_1 = 1.3.

3. When 5 km/hr < V $\leq$ 7 km/hr, the V-L curve can be approximated by a straight line with slope k_2a, where k_2 = 2. But the lower the car speed, the greater the randomness in the speed-decreasing rate (a).

4. When V $\leq$ 5 km/hr, the randomness in the speed-decreasing rate (a) is dominant. How far a rolling car can go is uncertain when its speed is less than 5 km/hr.

Based on the V-L curves, the ideal exit speed from a retarder can be determined as follows:

$$V_e = \begin{cases} 1.11 + 2aL & \text{when } L \leqslant (0.83/2a) \\ 1.94 + 1.3a\,[L - (0.83/2a)] & \text{when } 0.83/2a < L \leqslant 0.84/1.3a \\ 2.78 + a\,[L - (0.83/2a) - (0.84/1.3a)] & \text{when } L > (0.83/2a) + (0.84/1.3a) \end{cases} \tag{13}$$

Note that 1.11 m/sec ≐ 4 km/hr, 1.94 m/sec ≐ 7 km/hr, 2.78 m/sec ≐ 10 km/hr, and V_C = 4 km/hr.

For example, suppose that the preceding car is located some 400 m after the exit from a retarder; i.e., L = 400 m. The grade of the bowl track is zero. Before the retarder, the speed-decreasing rate has been measured as 0.5 km/hr per 100 m; i.e., a = 1.39 * 10^{-3} (m/sec)/m. According to Equation 10 and with 0.83/2a = 0.299 * 10^{-3} = 29.9 m and 0.84/1.3a = 0.469 * 10^{-3} = 46.9 m,

$$V_e = 2.78 + 1.39 * 10^{-3} (400 - 29.9 - 46.9) = 3.23 \text{ (m/sec)} = 11.6 \text{ (km/hr)} \tag{c}$$

The uncertainty in rolling-car rollability becomes evident when the car speed decreases. Therefore, correction factors k_1 and k_2 should be modified in different situations.

REMARKS AND CONCLUSIONS

The railway classification yard is considered the bottleneck in railway operations. CYCCS has significant benefits. Now that some work has been done on CYCCS, the problem of controllability has been posed. If the coupling rate is regarded as the ratio between coupling time at the allowed coupling speed and the total number of couplings, it appears difficult to realize the requirement of a 100 percent coupling rate. Even though it is possible to reach such a rate, the CYCCS would be prohibitively expensive. Cost and performance should be balanced. The cost increases exponentially with the coupling rate, especially when the coupling rate is higher than 90 percent.

A target-shooting control-system scheme for the CYCCS is presented in this paper. There are two fundamental problems in the system--one is rollability measurement and the other is a mathematical model. For rollability measurement, the accuracy of some existing rollability data is suspect. In this paper the primary error sources are analyzed and approaches to improving the accuracy are given. As a result, the error in rollability measurement has been found to be 0.1 kg/ton. In this paper a piecewise-linear mathematical model based on many V-L curves obtained from a series of experiments is proposed. Experiments showed that a coupling rate of 90 percent can be achieved with a CYCCS.

ACKNOWLEDGMENT

We would like to thank Edward J. McCluskey, director of the Center of Reliable Computing, for his advice and support during the preparation of this paper. We would also like to thank Peter J. Wong, Robert L. Kiang, and William A. Stock of SRI International for their proofreading of early drafts.

We wish to extend our deep appreciation to Shouheng Li and other participating members of the Classification Yard Automation Laboratory, Signalling and Communication Institute, China Academy of

Railway Sciences, for their contributions to this project.

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Effect of Measurement Errors on Car Rollability Distribution in a Yard

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The importance of car rollability data is generally recognized in the railroad community, and such data are routinely measured in modern classification yards to use in speed-control algorithms for real-time control of the cars. These data are also compiled and presented in various statistical formats, one of which is a histogram showing number of cars as a function of rolling resistance, that serve as critical input data to a yard designer. Although large quantities of rollability data are being collected, insufficient attention has been paid to the accuracy of such data. A small error in a wheel-detector measurement could result in a large error in the computed rolling resistance. Because of the large errors, the true rolling-resistance histograms may be quite different from the apparent histogram compiled from the measured data, and this distortion could cause overdesign of the yard speed-control systems. A method to compensate for uncertainties in rollability data is presented.

Control of car movement in a classification yard is crucial to the safety and operational efficiency of the yard. In a conventional yard, control points (the retarder sections) are few and widely spaced, so the motion of a free-rolling car in between and beyond these control points must be accurately predicted. The success of such a prediction depends on information about the rollability or, equivalently, the rolling resistance of the car.

The importance of car-rollability data is generally recognized in the railroad community, and such data are routinely measured in modern classification yards. These data are used both in algorithms that provide real-time control of the cars and in various statistical displays, one of which is a histogram showing number of cars as a function of rolling resistance, that serve as critical input data to a yard designer.

Although much effort has been devoted to acquiring large quantities of rollability data, too little attention has been given to the quality of these data. Measurement inaccuracies distort the data. In a recent study sponsored by the Federal Railroad Administration (1), a statistical analysis indicated that good rollability data demand extremely high measurement accuracy.

The effects of measurement errors in car movement on the rolling-resistance histogram are explored. A current method of measuring rolling resistance could result in large errors in its value. Such an error in rolling resistance is not a constant for all cars; its functional dependence on the true rolling resistance of a car is derived. One consequence of these errors is that they will distort, sometimes greatly, the compiled rolling-resistance histogram. This is demonstrated and conclusions and recommendations are given later in this paper.

ERROR MAGNIFICATION

One standard method of measuring a car's rolling resistance in a classification yard is to place four wheel detectors along a section of track. The first two determine the entering velocity of a car within this measurement section, and the last two determine the exit velocity. The distance between the first two wheel detectors is usually kept the same as that between the last two. That distance is denoted by ℓ. The total length of this measurement section, that is, the distance between either the first and the third or the second and the fourth wheel detectors, is denoted by L. It is assumed that this section lies on a constant grade G. As a car with constant rolling resistance travels through this section, its transit times through these two pairs of wheel detectors are measured. They are denoted by t_a and t_b. Given the values of the aforementioned parameters, the rolling resistance of this car can be calculated by the following equation: