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Washington, D.C. 20590

Assessment of Car Speed Control Systems

FRA/ORD-80/90
Final Report

DECEMBER 1980

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16. Abstract

The scope of this study has encompassed an evaluation of fourteen yard speed control devices, an identification of four generic speed control systems, a qualitative assessment of the four systems, and finally a quantitative analysis of three hypothetic yards each employing a system that is considered promising. These three systems are (1) the advanced clasp retarder system, (2) the quasi-continuous control system, and (3) a hybrid system incorporating quasi-continuous control. No ranking of these three systems is possible because each has its advantages and disadvantages; and one system may be more suitable than the others under a particular circumstance.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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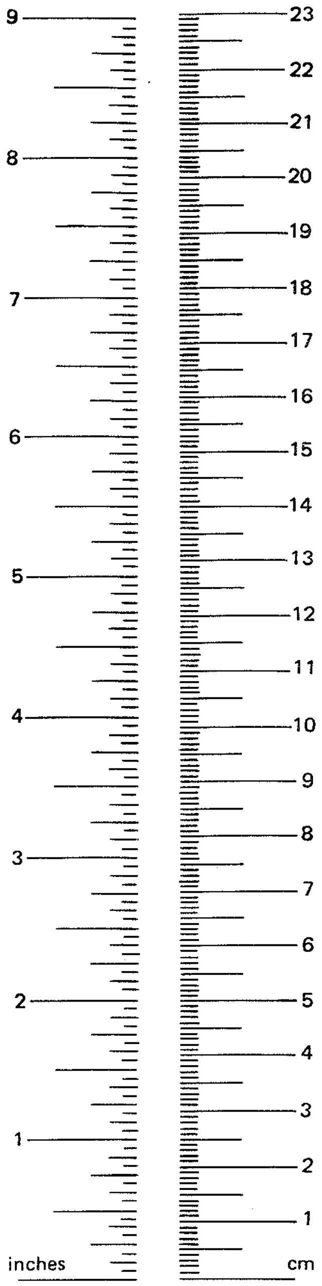
*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

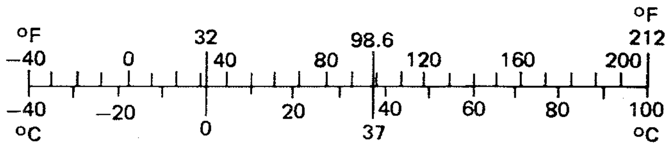
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This final report documents the results of a comprehensive evaluation of classification yard speed control systems.* The work was performed by SRI International under the sponsorship of the Office of Research and Development of the Federal Railroad Administration (FRA). The FRA project manager was Mr. William F. Cracker, Jr.

This study was conducted by personnel of the Engineering Sciences Laboratory and the Transportation Management System Center of SRI International. Dr. Peter J. Wong, Director of Operations Research, served as the project supervisor, Dr. Robert L. Kiang was the project leader. The project team consists of:

- Mr. Dale W. Ploeger, who was responsible for device evaluation, yard specification, and design of a baseline yard using clasp retarders.
- Dr. William A. Stock, who developed the SPEEDCON computer program.
- Mr. Joseph Eckerle, who evaluated the various retarder control algorithms.
- Dr. Robert L. Kiang, who was responsible for the system assessment and the overall approach and management of the project.
- Dr. Peter J. Wong, who developed cost information and was monitoring the overall performance of the project.

The authors would like to acknowledge the technical contributions of Dr. Masami Sakasita and consultants from the railroad industry: Mr. Barnard G. Gallacher of Southern Pacific Transportation Company, Mr. Dale A. Harrison of Atchison, Topeka & Santa Fe Railway Company, and Mr. Alfred V. Dasburg. We have since learned that Mr. Dasburg passed away on 3 June 1980. This news makes us more appreciative of the contributions he made to this study.

A number of vendors from other countries not only contributed technically but also arranged visits for project personnel to yards where their equipment is installed. These are the Dowty Hydraulic Units, Ltd., the ASEA A.B. and the Faiveley s.a. We wish to extend our deep appreciation to the participating members of these companies. A special thanks is due Mrs. Pamela J. McAlpine who did most of the typing of the final report manuscript as well as a great many of the documents associated with this project.

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*An interim report of this project was provided to the railroad industry at the Federal Railroad Administration (FRA) workshop in October 1979. The proceedings of the yard workshop are documented in FRA Report No. FRA/ORD-80/17, dated May 1980.

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EXECUTIVE SUMMARY

INTRODUCTION

The operation of freight trains necessitates remaking of trains from time to time. Known as classification, such an operation is carried out in a classification yard. Because a railroad car is powerless once it is detached from the locomotive, external power and a speed control system are needed to perform the classification operation. In a flat classification yard, the locomotive supplies the power by an acceleration/deceleration maneuver, thus "kicking" each car into its destination track. The speed control is provided by the kicking speed of the locomotive. In a hump yard, the power comes from both the hump locomotive and the earth's gravitational field. The use of gravitational energy greatly improves the efficiency of the classification operation.

In the United States, car speed control in a hump yard has traditionally been provided by clasp-type retarders. Although the fundamental hardware of the clasp retarders has remained the same for decades, the control of these retarders has developed from manual operation to very sophisticated computer operation. The computerized operation has improved the efficiency and safety of this conventional speed control scheme; it has also increased the capital cost of the system. In the meantime, radical new speed control devices and systems have been developed in many other countries. It is the objective of this Federal Railroad Administration (FRA) project to identify, from all recognized classification yard speed control systems, the most promising ones that could be demonstrated and integrated into the U.S. yards.

A study of the information compiled from a literature search shows clearly that, in order to make a sensible comparison of the various speed control systems, a distinction must be made between a speed control device and a speed control system. A speed control device is defined as a piece of hardware capable of altering the speed of a free rolling car. The outward appearance of this device can be very simple (e.g., a Dowty retarder), or it can be quite complex (e.g., a linear induction motor car mover). On the other hand, a speed control system encompasses everything that helps control the speed of cars from crest to the end of classification tracks in a hump yard; thus, retarders, wheel detectors, track circuits, computer and its software package are all part of a speed control system. This distinction between a device and a system led to a three-tier approach to the evaluation of the speed control systems: (1) device evaluation, (2) qualitative system assessment, and (3) quantitative system analysis.

DEVICE EVALUATION

Our device evaluation included thirteen speed control devices:

1. Full control clasp retarder
2. Weight responsive hydraulic retarder
3. Inert retarder
4. Siemens (Germany) electrodynamic retarder
5. Thyssen (Germany) rubber retarder
6. Dowty (Great Britain) retarder
7. ASEA (Sweden) spiral retarder
8. Faiveley (France) hydraulic retarder
9. Hydrabrake retarder
10. Cable-powered trolley
11. Hauhinco oscillatory cable device
12. JNR (Japan) linear induction motor car mover
13. S.N.C.F. (France) self-propelled car mover.

The first three clasp retarders listed are sufficiently well known to need no further elaboration. The electrodynamic retarder derives its retardation from both friction and eddy current dissipation. It has fewer moving parts than the clasp retarders with the exception of the inert type. The rubber retarder absorbs energy via deformation of a rubber rail. Its operation is quiet but is expected to be temperature sensitive. Durability of the rubber has not been determined. The Dowty retarder is one of four that rely on the forced flow of hydraulic fluid to achieve retardation. After three generations of development, the current Dowty retarder is a highly compact and reliable device. The operating principle of the ASEA hydraulic retarder is identical to that of the Dowty. It is a bigger unit that can absorb seven times the energy of a Dowty unit. Its current design, however, does not meet the A.R.E.A. criterion that no obstacle shall protrude more than 2-1/2 inches above the railhead. The most sophisticated of all hydraulic retarders, the Faiveley retarder is still in its development stage, and its cost and reliability are unknown. The Hydrabrake retarder is not suitable for yard usage since it does not incorporate internal logic as the other hydraulic retarders do. The cable-powered trolley is a low-profile carriage to move cars on the classification tracks. Like all cable systems, it requires external power and sophisticated sensing and control systems. The Hauhinco pusher trolley has its pusher arms mounted on an oscillating endless cable, allowing the system to move more than one car at a time within its span. The linear induction motor (LIM) car mover is a highly complex, self-contained carriage consisting of five units of different functions. The cost of this system is expected to be higher than that of a tangent point retarder system. The S.N.C.F. self-propelled is a forerunner of the LIM car mover. Although its complexity hardly matches that of the LIM car mover, the French railroad has decided to halt further development of it, presumably because of its complexity and cost.

Of the thirteen devices, five are deemed to be potentially useful in a U.S. yard, at least in their current states of development. The devices are the three types of clasp retarders, the Dowty retarder, and the Siemens electrodynamic retarder.

QUALITATIVE ASSESSMENT OF SYSTEMS

To accomplish its speed control function, a hump yard usually employs at least one type of speed control device. This study reveals that the speed control system in a modern hump yard generally belongs to one of four generic types:

1. System 1: The conventional clasp retarder system employing target shooting logic.*
2. System 2: The quasi-continuous control system.
3. System 3: The hybrid system of clasp retarders and quasi-continuous control devices.
4. System 4: The hybrid system of clasp retarders and car movers.

System 1 is the system used in the United States, but it refers to the most modern yards in which tangent point retarders are used in addition to the master and group retarders. Representative yards in this category are West Colton of Southern Pacific and Barstow of Santa Fe. System 2 refers to either a pure Dowty yard or a pure ASEA retarder yard. In such a yard, hundreds or even thousands of these hydraulic retarders are distributed along the tracks so that they exert a quasi-continuous control over a free-rolling car. Representative yards are Scunthorpe yard of Great Britain and Helsingborg yard of Sweden. System 3 uses master and group retarders to control headway in the switch area and quasi-continuous control devices on the classification tracks. An example of this system is found in the Malmö yard of Sweden. System 4 employs master and group retarders to control headway in the switch area and positive car moving devices on the classification tracks to ensure proper coupling. The Shiohama yard in Japan and DB's Maschen yard are typical examples.

System 1, which will also be called the advanced clasp retarder system, employs a target shooting scheme, because the control points along a track are few and far apart. In its most sophisticated form, a car's rolling resistance is measured prior to its entry into each of the three retarders. This rollability value is then used to determine the amount of energy to be removed by the retarder so that this car will reach a

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*The term "target shooting" refers to the objective of getting a free-rolling car to a specific point on the track at either a target time or a target velocity.

point along the track at either a target time or a target speed. If the car's rollability changes after the retarder, then no correction can be made until the car reaches the next retarder, if there is one. Changes in a car's rollability have been known to occur and can be caused by anything from uneven track conditions to shifting winds, a skewed truck, or internal variations in the axle bearings. Another factor that could degrade the performance of a conventional system is contaminated wheels that render the clasp retarders ineffective. When this occurs, the car rolls uncontrolled through the yard and can cause serious accidents. Less serious but no less a problem with the clasp retarders is the wheel squeal. Because of its highly sophisticated signaling and control, this system could be susceptible to electromagnetic interferences (EMI). An advantage is that the conventional system has by far the lowest capital cost. It may still be the most cost-effective system after accounting for the potentially high maintenance and operating costs. (Unfortunately, reliable cost estimates in these two categories are not available.) The abundance of operating experience that U.S. railroad companies possess in regard to this system is invaluable.

System 2, the quasi-continuous system, is a radically different system from the conventional system. Because of its closely spaced control points, the quasi-continuous system is not affected by changes in a car's rolling resistance. Since the quasi-continuous system does not rely on friction, it is not vulnerable to contaminated wheels. EMI is not expected to be a problem. The system has two other advantages. An obvious one is that the potentially more uniform coupling speed that results from an extended control region* along a classification track should reduce car and lading damage. A more subtle advantage, which applies more to the Dowty retarders than to either the ASEA or the Faiveley retarders, is that the system's performance is not noticeably degraded when a few retarders among the hundreds along a track are out of service. This aspect of the system, coupled with the ease of replacement of the Dowty capsules in the field, results in nearly zero downtime for the system. This, of course, means a savings in yard operation. The disadvantages of the quasi-continuous system are high capital cost, little operating experience in the United States, and the retarders' partial immunity to the noise problem.

System 3, the hybrid system with clasp retarders in the switch area and a quasi-continuous system on the classification tracks, has the dual advantage of an improved coupling performance and a reduced risk of runaway cars. It requires a high capital investment and has compounded the noise problem. This system is more adaptable to a renovated conventional yard than a new yard. It is often installed as an adjunct to an old hump yard where the grade in the bowl is steep because of the higher rolling resistance of the old generation cars.

System 4 is a hybrid system employing clasp retarders in the switch area in conjunction with a positive car moving device on each of the classification tracks. This system almost ensures proper couplings at all times. The car moving device may be an S.N.C.F. (French National Railroad) car mover, a JNR (Japanese National Railway) linear induction motor car mover, or any of the cable devices. The extreme complexity of the first two car movers makes them unlikely to be cost effective. Despite the lower cost of the cable devices compared with the other two, System 4 still has a high capital cost. Two of the ultramodern yards in Europe--the Limmattal yard near Zurich and the Maschen yard near Hamburg--have comparable cable devices on their classification tracks. The cost of these two yards, in 1973 dollars, is approximately $3 million and $2 million per classification track, respectively. These figures can be compared with approximately $800,000 per track for either the West Colton yard or the Barstow yard--two state-of-the-art yards using conventional speed control systems. (The cable hauling system in foreign yards contributes greatly to the cost difference.) The cable device is also known to require high maintenance. The clasp retarders in the switch area still inherit most of the disadvantages associated with the conventional system. Finally, most cable systems can only receive cars within a narrow speed range, and, as a result, a tangent point retarder or its equivalent is still needed on each classification track.

The qualitative assessment demonstrates that the conventional clasp retarder system should remain a strong contender among the competing systems. The quasi-continuous control system, particularly the Dowty system, is the most promising foreign system. Its success in the United States will depend on whether its potential operational advantages can be demonstrated in an actual yard. Attention will be focused on the Flynn yard, presently under construction near Oklahoma City. The hybrid system incorporating Dowty retarders on the classification tracks will be cost-effective only under certain circumstances (e.g., in the renovation of an old yard with steep grades). It is anticipated that the hybrid system incorporating car movers on the classification tracks will not be adopted in the United States.

QUANTITATIVE ANALYSIS OF SYSTEMS

Despite, or perhaps because of, the generality of the qualitative assessment SRI's conclusions are, in many respects, more significant than the results of the subsequent quantitative analysis. One important insight acquired in this study is that the relative merit of a speed control system depends on the yard design specification, which includes the size (i.e., the number and length of the classification tracks) and the required throughput of the yard. For this reason, ratings of the different systems should be made under various yard sizes and throughputs. Unfortunately, the resources allocated for this project did not permit such a comprehensive analysis. As a compromise, quantitative analyses for three specific hypothetical yards were performed using the three chosen speed control systems all designed to one yard specification. Despite the limited number of systems selected, the quantitative analysis was still a major undertaking. It involved the development of an all-new stochastic computer program named SPEEDCON,† the design of baseline yards incorporating different speed control systems, the calculation of the performances of these baseline yards, and the estimate of the relevant costs associated with each system.

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*A quasi-continuous system usually has the retarders installed on up to one-third of the classification tracks.

†SPEEDCON represents a significant contribution to this project as well as to the future design of speed control systems. The program is useful not only as a performance evaluation tool, but also as a highly refined design aid for any new speed control system. The use of modular subroutines is intended to facilitate the use of this program by other users, and a comprehensive documentation of this program, including sample results, is given in Appendix D for that reason. Program listing of this FORTRAN program will be available from the National Technical Information Services (NTIS).

The results of SRI's quantitative analysis, which stipulates among other parameters a 32-track yard with a hump speed of 200 feet per minute, are as follows:

- The capital cost of the advanced clasp retarder system, at $7.8 million, is the lowest. A comparable Dowty system or a hybrid system incorporating Dowty retarders on the classification tracks costs at least a third more.
- With some uncertainty about the maintenance cost of the advanced clasp retarder system, a quantitative comparison among the three systems becomes difficult. Nevertheless, the available information indicates that all three systems will have the comparable maintenance and operating costs. The annual figure is approximately 3 percent of the capital cost of the advanced clasp retarder system.
- Two sets of performance calculations were made using SPEEDCON. One set assumes a conservative rolling resistance distribution (more hard rollers); the other set assumes a more optimistic rolling resistance distribution.
- Using the conservative rolling resistance distribution, the advanced clasp retarder system shows 0 percent misswitch, 0.03 percent stall in the switch area; 16 percent stall on classification tracks, and 7 percent overspeed (>6 mph) coupling. Comparable figures for the Dowty system are 0.15 percent, 3 percent, 41 percent, and 3 percent, respectively. Comparable figures for the hybrid system are 0 percent, 0.03 percent, 41 percent, and 3 percent.
- Using the optimistic rolling resistance distribution, the advanced clasp retarder system shows 0 percent misswitch, 0 percent stall in the switch area, 8 percent stall on the classification tracks, and 4 percent overspeed coupling. Comparable figures for the Dowty system are 0.02 percent, 0.46 percent, 23 percent, and 10 percent. Comparable figures for the hybrid system are 0 percent, 0 percent, 23 percent, and 10 percent.

The quantitative results of three specific hypothetical yards as summarized above show that the advanced clasp retarder system has the best overall performance. The reason for the relatively poor performance of the Dowty system can be traced partially to the fact that Dowty has based their design on rolling resistance values even more optimistic than the design values assumed by SRI. The sensitivity of the system performance to the assumed rolling resistance distribution highlights the importance of providing the yard designers with accurate rolling resistance distribution. Acquisition of reliable rolling resistance data should be among the highest priorities for the railroad industry as well as for the government.

This leads to the recommendation of future effort. SRI's major recommendations are:

- Fundamental research on car rolling resistance.
- Development of more advanced clasp retarder control algorithms.
- Acquisition of field performance data.

SECTION 1 — INTRODUCTION

1.1 BACKGROUND

Operating freight trains requires reblocking of cars at intervals. A particular freight car may undergo several reblocking maneuvers, known as classifications, between its point of origin and its destination. Because a railroad car is powerless once detached from the locomotive, external power and a speed control system are needed to perform the classification operation. In a flat classification yard, the locomotive supplies the power by an acceleration/deceleration maneuver, thus "kicking" each car into its destination track. The speed control is provided by the kicking speed of the locomotive. In a hump yard, the power comes from both the hump locomotive and the earth's gravitational field. The use of the free gravitational energy significantly improves the efficiency of the classification operation. In the United States, car speed control in a hump yard has traditionally been provided by clasp-type retarders. Although the fundamental hardware of the clasp retarders has remained unchanged for decades, the control of these retarders has developed from manual operation to sophisticated computer operation. The computerized operation has improved the efficiency and safety of this conventional speed control scheme, and increased the capital cost of the system. In the meantime, radical new speed control devices and systems have been developed in other countries. Whether any of these new systems is better and more cost-effective than the conventional U.S. system is unknown, but an unbiased comparative study of these various car speed control systems seems warranted.

1.2 OBJECTIVE AND SCOPE

The objective of this Federal Railroad Administration (FRA) sponsored project is to identify the most promising speed control systems that may someday be demonstrated and integrated into the U.S. yards. Because the speed control system requirements of a hump yard are more complex and demanding than those of a flat yard, the scope of this research project has been limited to state-of-the-art hump yards, i.e., yards with high throughput and automation.

1.3 REPORT ORGANIZATION

This report is organized to reflect the three-tier approach adopted in evaluating the classification yard speed control systems: the device evaluation, the qualitative system assessment, and the quantitative comparison of three specific systems. An explanation of evaluation criteria and methodology in Section 2 is followed by an encompassing discussion of 13 identified speed control devices. The discussion of each device includes the principle of operation, the special features, the advantages and the disadvantages, the extent of its use, and the available cost information. Whenever possible, a sketch of the device under discussion is provided, and its manufacturer is identified. The former should help readers to identify the device, the latter should facilitate readers who seek more detailed information about any of these devices. For quick reference, a condensed assessment summary for each of the 13 devices is prepared and shown in Figures 3-13 through 3-25 at the end of Section 3.

In spite of the large number of speed control devices, only four generic speed control systems are identified:

- The conventional clasp retarder system
- The quasi-continuous control system
- The hybrid system incorporating quasi-continuous control on the class tracks
- The hybrid system incorporating car movers on the class tracks

The descriptions and the qualitative assessments of these four systems are given in Section 4. The conclusions drawn from this qualitative assessment (Section 4.6) are, in many respects, more significant than the results of the subsequent quantitative analysis.

One important insight acquired in this study is that the relative merit of a speed control system depends on the yard design specification, which includes the number and length of the classification tracks and the hump speed (i.e., the size and the expected throughput of the yard). For that reason ratings of the different systems should be made under various yard sizes and throughputs. Unfortunately, the resource allocated for this project does not permit such a comprehensive analysis. As a compromise, quantitative analyses for three specific hypothetical yards using the three chosen speed control systems were performed. Despite the limited number of systems selected, the quantitative analysis was still a major undertaking. It involved the development of an all-new stochastic computer code named SPEEDCON,* the design of baseline yards incorporating different speed control systems, the calculation of the performances of these baseline yards, and the estimate of the relevant costs associated with each system. The quantitative analysis and its results are given in Section 5. The description of the SPEEDCON code is given in Appendix D.

General conclusions and recommendations from this study can be found in Section 6. The five appendices address various other subjects treated in this study.

SECTION 2 — EVALUATION CRITERIA AND METHODOLOGY

2.1 DEVICE VERSUS SYSTEM

Because of the tangible nature of a device and the existence of many speed control devices, it is understandable that the distinction between a yard speed control device and a yard speed control system is often unclear. In a research project such as this in which one studies the operation principle of a device on one hand and the performance of a system on the other hand, the difference between a device and a system is important. A speed control device is defined as a piece of hardware capable of altering the speed of a free rolling car in a classification yard. The outward appearance of this device can be very simple, such as a Dowty retarder, or it can be quite complex, such as a linear induction motor car mover. A speed control system, on the other hand, is defined as encompassing everything that helps control the speed of cars from

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*SPEEDCON represents a significant contribution to this project as well as to future design of speed control systems. The code is useful not only as a performance evaluation tool but also as a highly refined design aid for any new speed control system. The use of modular subroutines is intended to help others use this program. A comprehensive documentation of this code, including sample results, is given in Appendix D for that reason. Program listing of this FORTRAN code will be available from the National Technical Information Services (NTIS).

crest to the end of classification tracks in a hump yard. Wheel detectors, track circuits, a computer and its software package are all parts of a speed control system. Even the grades, which supply the motive power of all uncoupled cars, should be considered part of the system.

As mentioned earlier, the intended function of a yard speed control system is to control the motion of free-rolling cars. In a hump yard, the only place that cars are allowed to free roll is the classification area. For this reason, all components of a speed control system are usually found in this area--from the crest to the end of the classification yard--often abbreviated as the class yard.*

A common speed control system will include energy absorbing or providing devices, power supply, sensing and control instruments, signal cables, control system, communication system, and fail-safe devices, such as emergency batteries and standby computers. The following components will not be considered part of the speed control systems: tracks, switches and their associated control system.

2.2 REQUIREMENTS AND PERFORMANCE CRITERIA FOR SYSTEMS

Requirements are the constraints placed on the speed control system to assure its proper functioning in a yard operating environment. More simply, they are the criteria that all speed control systems must satisfy. As shall be discussed later, the commonly accepted requirements cannot be enforced rigidly or none of the existing systems will qualify.

Within the railroad community there exists a set of mutually accepted requirements for the speed control system:

1. Headway in the switch area must be greater than 50 ft, or misswitch may occur.
2. Speeds on curved sections of track must be less than 15-17 mph, or derailment could occur.
3. Cars should not stall more than a couple of hundred feet from the coupling points, or costly maneuvering of the hump engine will be required.
4. Coupling speeds should be between 4 and 6 mph, or proper coupling will not be achieved and damage to cars and lading could occur.
5. All systems should have sufficient energy-absorbing capacity plus a certain amount of reserve to handle the excess kinetic energy of a 160-ton car.
6. All systems should be able to handle axle loadings ranging from 8,000 to 80,000 lb/axle, and wheel diameters from 28 to 38 inches.
7. All systems should provide clearances for the passage of locomotives and cars. One such clearance specified in the AREA manual is that no device should protrude more than 2-1/2 inches above the rail head.

In addition to the industry's self-imposed requirements, there is a new noise requirement recently imposed by the U.S. Environmental Protection Agency (EPA):

8. The wheel squeal noise caused by the action of clasp retarders should not exceed 83 decibels as measured on adjacent property.

Some of the above requirements are absolute, such as 6 and 7. Others are regarded as guidelines, such as 1, 2, 3, and 4.

As an example of how practicality dictates that some of these requirements cannot be followed rigidly, consider requirement 4. Part of that requirement says that no car shall couple at speed greater than 6 mph. In actuality, coupling speeds greater than 6 mph do occur in a significant number of cars. The yard operator could adjust the reatrder control algorithm so that this 6 mph requirement is met, but the number of stalled cars will undoubtedly become unacceptable. That this trade-off aspect can be found with all existing speed control systems does not mean that the speed control systems in use are unacceptable. So an evaluation of the various speed control systems will not include the requirements as a screening device but only as a set of guidelines. The emphasis will be on the performance and sometimes potential performance, of the system.

By definition, performance parameters are those which measure directly the operational capability of the system. This study has identified four parameters by which to measure the performance of a speed control system:

- Percentage of high speed impacts (i.e., coupling speed in excess of 6 mph).
- Percentage of stalled cars (short of coupling point by at least a few hundred feet, as well as short of clearance point).
- Percentage of misswitched cars.
- Hump speed (measured in feet of cars per second over the hump).

The desirability of a system measured in terms of each of the four parameters is obvious. Where the overall ratings of systems are concerned, one must consider the economic tradeoffs. It is not clear whether a system that will result in significantly lower percentage of higher speed impacts at the price of higher percentage of stalled cars and higher capital investment is more desirable. More details of this relationship between cost and performance will be discussed in Section 2.4.

The interdependence of the four identified performance parameters should be noted. A particular speed control system can usually be made to perform better in one aspect at the expense of other aspects. For instance, the percentage of misswitch cars can always be improved by lowering the hump speed. Another example is the relationship between the percentage of high speed impacts and the percentage of stalled cars discussed earlier; an improvement in the percentage of high speed impacts can be achieved if the percentage of stalled cars is relaxed.

2.3 METHODOLOGY OF PERFORMANCE EVALUATION

Ideally, for each qualified speed control system, all the performance parameters would be quantified, transformed into an operating cost, then added to the capital and maintenance costs to obtain a single "economic index" of that system. Rating the various

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*Here the term is used in its narrower sense. A class yard does not constitute the entire hump yard; a hump yard is usually composed of a receiving yard, a class yard, and a departure yard. All discussions in this report will be focused on the class yard defined in this narrower sense.

systems is then possible by simply comparing the economic indices. Unfortunately, such an idealistic approach is not feasible for a number of reasons. The primary reason is that most performance data are not available. Some are believed to be nonexistent, such as the stall distribution.* Others are considered proprietary information by the various railroad companies, for example, the coupling speed distribution. Even if all the relevant data are available, trying to derive comparative performances of difference speed control systems belonging to different yards is like comparing apples and oranges. The performance of a system is dependent on the size of the yard, the grades, the vintage of the system, and even the quality of the yard crew. Thus, poor performance data from a particular yard do not necessarily reflect the inferiority of the speed control system installed in that yard.

The realization of the above-mentioned limitations prompted the adoption of a two-level approach to this evaluation task. The first level involves fact finding and qualitative analysis. Information sources include published and unpublished literature, yard visits by project personnel, and meetings and conversations with railroad personnel hired as consultants for this project. The results of this effort include the identification of four generic speed control systems and qualitative assessment of each system. These are reported in Section 4.

A second-level effort involves quantitative comparison of a baseline yard fitted with different speed control systems. The reason for using such a hypothetical baseline yard is to introduce a common denominator for the quantitative comparisons. Thus, the baseline yard specifies 32 classification tracks, 200 ft/min hump speed, and so on. Next, a Dowty system and an advanced clasp retarder system were designed for the baseline yard. Dowty ROTOL Inc. supplied the design for the Dowty system and SRI designed the advanced clasp retarder system.† Third, the SPEEDCON computer model was developed to evaluate the performance of these two systems under the specified baseline yard configuration. In addition, a hybrid of the two systems was also analyzed.

The SPEEDCON model provided quantitative information regarding the following performance attributes of the various systems:

- Percentage of misswitched cars
- Percentage of stalled cars in the switching area
- Percentage of cars at various coupling speeds on the classification track
- Percentage of cars stopping short of coupling on the classification track.

The above quantitative analyses present important engineering performance data for the specific systems studied; more importantly, they demonstrate the underlying rationale for the development of SPEEDCON and the capabilities of the stochastic computer model. Should questions about the relative performances of the various speed control systems for a different baseline yard configuration arise in the future, SPEEDCON would serve as a valuable evaluation tool.

2.4 SCOPE OF ECONOMIC ANALYSIS

Promising speed control systems can be compared in terms of engineering design and performance, but they must be compared on an economic basis ultimately. Unfortunately, much of the data needed to perform an accurate economic analysis simply does not exist. For example, the economic benefits of (1) reducing overspeed impacts of the class tracks, (2) increased car coupling on the class tracks, (3) reduced car stalling in the switch area, or (4) reduced misswitching of cars; are not readily quantified. For this reason, the economic analyses presented in Section 5 are rough estimates, based on the best available data, of the capital, maintenance and operating costs of the various speed control systems. Assumptions and approximations will be noted whenever possible.

SECTION 3 — SPEED CONTROL DEVICES

3.1 FULL CONTROL CLASP RETARDER

The full control clasp retarder is manufactured by:

1. Westinghouse Air Brake Company (WABCO)
   Union Switch and Signal Division
   Swissvale, Pennsylvania 15218
2. General Railway and Signal Company (GRS),
   a unit of General Signal
   Rochester, New York 14602
3. Thyssen Umformtechnik Bergbautechnik
   Postfach 28 11 44
   Ehinger Strasse 80
   D-4100 Duisburg 28
   West Germany

3.1.1 Principle of Operation

The clasp type retarder slows a rolling car by gripping the rim of the car's wheels and by dissipating energy through friction. The retarder consists of a pair of long brake beams, mounted parallel to the top of each rail and slightly above it. The beams can be moved inward so that a wheel rolling on the rail will be squeezed. The beams cannot move parallel to the rail. Retarders can be approximately 100 feet long.

Each manufacturer uses a different scheme to support and move the retarder beams. WABCO mounts the beams to pivoted arms and powers them with compressed air. A schematic of this configuration is shown in Figure 3-1. GRS uses electric motors and a worm drive to move the beams. Thyssen uses a hydraulic system and wedges to move the beams.

The clasping force controls the amount of retardation. In the full-control-type retarder, the clasping force can be varied while the car is in the retarder. This allows the retarder and control system to achieve accurate let-out speeds.

The full control clasp retarder is the most important element in the conventional control system. A target-shooting control algorithm is used in automated yards. The car's rolling resistance and speed is measured prior to the retarder, and the control algorithm computes the retarder outlet speed necessary for the car to reach a target point farther down the track at a specified time. Adequate headways can be maintained by keeping the same time schedule for all cars. The retarder clasps the wheels of the car as it enters the

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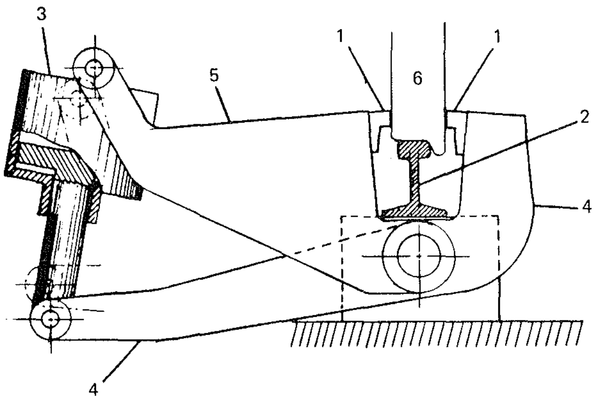
*Number of cars stalled as a function of fall-short distance.

†The U.S. signal companies were asked to assist in the design of the conventional system, but they declined to participate.



1. BRAKE SHOE
2. RUNNING RAIL
3. ACTIVATING CYLINDER
4. LOWER LEVEL ARM
5. UPPER LEVEL ARM
6. WHEEL

Figure 3-1. Clasp Retarder--Full Control

retarder and removes energy until its speed is as specified, then it releases the car. If the car speeds up while in the retarder, the retarder is reapplied. Typically, exit speed can be within ±0.1 mph of the specified speed.

3.1.2 Advantages

Although more expensive than other types of clasp retarders, the full control clasp retarder efficiently removes energy from a car. Yards in the United States have a large amount of operating experience with these (and other) clasp retarders, and manufacturers have developed sophisticated control systems for them.

3.1.3 Disadvantages

While the cost for the retarder itself is relatively low, the control system and track-side sensors required for automated operation are expensive. In large high-throughput yards many retarders may be required. The target-shooting control system has advantages; for example, each car can be controlled at a few, discrete points along its path. Success of the system depends not only on the retarder, but also on the measurement of a car's speed and rolling resistance and the prediction of the car's behavior following the retarder. Poor performance can be caused by incorrect or unforeseen behavior of a car.

The effectiveness of any clasp retarder depends on friction between the wheel and the brake beam. If a substance on the rim of the wheel does not permit the clasp retarder to generate enough friction, the car will be uncontrollable. In addition, friction between the wheel and the brake beam creates a very loud squeal. This noise is objectionable and is costly to eliminate or mask.

3.1.4 Extent of Use

The full control clasp-type retarder is used in almost every U.S. yard with both automated and manual control installations. It is also common in European yards.

3.1.5 Cost Estimate

The full control clasp-type retarder costs approximately $3,000 per foot for the retarder mechanism alone. This translates to approximately $0.09 per ft-lb of energy removal capacity. This figure does not include the costs of power supply system, track-side sensors, and computer hardware and software. (An estimate of the system cost is discussed in Section 5.3.2.)

3.2 WEIGHT RESPONSIVE CLASP RETARDER

The weight responsive clasp retarder is manufactured by:

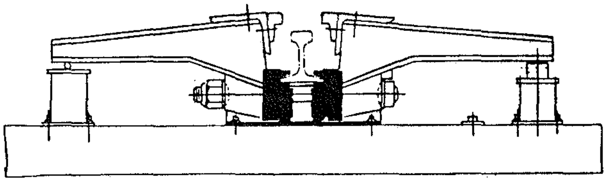
1. Westinghouse Air Brake Company
   Union Switch and Signal Division
   Swissvale, Pennsylvania 15218

2. General Railway and Signal Company,
   a unit of General Signal
   Rochester, New York 14602

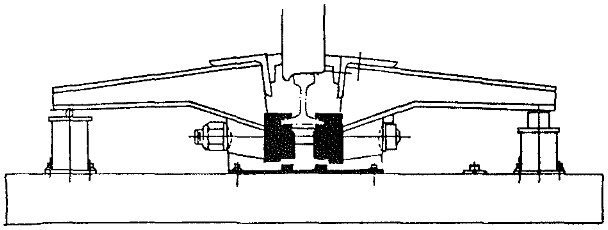
3. Railroad Products Group
   Abex Corporation
   1010 Russ Building
   San Francisco, California 94104

3.2.1 Principle of Operation

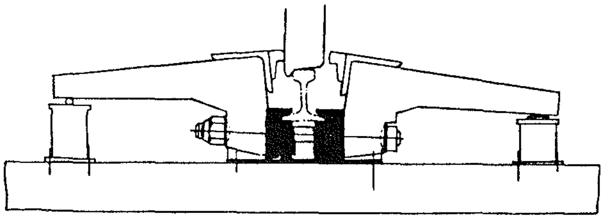
The weight responsive clasp retarder, like the full control clasp retarder, slows a car by gripping the rim of the wheel with brake beams and by dissipating energy through friction. The brake beams are mounted to only one rail. The clasping force is provided only by the weight of the car through a system of levers, as illustrated in Figure 3-2. When the power is switched on, the clasping force and hence, energy removal, is proportional to the weight of the car; when the power is turned off the car passes through unretarded. A simple hydraulic system is used to activate the retarder.



RETARDER CLOSED — NO CAR PRESENT



RETARDER CLOSED — CAR PRESENT



RETARDER OPEN — CAR PRESENT

Figure 3-2. Clasp Retarder--Weight Responsive

The retarder is designed so that it must be switched on before the car enters the retarder; the hydraulic system is not strong enough to raise a car while it is in the retarder. Unlike the full control retarder, which can be turned off and on while the car is in the retarder, the weight responsive retarder can only be turned off one time per car. For this reason the speed of a car leaving the retarder cannot be as closely controlled. Weight responsive retarders have an accuracy of ±0.25 mph on the exit speed.

Weight responsive clasp retarders are used in large yards as tangent point retarders where their cost is especially important and performance limitations are acceptable. In smaller yards they are used as master-group retarders.

3.2.2 Advantages

Weight responsive clasp retarders have a lower cost per unit energy removal capacity and thus are well suited to applications where a large number of them is required, such as at the tangent point. Weight responsive retarders are simpler than full control retarders and require less maintenance.

3.2.3 Disadvantages

Because the weight responsive retarders have a lower energy removal capacity per foot than the full control retarders, they must be elongated to accomplish the same task. The control over the retarder is limited, making the exit car speed less accurate. The weight responsive retarder clasps the wheel with a force proportional to the car's weight. If a larger force is required, such as with a slippery wheel, it is not available.

3.2.4 Extent of Use

The weight responsive retarder is found in virtually all U.S. yards using tangent point retarders. Weight responsive retarders have been used as master and group retarders in some smaller U.S. yards.

3.2.5 Cost Estimate

The weight responsive clasp retarder costs approximately $1,000 per foot for the retarder mechanism alone. This translates to approximately $0.05 per ft-lb of energy removal capacity. The system to provide pressurized hydraulic fluid to the retarders costs extra as does the computer control system.

3.3 INERT CLASP RETARDER

The inert clasp retarder is manufactured by:

1. Westinghouse Air Brake Company
   Union Switch and Signal Division
   Swissvale, Pennsylvania 15218

2. General Railway and Signal Company,
   a unit of General Signal
   Rochester, New York 14602

3. Railroad Products Group
   Abex Corporation
   1010 Russ Building
   San Francisco, California 94104

3.3.1 Principle of Operation

The inert clasp retarder slows a car by gripping the rim of its wheels and by dissipating its energy through friction. The function of an inert retarder is not to control speed but to stop cars at the end of the classification tracks. No control other than a manual on-off is possible in most models.

The Abex retarder uses spring force to produce the clasping force as illustrated in Figure 3-3. The GRS and WABCO retarders use the car's own weight, similar to the weight-responsive retarder, to produce the clasping force.

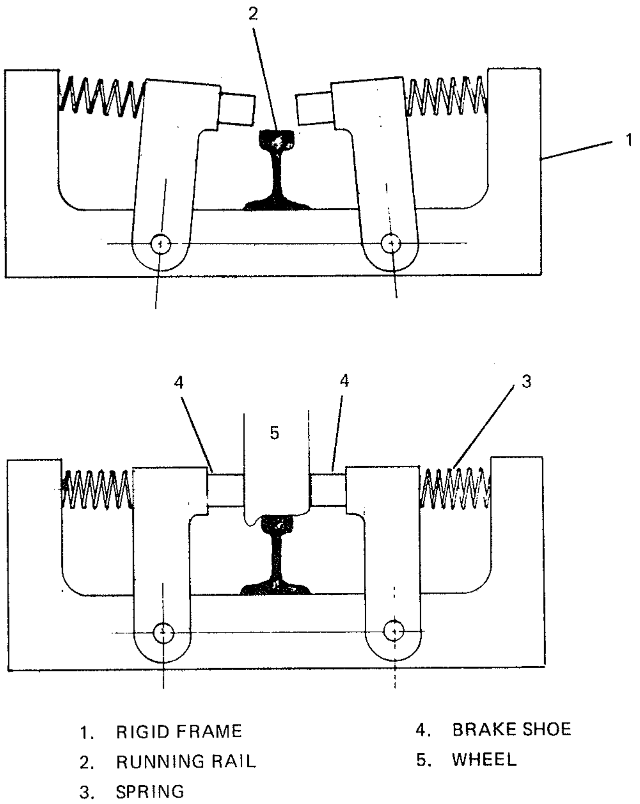


Figure 3-3. Clasp Retarder--Inert

3.3.2 Advantages

The inert retarder is a low-cost, low-complexity arrestor only. It can be released to ease pull-out operations.

3.3.3 Disadvantages

A source of external power is required (hydraulic or electric) to turn the retarder on and off.

3.3.4 Extent of Use

Inert retarders are used in many yards in the United States in conjunction with a reverse grade at the end of the class tracks.

3.3.5 Cost Estimate

Inert clasp-type retarders cost approximately $5 to $6,000 per retarder (WABCO and GRS retarders are approximately 19 feet long; the Abex retarder is approximately 36 feet long). The hydraulic system and manual control system costs are not included in the estimated cost.

3.4 ELECTRODYNAMIC RETARDER

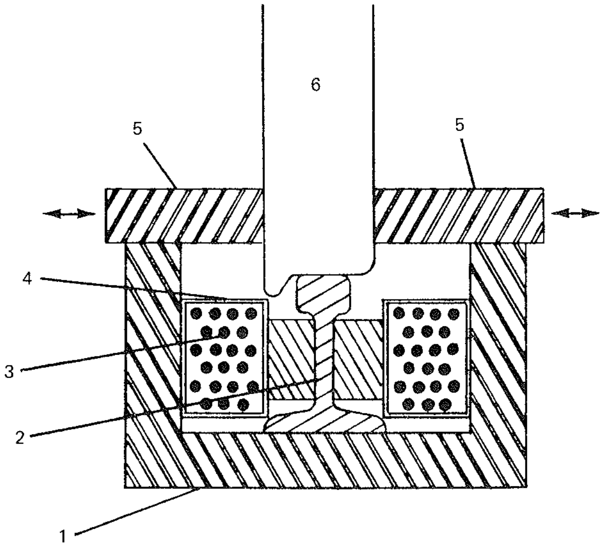
The electrodynamic retarder is manufactured by:

Power Engineering Division
Siemens
U.S. Sales Office
186 Wood Avenue, S.
Islin, New Jersey 08830

3.4.1 Principle of Operation

A schematic of the electrodynamic retarder is shown in Figure 3-4. A large current passes through the energizing coils, creating a strong magnetic field between the brake beams (pole pieces). When a wheel rolls through this field, strong eddy currents are set up in it and energy is dissipated. In addition, the brake beams, which are free to move from side to side, rub against the wheel and dissipate energy through friction. The total energy dissipation is divided equally between these two modes. The retarder is usually mounted to both rails.

The capacity of the electromagnetic retarder is comparable to that of the weight responsive clasp-type retarder. The device is used most frequently as a tangent point retarder.



1. U-SHAPED SECTION
2. RUNNING RAIL
3. ENERGIZING CONDUCTOR
4. INSULATION
5. MOVABLE BRAKE SHOE
6. WHEEL

Figure 3-4. Electrodynamic Retarder

3.4.2 Advantages

Because the electrodynamic retarder has only four moving parts (two per rail), the cost of the retarder and the required maintenance are probably less than for a weight responsive clasp retarder. Since it depends only partly on friction, it is not as susceptible to wheel contamination as a clasp-type retarder. Retardation is proportional to the current and the wheel speed. No hydraulic or pneumatic system is required.

3.4.3 Disadvantages

The electromagnet requires a high-current, low-voltage power source which might not otherwise be installed in a yard (as a pneumatic or hydraulic system would be). The possibility of electromagnetic interference with electronic circuits in the yard must be considered.

3.4.4 Extent of Use

The electromagnetic retarder is operated in Europe as a tangent point or siding retarder and has been used in Japan as well. No examples are known in the United States.

3.4.5 Cost Estimate

The retarder itself is estimated to cost less than a weight responsive retarder because of the simpler construction and fewer moving parts in the electrodynamic retarder. The power supply should be comparable in cost to the hydraulic or pneumatic system required for clasp-type retarders. However, the electric power supply would be devoted to the electrodynamic retarders alone, while a central pneumatic system could supply air to all the retarders and to the switches in a yard.

3.5 RUBBER BEAM RETARDER

The rubber beam retarder is manufactured by:

Thyssen Umformtechnik Bergbautechnik
Postfach 28 11 44
Ehinger Strasse 80
D-4100 Duisburg 28, West Germany

3.5.1 Principle of Operation

A schematic of the rubber beam retarder is shown in Figure 3-5. The retarder consists of a special running rail and a rubber beam or rail that can be raised and lowered. In its nonretarding mode, the rubber beam is lowered and the wheel rolls on its flange on the special running rail. The rubber rail does not touch the wheel in this mode. In the retarding mode the rubber rail is raised by a hydraulic system so that the entire weight of the car is supported by the rubber. The rubber is deformed and dissipates energy through internal friction. The retardation is a function of the deformation which, in turn, is a function of the car weight.

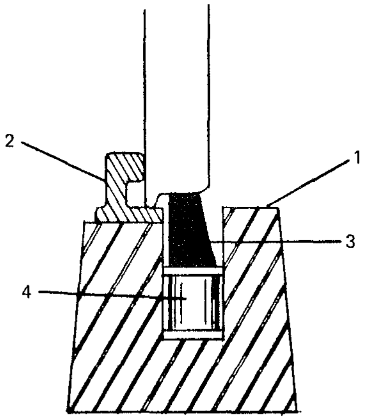
No energy removal figures were found. The retarder is normally used as the tangent point retarder in yards with conventional control systems, and its energy removing capability is assumed to be comparable to that of the weight responsive clasp retarder and the electrodynamic retarder.

3.5.2 Advantages

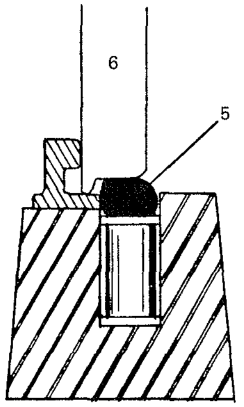
The rubber beam retarder is very quiet in operation. It does not rely on friction to dissipate energy so it is not affected by wheel contamination.

3.5.3 Disadvantages

The retarder must be energized (i.e., the beam must be raised) before a car enters the retarder. Since the car is lifted off the rail slightly for retardation, this causes a jolt as the car enters the energized



a. NO RETARDATION



b. RUBBER RAIL COMPRESSED

1. FRAME
2. RUNNING RAIL
3. RUBBER RAIL
4. ACTIVATING CYLINDER
5. COMPRESSED RAIL
6. WHEEL

Figure 3-5. Rubber Rail Retarder

retarder and is raised off the rail. Having the car roll on the wheel flanges may not be acceptable to some railroads. The effectiveness of the retarder will vary greatly with the temperature and hardness of the rubber. The durability of the rubber beam is untested.

3.5.4 Extent of Use

Rubber beam retarders are used as tangent point retarders in several large West German yards including Seelze, Mannheim, Duisburg-Wedau and Maschen.

3.5.5 Cost Estimate

Since the level of complexity is similar to that of a weight responsive clasp retarder, the cost should be comparable. A hydraulic power supply is required as are a control system and trackside sensors similar to the clasp retarder.

3.6 DOWTY HYDRAULIC RETARDER

The Dowty hydraulic retarder is manufactured by:

Dowty Hydraulic Units Ltd.
Arle Court
Cheltenham
Gloustershire, England

3.6.1 Principle of Operation

The Dowty retarder is shown schematically in Figure 3-6. Each unit consists of a cast pot which is bolted to the inside web of the rail and a capsule which slides in the pot. The capsule is a steel cylinder within which slides a piston assembly containing a relief valve and a speed-sensitive valve. The flange of a passing wheel depresses the cylinder into the pot against the piston. The cavity in the cylinder is filled with oil except for a small charge of nitrogen in the top. As the cylinder moves past the piston, oil is forced through the speed-sensitive valve. The speed valve can be adjusted so that, below a preset speed, the oil passes unrestricted past the piston; above the speed the oil flows through an orifice. The flow of the oil through the orifice restricts the depression of the cylinder and extracts energy from the car. The retarding force is constant above the preset speed. After the wheel passes, compressed nitrogen gas returns the cylinder to its original position.

Each retarder extracts a small amount of energy (approximately 1,000 ft-lb per stroke or 0.0125 feet velocity head per passage of a 160-ton car). The Dowty retarder is designed for use as a quasi-continuous speed control system. (In a quasi-continuous system many retarders are used in series, each set to a desired speed so that a rolling car will be maintained at that speed.) The Dowty retarder has also improved coupling performance in conventional yards when installed in the class tracks alone.

In addition to the pure retarder unit, Dowty also manufactures a two-cylinder booster/retarder unit. In the booster/retarder unit, the retarding head functions either as a retarder or as a below-threshold-speed sensor which then activates the booster head to exert pressure on the passing wheel. A hydraulic system must be installed to supply power to the booster units. The higher cost of the booster/retarder systems can be justified only under special circumstances such as improving the performance of an existing yard that has too flat a grade.

3.6.2 Advantages

The Dowty retarders are entirely self-contained and require no external hydraulic system or control system. They are designed so that the sliding cylinder/piston assembly is easily removed. On-track maintenance consists of locating defective units by visual inspection and replacing them with fresh ones. The defective units are overhauled at another location.

The Dowty retarder does not rely on friction to remove energy. The amount of energy removed is independent of the car speed as long as it is above the threshold speed. The energy removal is neglegible for cars moving below the threshold speed.

The operation of Dowty retarders creates an intermittent noise less objectionable than the squeal noise.

3.6.3 Disadvantages

The Dowty retarder cannot be retracted or deactivated.* The pullout locomotive must thus overcome the resistance of the Dowty retarders in the class track.

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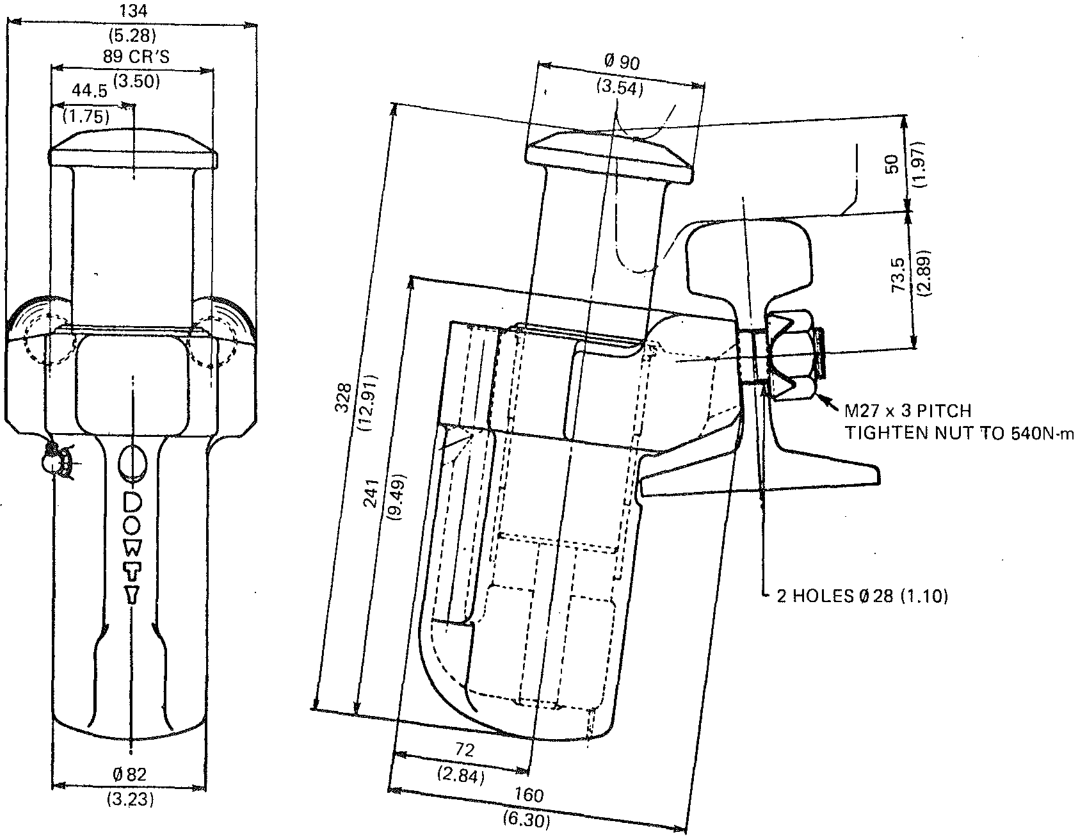
*Dowty has recently developed a retarder with a retractable head. A pneumatic system is needed to operate it. The assessment of the Dowty system does not include this new generation of retarders.

The method of mounting to the rail and the principal external dimensions are shown on the drawing below.

Maximum Stroke	82.5 mm (3.25 in)
Oil Volume	228 cm^3 (13.9 in^3)
Charging Pressure	6.9 bar (100 psi)
Ratio oil/nitrogen (by volume)	4:1 approx.
Critical Speed Setting	0 to 5 m/s (0 to 16.4 ft/s)
Sliding Cylinder dia.	65 mm (2.56 in)
Piston Rod dia.	20 mm (0.78 in)
Capsule weight	4.3 kg (9.5 lb)
Pot weight	8.6 kg (19 lb)

Materials

Pot	SG iron
Sliding Cylinder	High tensile steel, chromium plated, mushroom head induction hardened
Piston	High tensile steel – chromium plated rod
Bearings	Phosphor Bronze
Studs	High tensile steel



DIMENSIONS IN mm WITH INCH EQUIVALENTS IN BRACKETS

Figure 3-6. Dowty Hydraulic Retarder

Dowty retarders are not weight sensitive. Because an equal amount of energy is removed from each car by each retarder regardless of weight, a light car will lose more velocity than a heavy car. In addition, the upward resistance exerted by the retarder must be set to less than the minimum wheel load in order to prevent wheel lift.

3.6.4 Extent of Use

The Dowty retarder is currently used in 14 yards worldwide. The Atcheson, Topeka and Santa Fe railroad is installing Dowty retarders in their new Oklahoma City yard.

3.6.5 Cost Estimate

The cost estimate ranges between $350 and $500 per retarder, depending on the quantity ordered (this includes spare capsules). At 1,000 ft-lb energy removal per stroke, this translates to $0.35 per ft-lb to $0.50 per ft-lb. (If one assumes a four-axle car, this reduces to $0.09 per ft-lb to $0.125 per ft-lb energy removal per car passage.) No support equipment is required for a Dowty speed control system.

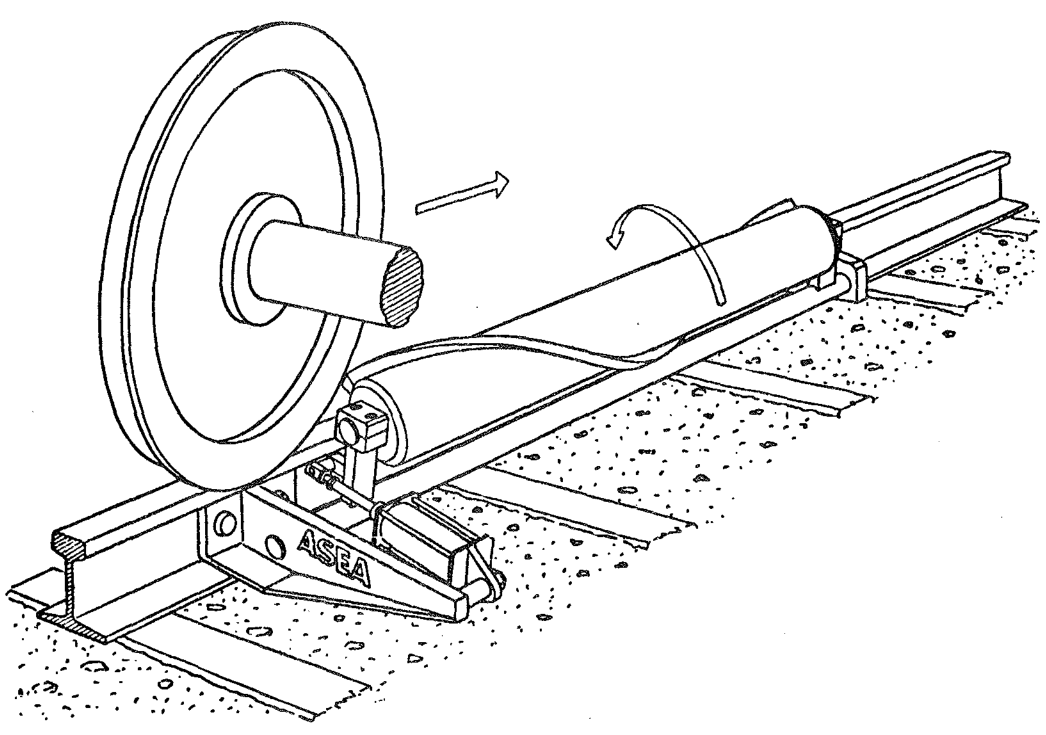
3.7 ASEA HYDRAULIC RETARDER

The ASEA hydraulic retarder is marketed by:

ASEA A.B.
Stationary Transport Equipment
Transport Division
Dept. TFF
S-721 83 Västerås, Sweden

3.7.1 Principle of Operation

A diagram of the ASEA retarder is shown in Figure 3-7. The unit consists of a large cylinder mounted with its axis parallel to the top of the rail. A helical rib is welded to the circumference of the cylinder. The



CROSS-SECTION

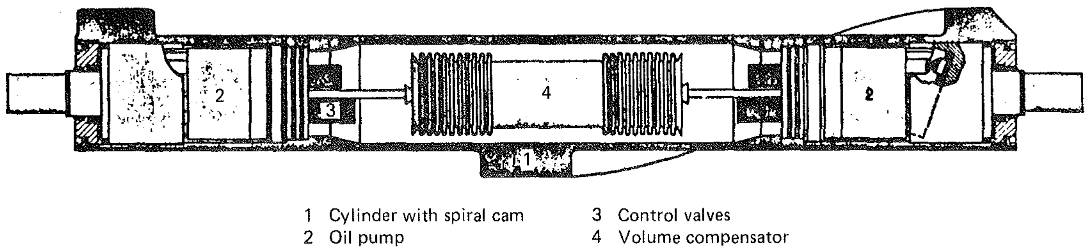


Figure 3-7. ASEA Hydraulic Retarder

cylinder is approximately 42.5 inches long and 8.7 inches in diameter to the outside of the helical rib. The flange of a passing wheel engages this rib and rotates the cylinder once. The rotation drives oil pumps in each end of the unit which forces oil through speed-sensitive valves. The speed-sensitive valves can be adjusted at the factory so that below threshold speed the oil flows unrestricted through the valves, and above threshold speed the oil flows through an orifice. The flow of oil through the orifice resists the rotation of the cylinder and extracts energy from the car. The retarding force is relatively constant above the preset speed.

Each retarder extracts a small amount of energy (approximately 7,400 ft-lb per wheel passage or 0.092 feet of velocity head removed from a four-axle, 160-ton car). The ASEA retarder is designed for use in quasi-continuous speed control systems where numerous retarders are used in series in the switching area and class tracks. When the retarders are set to a desired speed, a rolling car will maintain that speed. The ASEA retarder is also used in the classification tracks of yards that previously used skatemen to control the coupling speeds.

3.7.2 Advantages

The ASEA retarder can be retracted (swung away from the rail), allowing rapid pull-out from the class tracks, uninhibited passage of locomotives, and travel in the reverse direction. The retarder itself is entirely self-contained. Energy removal below the threshold speed is negligible, while the energy removed from the car above the threshold speed is not speed-dependent.

3.7.3 Disadvantages

The retraction mechanism requires a source of compressed air and a piping network. Maintenance is more difficult than on the Dowty retarders. Faulty units must be detected with a specially instrumented car. Removal from the track requires several minutes, and service on the removed unit requires an average of eight labor-hours. Most significantly, in its present configuration the top of the helix protrudes five inches above the top of the running rail. This would interfere with some cars allowed by the AAR standards, and many U.S. railroads would not consider using the ASEA retarder for this reason.

3.7.4 Extent of Use

The ASEA retarder is used in about half a dozen yards in Europe, mostly in Scandinavia. The Swedish national railroad is updating many of its yards with ASEA retarders.

3.7.5 Cost Estimate

The cost is estimated at $3,000 to $5,000 per retarder, depending on the number ordered. At 7,400 ft-lb energy removal per wheel passage, this translates to $0.41 per ft-lb to $0.68 per ft-lb. (If one assumes a four-axle car this is reduced to $0.10 per ft-lb to $0.17 per ft-lb energy removal per car passage.) The supply of compressed air and the piping system for the retraction system would be extra. (Compressed air would already be available in most yards.)

3.8 FAIVELEY RETARDER

The Faiveley retarder is manufactured by:

Faiveley s.a.
93 rue du Docteur Bauer
93404 Saint-Ouen Cedex, France

3.8.1 Principle of Operation

A schematic of the Faiveley retarder is shown in Figure 3-8. The retarder consists of five rail-mounted pedals, each activated by the wheel of a passing car; it can be set to respond to different threshold speeds. The pedals operate pistons which pump hydraulic fluid to the central control system and through an orifice. Preceding the retarding pedals are a weighing pedal and a reset pedal. The weighing pedal measures the wheel load and adjusts the orifice so that the maximum retarding force is always 75 to 80 percent of this value. The reset pedal detects the approach of a new wheel and relieves the pressure setting of the previous wheel. The Faiveley retarder is preset internally for a threshold speed above which the passing wheel is retarded and below which the wheel passes unhindered. Above the threshold speed, the retardation is independent of speed. The control system also includes a manual shutoff.

The retarder measures approximately 68 inches from the reset pedal to the last retarder pedal. The retarder section alone is 49.6 inches long.

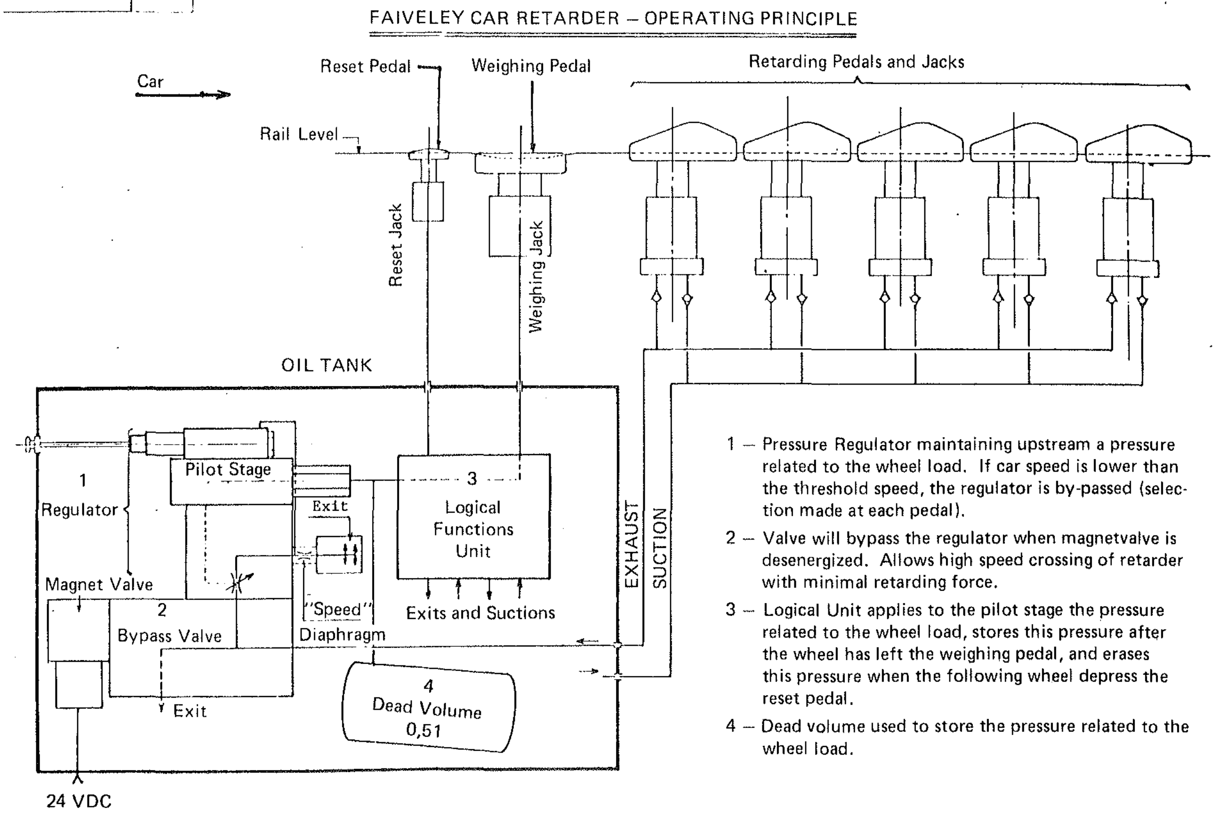
The Faiveley retarder is designed for use in a quasi-continuous control system. Each retarder (all five pedals) extracts 0.36 feet velocity head on approximately 28,800 ft-lb per axle for a 40-ton axle. When used in large numbers in series, all set to a desired critical speed, the retarders will hold a rolling car at that critical speed.

3.8.2 Advantages

The Faiveley retarder is entirely self-contained. It includes a manual shut-off that can be controlled from a central station, so pull-out operations can proceed unhindered. Cars are controlled to a constant speed, and since the energy removed is proportional to car weight, wheel lift is eliminated and light cars are not retarded too quickly. The design of the pedals makes the retarder insensitive to wheel diameter.

3.8.3 Disadvantages

The retarder is more complex than other quasi-continuous retarders so service could be more difficult. The size of the retarders and their control unit will make installation in some areas (i.e., near switches) difficult. The retarder requires a special section of rail, with a portion of the railhead removed, for installation.



1 – Pressure Regulator maintaining upstream a pressure related to the wheel load. If car speed is lower than the threshold speed, the regulator is by-passed (selection made at each pedal).

2 – Valve will bypass the regulator when magnetvalve is desenergized. Allows high speed crossing of retarder with minimal retarding force.

3 – Logical Unit applies to the pilot stage the pressure related to the wheel load, stores this pressure after the wheel has left the weighing pedal, and erases this pressure when the following wheel depress the reset pedal.

4 – Dead volume used to store the pressure related to the wheel load.

Figure 3-8. Faiveley Hydraulic Retarder

3.8.4. Extent of Use

The retarder was developed for the French National Railroad. At this time the retarder is in its final stage of development and it has been installed only in the Ambèrieu yard in France for testing purposes.

3.8.5 Cost Estimate

The manufacturers have estimated the cost per retarder at between $4 and $5,000 per unit. This translates to $0.14 per ft-lb to $0.17 per ft-lb. (For a four-axle car this becomes approximately $0.04 per ft-lb energy removal per car passage.) This cost estimate is speculative because the device is still in its development stage. The eventual cost may be higher than the above figures because of the level of complexity of the device. No external systems are required for the operation of the retarder.

3.9 HYDRABRAKE RETARDER

The Hydrabrake retarder is distributed by:

Whiting Corporation
Harvey, Illinois

3.9.1 Principle of Operation

A schematic of the Hydrabrake retarder is shown in Figure 3-9. It consists of a rocker arm fixed to the inside of the rail. As a wheel passes, its flange will depress first one side, then the other side, of the arm. The rocker arm operates two pistons which pump fluid through an orifice. The resistance to flow through the orifice restricts the motion of the arm and retards the car. Each piston works once as the car passes. No information was found on its retarding capacity.

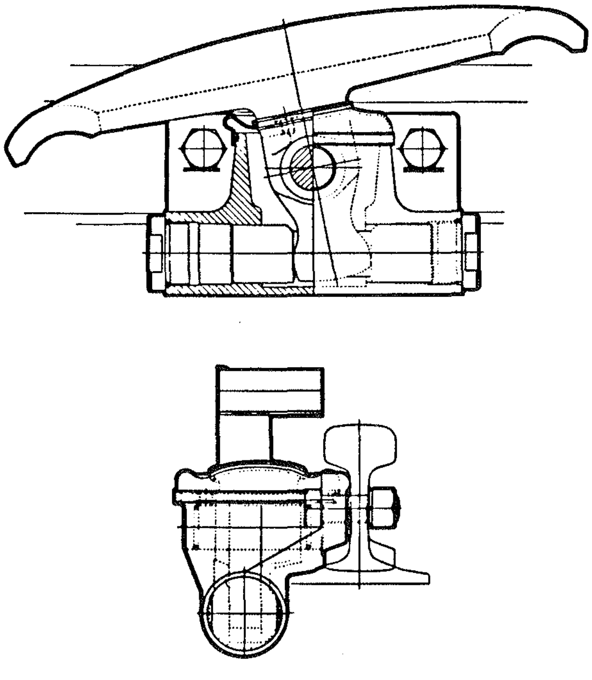


Figure 3-9. Whiting Hydrabrake Retarder

3.9.2 Advantages

The double action available in this design has the potential for more energy removal per wheel passage than a Dowty retarder. The retarder is self-contained and requires no external systems for its operation. An on-off feature which is operated from a central control is available, however.

3.9.3 Disadvantages

Unlike the previously described devices, this device has no built-in logic. It does not contain a speed-sensitive valve, so it retards all cars that pass. An option is available that will deactivate the retarder using a solenoid valve. But even this modified version is not weight sensitive. The retarder was designed for use in industrial yards for car spotting and was not intended for rigorous use in a class yard.

3.9.4 Extent of Use

This device is not used in any classification yard in the United States. The distributor has discontinued the device, citing problems with durability.

3.9.5 Cost Estimate

The cost is estimated to be comparable to but slightly less than the Dowty retarder.

3.10 CABLE-POWERED TROLLEY

The cable-powered trolley is manufactured by:

1. ASEA A.B.
   Stationary Transport Equipment
   Transport Division
   Dept. TFF
   S-721 83 Västerås, Sweden
2. Hauhinco Maschinen Fabrik
   G. Hansherr, Jochums GmbH & Co. KG
   Zweigertstrasse 28/30
   D-4300 Essen 1, West Germany

3.10.1 Principle of Operation

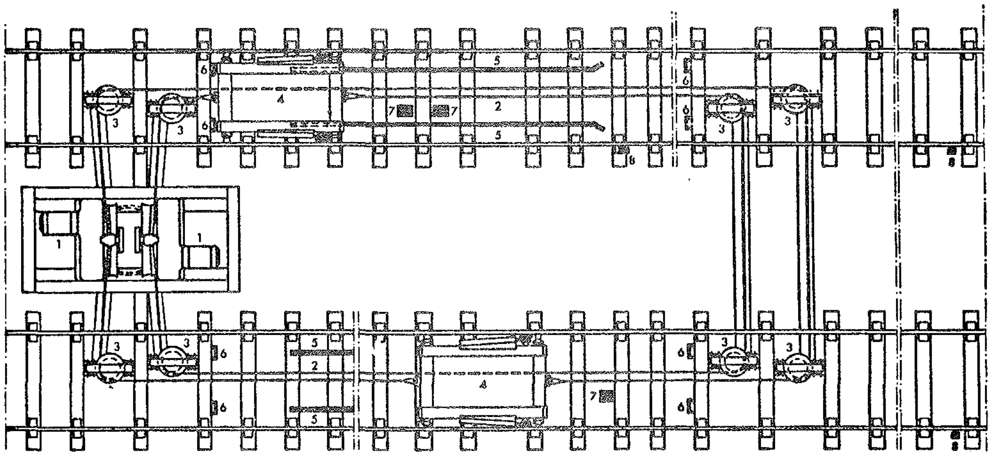
The cable trolley is used on the classification tracks to insure proper coupling and prevent stalls. The trolley is used in conjunction with clasp retarders or quasi-continuous control retarders in the switch area.

A schematic of a cable trolley system is shown in Figure 3-10. A low-slung car (trolley) rides between the running rails on the rail's mounting flanges. The trolley is low enough to pass under a freight car and has arms which can be extended to engage the wheels of a freight car and push it. The trolley is powered by a cable that runs the length of the class track. The power comes from an electric motor and drive system mounted to the side or below the tracks at the head of the class tracks.

A central control system and trackside sensors are used to control the trolley. The trolley is initially held at rest at the head of the class track. When a car leaves the tangent point retarder and passes the trolley, the trolley leaves its start station and moves down the track at constant speed. It eventually catches the car and engages its wheels with its pusher arms and keeps it moving at constant speed. Shortly

SCHEMATIC DIAGRAM OF AUTOMATIC WAGON HAULING SYSTEM
FOR MARSHALLING YARDS

1 Capstan	5 Guides
2 Rope	6 Stop
3 Deflection sheave	7 Limit switch
4 Carriage	8 Wagon sensor



An ASEA carriage on its way towards a railway wagon. Note the pushing rolls of the carriage near the wagon wheel. (F98360)

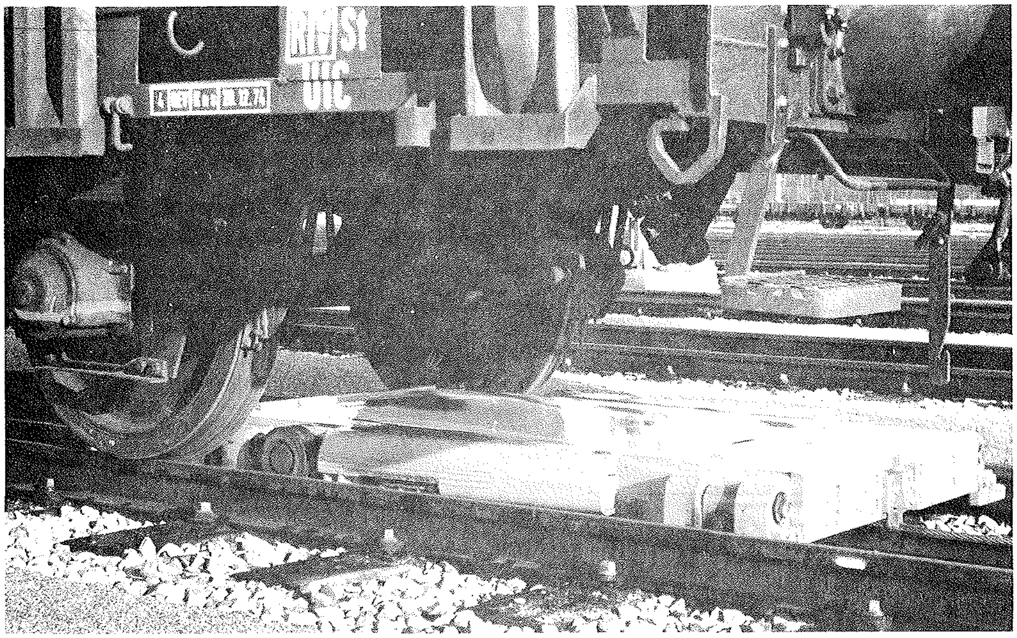


Figure 3-10. Cabled Powered Trolley

before reaching the previous car (now coupled) the trolley stops and lets the freight car coast to coupling, then return at higher speed to its start point. Track circuits are typically used to detect the last car. If a car enters the class track before the trolley releases the previous car, the trolley will stop and reverse to "catch" the new car, then push both cars to the release point.

This system is only installed on classification tracks. European railroads consider the extra expense of this system justifiable because European cars do not have automatic couplers. Cars must be pushed together at low speed or they will bounce apart. The cable system is a reliable way to prevent this.

3.10.2 Advantages

The cable trolley system assumes coupling of all cars at acceptable speeds and eliminates stalls. The cable trolley, pushing on both wheels of one axle, can move heavy cars or cuts.

3.10.3 Disadvantages

The system requires a control system (computer) and track sensors for its operation. Most systems can accelerate slow cars but cannot decelerate fast rollers. The rate at which cars can enter a class track is limited by the system's cycle time (the time required to move part way down the track and return). The system must be used with tangent point retarders, which adds to the expense of the entire yard. The high cost of such a system is difficult to justify in the United States where automatic couplers are used.

3.10.4 Extent of Use

Cable operated mule systems are in use in many large high-capacity yards in Europe, including Limmattal in Switzerland and Maschen, Basel-Muttenz II, Seelze and Mannheim in West Germany.

3.10.5 Cost Estimate

A cable system, which must include a cable drive, a trolley and a control system for each track, is highly complex. We estimate that the cost of a cable system alone would be comparable to the cost of a conventional speed control system for an entire yard.

3.11 HAUHINCO RECIPROCATING CABLE DEVICE

The Hauhinco reciprocating cable device is manufactured by:

Hauhinco Maschinen Fabrik
G. Hansherr, Jochums GmbH & Co. KG
Zweigerstrasse 28/30
D-4300 Essên 1, West Germany

3.11.1 Principle of Operation

The oscillating trolley is used on the classification tracks to move cars to coupling. It can be installed over a short length of track near the tangent point retarder or over the entire class track length.

A schematic of the Hauhinco oscillating trolley is shown in Figure 3-11. Small pusher trolleys run between special rails and each running rail. Each trolley has a pusher arm that engages one wheel to move a freight car. The trolleys are connected to a single cable that runs in a loop, down along one rail and back along the other. The cable is powered by an electric motor and drive. The motor's rotation is reversed cyclically, causing each trolley to move with an oscillating motion. The amplitude of oscillation, called the transport distance, is approximately one to two car lengths.

On the class track one cable can have several pusher trolleys on each side, each separated by the transport distance. At the endpoint of travel of each trolley, a control device is installed which raises the pusher arm when the trolley motion is in the direction of travel and lowers it when the motion is reversed.

When in operation one pusher trolley is always moving in the direction of car motion with its arm raised ready to engage the wheel of any car on that section. As cars enter the track, each one is engaged on one wheel and pushed to the next section where it is picked up and moved along by another trolley. The trolley can be single, to push only on one side of the wheel, or double, to trap the wheel between two arms and keep the car from accelerating.

3.11.2 Advantages

The oscillating cable system requires no control system and no trackside sensors to operate with the exception noted in 3.11.3. Only an on-off control is required. Since the transport distance and cycle time is short, there is no practical limit to the rate at which cars can enter the track.

3.11.3 Disadvantages

The pusher trolley pushes on one wheel of an axle at a time. This can skew a truck of a four-axle car and increase its rolling resistance. The device requires installation of two special rails as well as the other equipment required by a cable system (motors, cable, trolleys, etc.). As with all other car moving devices, this must be used with a speed control system in the switch area that delivers cars to the cable system at an acceptable speed.

3.11.4 Extent of Use

The Hauhinco oscillating trolley is used on several yards in Europe. In the new Maschen yard in West Germany, the system is used on a short section between siding retarders and a more conventional cable trolley system.

3.11.5 Cost Estimate

The cost for hardware for the oscillating trolley is estimated to be comparable to that for the cable trolley described earlier. No control system is required, however, so the total estimated cost will be lower.

3.12 JAPANESE LINEAR INDUCTION MOTOR CAR MOVER

A linear induction motor car mover was developed for the Japanese National Railroad.

3.12.1 Principle of Operation

The linear induction motor car mover (LIM) is designed for use on the classification tracks to move cars from the tangent point to coupling at a positively controlled speed. A schematic of the LIM is shown in Figure 3-12. The LIM consists of five separate cars or modules linked together:

- A pusher module containing the pusher arms that engage the wheels of a freight car.
- A brake car housing the braking device.
- A control car containing the computer system required for operation (no external computer is required).
- A motor car containing the linear induction motor acting on the central reaction rail.
- A distance car extending behind the other cars to detect approaching freight cars. It also measures car length and the distance of travel for each trip.

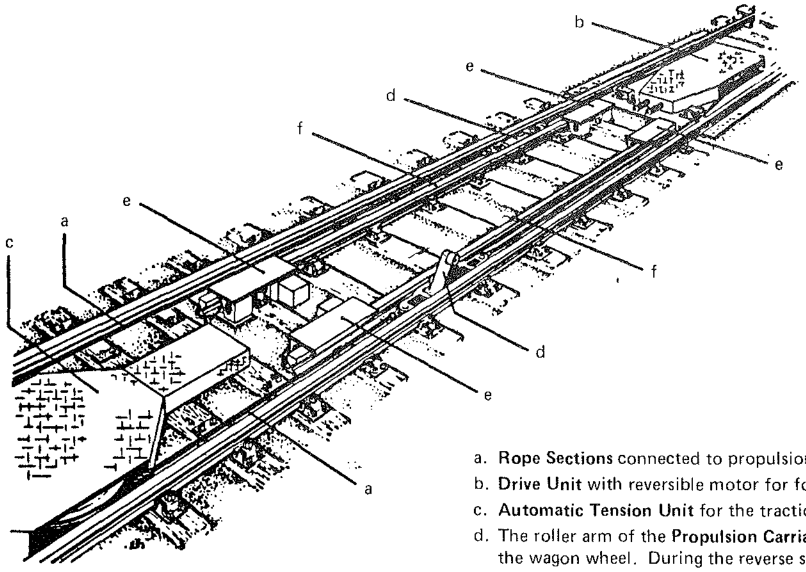
All the modules ride on special rails between the running rails.

The LIM is initially at rest at the head end of the class track. The distance car detects the approach of a freight car, and the LIM accelerates and "traps" the wheels of one axle with its pusher arms. The LIM then accelerates to a high speed for the trip down the class track. Just before coupling, the LIM decelerates to an acceptable coupling speed and releases the car. The LIM "remembers" the distance-to-travel from the previous car and subtracts the length of the new car to obtain the new distance-to-travel. The LIM then returns at high speed to its start point, ready for the next car. If the LIM encounters a new car on the class track before it reaches its start point, it will stop, reverse its direction, and "catch" the new car. The high

Hauhinco

WAGON HANDLING EQUIPMENT

BASIC COMPONENTS



a. **Rope Sections** connected to propulsion carriages form an endless traction system.
b. **Drive Unit** with reversible motor for forward and reverse haulage of the traction system.
c. **Automatic Tension Unit** for the traction rope.
d. The roller arm of the **Propulsion Carriages** is raised during the forward stroke to engage with the wagon wheel. During the reverse stroke the arm is lowered and relocked.
e. **Control Devices** raise the roller arm for the transport operation and lower and relock it when reversed.
f. **Guide Rails** run along the runner rails to form guide tracks for the propulsion carriages.

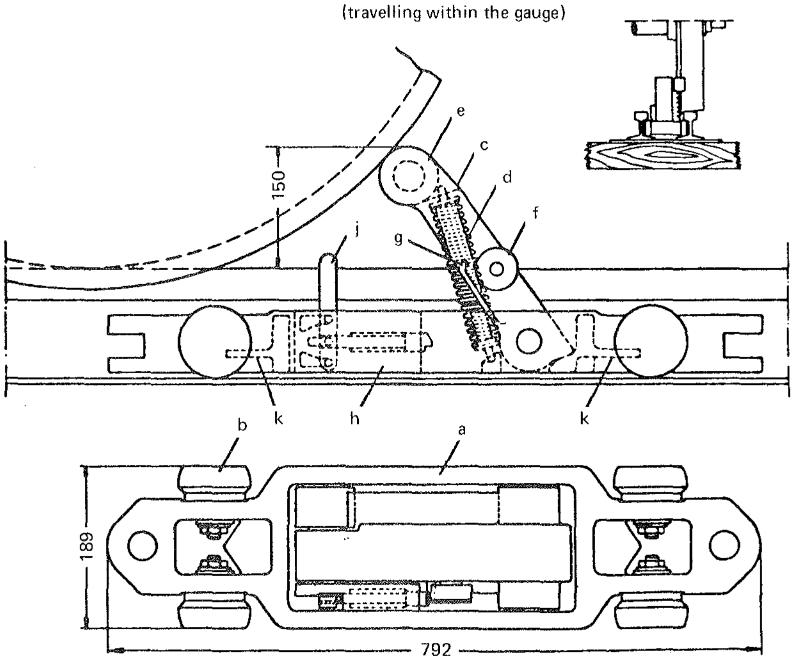
The wagon handling system can be controlled either manually or semi- or fully-automatic.

Hauhinco

Wagon Handling Equipment

C 1

Propulsion Carriage for engagement with the wheel flange (travelling within the gauge)



a propulsion carriage
b runner rollers
c roller arm
d pressure spring
e thrust roller
f guide roller
g locking piece
h dead lock
j release lever

At the points marked k signalling magnets can be screwed-on to initiate impulses through magnetic switches.

Figure 3-11. Reciprocating Cable System

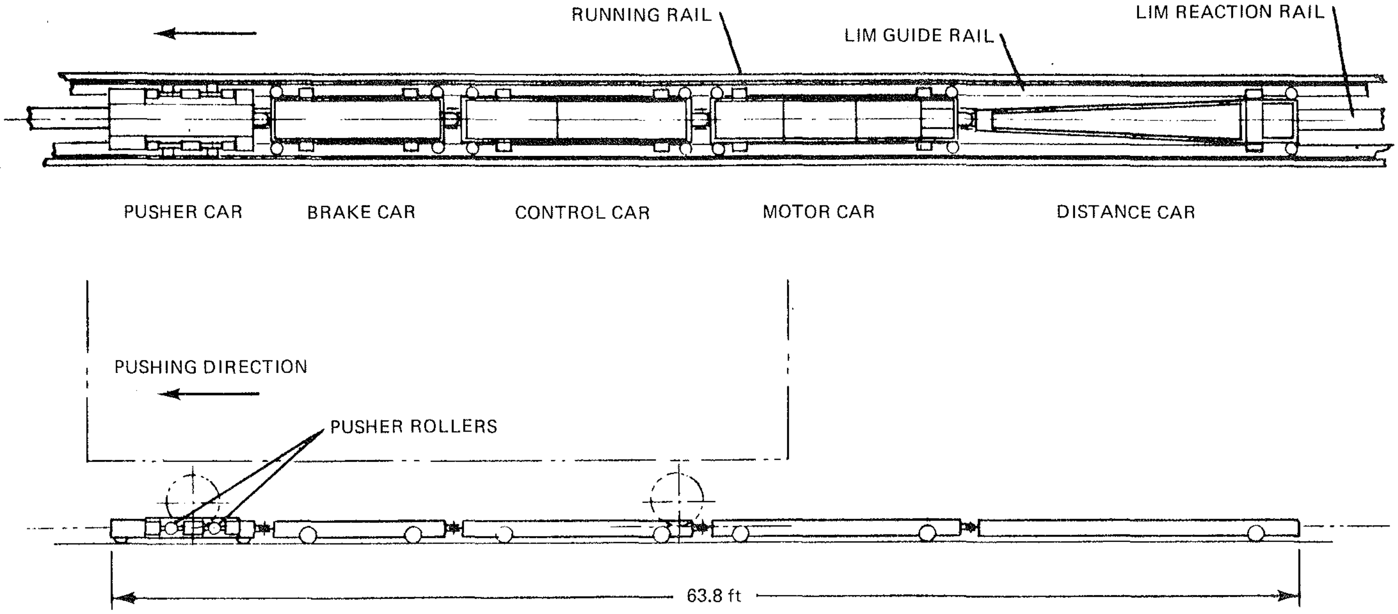


Figure 3-12. Linear Induction Motor Car Mover

tractive effort available from the LIM allows the rapid acceleration and deceleration required by its operation.

3.12.2 Advantages

The LIM is entirely self-contained and requires no external sensors or computers. Because the LIM can accelerate and decelerate a car and thus can move the freight car at high speed along most of its path, cycle time is minimized, allowing a higher rate of car entry onto the track.

3.12.3 Disadvantages

Each LIM train represents a large investment. Each car is quite complex and is likely to require a great deal of maintenance. Installation calls for special running rails and a LIM reaction rail. A power supply for the LIM is also required.

3.12.4 Extent of Use

The LIM car mover is used only in Shiohama, Fusotonada and Kitakami yards in Japan. It has not been marketed for sale.

3.12.5 Cost Estimate

The complex machinery and sophisticated electronics of this device indicate that the price will be high. We estimate the total cost to be greater than that for a cable system. The maintenance costs would also be high.

3.13 FRENCH SELF-PROPELLED CAR MOVER

A self-propelled car mover was developed for the French National Railroad.

3.13.1 Principle of Operation

The French self-propelled car mover is designed for use on the classification tracks to move cars from the tangent point to coupling at a positively controlled speed. The car mover is a low-slung pusher car that rides on special rails between the normal rails. The car rolls on rubber tires and is powered by a 48-volt 350-ampere electric motor drawing power from a third rail. The exact specification of the control system is unknown, but its operation is assumed to be similar to that of the LIM.

3.13.2 Advantages

The French car mover is able to accelerate and decelerate a car, thereby shortening the transit time. No cable system is required.

3.13.3 Disadvantages

Each car is expensive, complex, and difficult to maintain. The tractive force, and hence the acceleration and deceleration, is limited by the rubber tires; traction would be reduced in wet weather.

3.13.4 Extent of Use

The device has been installed in the Ambèrieu yard in France on a trial basis. No further development is planned.

3.13.5 Cost Estimate

The cost of the French self-propelled car mover is estimated to be comparable to that of the cable trolley system. Its cost should be less than that of the Japanese system because it is less complex.

3.14 SUMMARY OF DEVICE EVALUATION

As a quick reference, a one-box assessment sheet for each of the 13 devices was prepared. This device assessment package is appended to this section as Section 3.15.

Most of the 13 devices evaluated are considered unlikely candidates for application in the United States for a variety of reasons. The Hydrabrake retarder, for example, was never designed for classification yard use. In addition, the primary function of some devices is to improve the coupling performance of cars without automatic couplers, but the better performance is achieved at the expense of high capital and maintenance costs. Falling into this category are the French self-propelled car mover and the cable devices. The rubber retarder and Faiveley's hydraulic retarder are still in their development stages; their potential as speed control devices in classification yards is yet to be demonstrated. Finally, there is the ASEA spiral retarder: Its adaptation to the U.S. yards is questionable at present because of its above-rail protrusion problem.

In view of the advantages and disadvantages discussed in relation to each system it seems that speed control devices best suited for use in the United States are:

- The full control clasp retarder (Section 3.1)
- The weight responsive clasp retarder (Section 3.2)
- The inert clasp retarder (Section 3.3)
- The electrodynamic retarder (Section 3.4)
- The Dowty hydraulic retarder (Section 3.6).

3.15 CONDENSED SUMMARY OF SPEED CONTROL DEVICES

In Figures 3-13 through 3-25 a summary of speed control devices is graphically presented in condensed form.

Assessment sheet #1

FULL CONTROL CLASP RETARDER

Operating principle: clasp of wheel rims by beam brake shoes

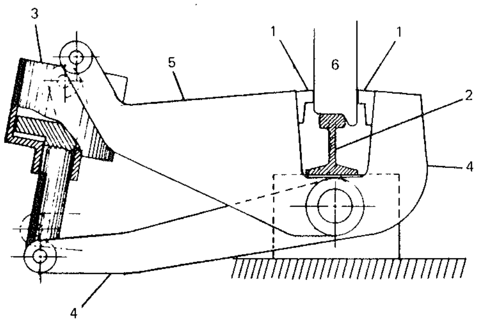
Special features: power supplied by compressed air or electric motor; retardation force variable from 0 to maximum in several steps

Application: on switch area tracks

Detrimental features: none

Order of magnitude cost estimate: approximately $0.15/ft-lbf plus cost of computer system and software

Remarks: successfully used in the U.S. and foreign countries for years; improved performance via the adoption of automatic control; cost of control system can be substantial, retardation by friction creates wheel squeal noise



1. BRAKE SHOE
2. RUNNING RAIL
3. ACTIVATING CYLINDER
4. LOWER LEVEL ARM
5. UPPER LEVEL ARM
6. WHEEL

Figure 3-13.

Assessment sheet #2

WEIGHT RESPONSIVE CLASP RETARDER

Operating principle: employment of fulcrums allows clasp force to vary in proportion with car weight

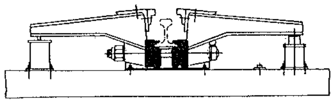
Special features: incorporation of hydraulic piston allows a one-time release of retarder per car

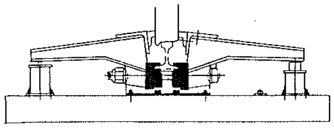
Application: on switch area or classification tracks

Detrimental features: none

Order of magnitude cost estimate: approximately $0.1/ft-lbf plus cost of computer system and software

Remarks: because of their low cost, these retarders are commonly used in smaller hump yards and on tangent tracks of big hump yards


RETARDER CLOSED — NO CAR PRESENT


RETARDER CLOSED — CAR PRESENT

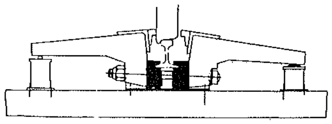

RETARDER OPEN — CAR PRESENT

Figure 3-14.

Assessment sheet #3

INERT CLASP RETARDER

Operating principle: spring loaded retarder beams

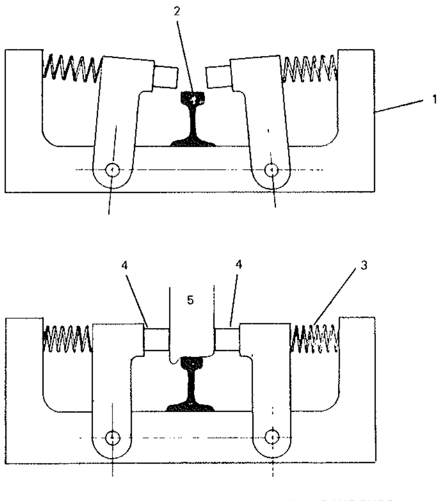
Special features: noncontrollable

Application: at the end of a classification track to prevent runouts

Detrimental features: none

Order of magnitude cost estimate: approximately $0.03/ft-lbf

Remarks: more of a safety device than a speed control device



1. RIGID FRAME
2. RUNNING RAIL
3. SPRING
4. BRAKE SHOE
5. WHEEL

Figure 3-15.

Assessment sheet #4

ELECTRODYNAMIC RETARDER

Operating principle: retardation is effected by both friction and eddy current

Special features: retardation is proportional to the current and the wheel speed; less moving parts than a conventional retarder; requires a high current power source

Applications: identical to a conventional retarder

Detrimental features: may create severe electromagnetic interference problem

Order of magnitude cost estimate: system cost is expected to be comparable to that of a weight responsive conventional retarder system

Remarks: from a user's point of view, the close similarity between an electrodynamic retarder and a conventional retarder hardly makes the former a novel device

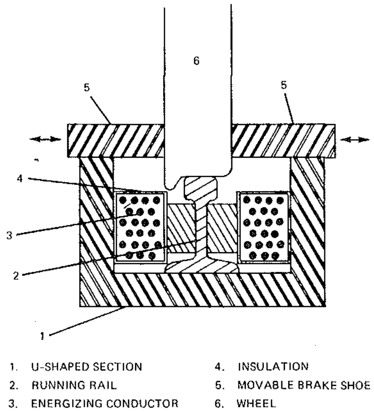


Figure 3-16.

Assessment sheet #5

RUBBER BEAM RETARDER

Operating principle: energy is absorbed by deformation of a rubber rail

Special features: the rubber rail can be raised and lowered depending on whether retardation is needed; when the rubber rail is lowered, the car rolls on its wheel flanges

Application: unspecified; presumably on both switch area and classification tracks

Detrimental features: inconsistent performance from season to season due to sensitivity of rubber properties to temperature; flange loading may cause wheel damage

Order of magnitude cost estimate: capital investment cost is expected to be comparable to that of a weight responsive conventional retarder system; maintenance cost may be high because the durability of the rubber has not been established

Remarks: in use in Maschen, Germany, yard; the higher axle loads of the U.S. cars will put more strain on the rubber section

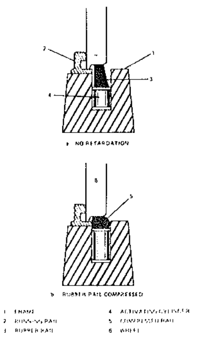


Figure 3-17.

Assessment sheet #6

DOWTY HYDRAULIC RETARDER

Operating principle: forcing hydraulic fluid through metered orifices

Special features: entirely self contained; negligible energy absorption below a threshold speed; threshold speed preset in the factory

Applications: can be used on both switch area and classification tracks

Detrimental features: none

Order of magnitude cost estimate: approximately $350/unit, or $0.35/ft-lbf

Remarks: definitely beyond development stage; deployed in more than 10 yards around the world; offers a distinct alternative to the conventional target shooting system; booster unit available from Dowty, but its high cost and need for a hydraulic network greatly diminish its popularity

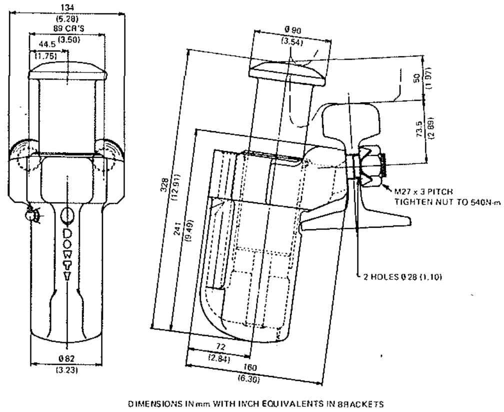


Figure 3-18.

Assessment sheet #7

ASEA HYDRAULIC RETARDER

Operating principle: forcing hydraulic fluid through metered orifices

Special features: entirely self contained; negligible energy absorption below a threshold speed; threshold speed preset in the factory; can be retracted to deactivate

Applications: can be used on both switch area and classification tracks

Detrimental features: the spiral cylinder protrudes 5 inches above rail head in the operating mode, thus presenting a clearance problem

Order of magnitude cost estimate: cost per ft-lbf should be somewhat higher than the Dowty retarder, because of the necessary compressed air system

Remarks: beyond development stage; primary deployment is in Europe; clearance problem, unless corrected, is considered intolerable by U.S. rail companies

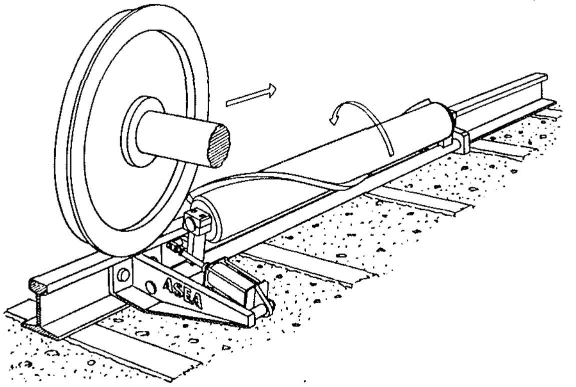


Figure 3-19.

Assessment sheet #8

FAIVELEY RETARDER

Operating principle: forcing hydraulic fluid through metered orifices

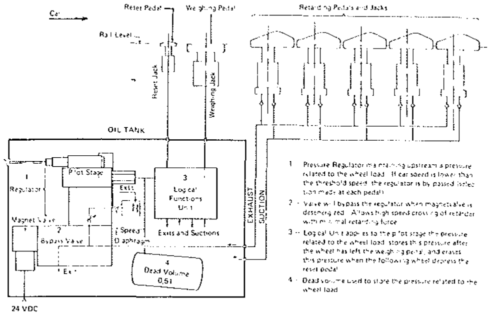
Special features: one hydraulic regulator controls five retarding heads; self contained; negligible energy absorption below a threshold speed; threshold speed preset; axle load is measured and is used to vary the retardation force

Application: on classification tracks

Detrimental features: has to be deactivated for high-speed (>9 mph) or reverse movement; external power needed to deactivate device; special section of rail needed to install

Order of magnitude cost estimate: expected to be higher than Dowty and ASEA retarders because of added complexity

Remarks: except for the weight responsive feature, this device is very similar to the Dowty and the ASEA retarders; it has only been installed on one track of a French yard to date



1 — Pressure Regulator maintaining upstream a pressure related to the wheel load. If car speed is lower than the threshold speed the regulator is by passed (selection made at each pedal)

2 — Valve will bypass the regulator when magnet valve is deenergized. Allows high speed crossing of retarder with minimal retarding force

3 — Logical Unit applies to the pilot stage the pressure related to the wheel load, stores this pressure after the wheel has left the weighing pedal, and erases this pressure when the following wheel depress the reset pedal

4 — Dead volume used to store the pressure related to the wheel load

Figure 3-20.

Assessment sheet #9

HYDRABRAKE RETARDER

Operating principle: forcing hydraulic fluid through metered orifices

Special features: entirely self contained; no threshold speed, hence every passing wheel is retarded

Application: on both switch area and classification tracks

Detrimental features: the device has no internal logic and no provision for external control

Order of magnitude cost estimate: expected to be less expensive than the Dowty and the ASEA retarders

Remarks: the lack of control of this device puts it in the same class as an inert retarder; device was developed in England, and was distributed by Whiting Corp. in Harvey, Ill.; Whiting has since discontinued its distribution because of the inferior performance of the device

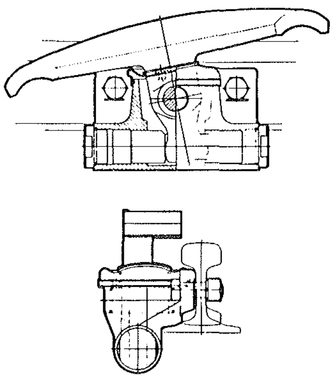


Figure 3-21.

Assessment sheet #10

ASEA CABLE POWERED TROLLEY
HAUHINCO CABLE POWERED TROLLEY

Operating principle: externally powered cable system propelling a low-profile carriage

Special features: none

Application: on classification tracks and sidings

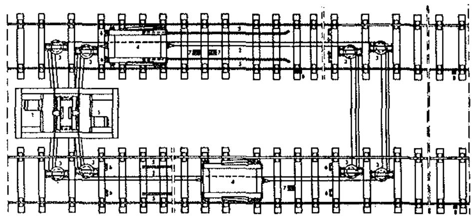
Detrimental features: unknown

Order of magnitude cost estimate: no dollar value is available; the complexity of the device indicates that a production system would still be many times the cost of a tangent point retarder system

Remarks: a modified version of the ASEA device is being used in Limmattal yard near Zurich; the very high cost of Limmattal yard is undoubtedly partially contributed to by the high cost of this device

SCHEMATIC DIAGRAM OF AUTOMATIC WAGON HAULING SYSTEM FOR MARSHALLING YARDS

1 Capstan	5 Guides
2 Rope	6 Stop
3 Deflection sheave	7 Limit switch
4 Carriage	8 Wagon sensor



An ASEA carriage on its way towards a railway wagon. Note the pushing rolls of the carriage near the wagon wheel. (F98360)

Figure 3-22.

Assessment sheet #11

HAUHINCO RECIPROCATING TROLLEY

Operating principle: an externally powered cable system

Special features: an oscillating cable system with ratchet-action arms; no control system is required

Application: on classification tracks

Detrimental features: none

Order of magnitude cost estimate: like the ASEA cable device, cost is expected to be many times that of the tangent point retarder system

Remarks: the oscillating feature of this device allows continuous feeding of cars into the cable equipped section of track; pushing one wheel could aggravate truck skewing; in our opinion, it is one of the more practical devices among all cable-like devices

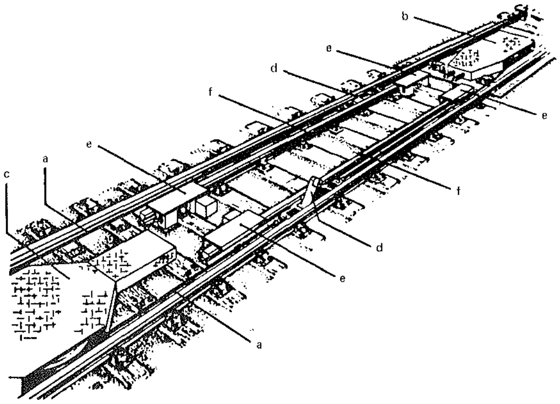


Figure 3-23.

Assessment sheet #12

JNR LINEAR INDUCTION MOTOR CAR MOVER

Operating principle: similar to cable devices but with linear induction motor supplying the motive force

Special features: the low profile carriage consists of five units – pushercar, brakecar, controlcar, motorcar, distancecar, self contained as far as control system is concerned

Application: on classification tracks

Detrimental features: unknown

Order of magnitude cost estimate: system cost is expected to be an order of magnitude higher than that of a tangent point retarder system

Remarks: the system can be thought of as an industrial robot device; in our opinion, it is still in its experimental stage; the extreme complexity of the device, hence the accompanying high cost, makes it very unlikely to compete with other devices

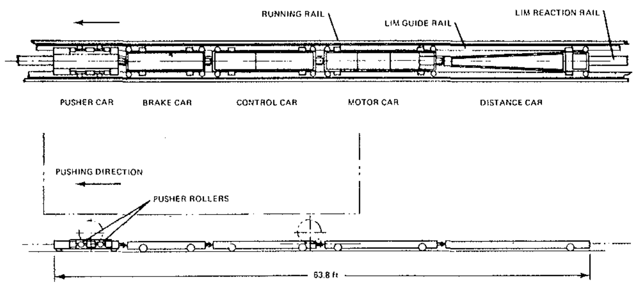


Figure 3-24.

Assessment sheet #13

SNCF SELF-PROPELLED CAR MOVER

Operating principle: low-profile carriage powered by an internal electric motor

Special features: carriage runs on rubber tires between rails; power from a third-rail, self-contained control system; can boost or retard a car

Application: on classification tracks

Detrimental features: unknown

Order of magnitude cost estimate: system cost is estimated to be higher than for cable operated pusher systems due to complexity of each car and its control system

Remarks: system is similar in concept to the JNR linear motor car; developed for SNCF and since discontinued due to poor cost effectiveness; in use in only one yard in France

(Illustration not available)

Figure 3-25.

SECTION 4 — SPEED CONTROL SYSTEMS

4.1 FOUR IDENTIFIED SYSTEMS

To accomplish its speed control function, a hump yard usually employs at least one type of speed control device. The devices are supplemented with other essential components and subsystems to make up a speed control system. A speed control system in a modern hump yard belongs to one of four generic systems.

1. System 1: The conventional system employing clasp retarders and target shooting logic.*
2. System 2: The quasi-continuous control system.
3. System 3: A hybrid system employing clasp retarders and quasi-continuous control devices.
4. System 4: A hybrid system employing clasp retarders and car movers.

The above classification of systems is by no means encompassing. From yard to yard, no two systems are alike. Yard design is necessarily customized: The designers of a new yard must consider factors such as the anticipated traffic pattern, the types of cars and cargos to be handled, the existing topography of the land, the effects of the yard on the surrounding communities, and the target performance of the yard, (e.g., throughput and average car retention time). Efforts by yard designers to incorporate the most current technological advances create differences in the generic systems from year to year and are manifested in yard-unique features. For example, because of the large distance between crest and tangent points, some groups of tracks in Southern Pacific's West Colton Yard are equipped with intermediate retarders in addition to the conventional master, group, and tangent point arrangement. As another example, the speed control systems of Limmattal Yard in Switzerland and of Maschen Yard in West Germany can both be classified as System 4 systems, but they differ in detail. Because the cable devices on the class tracks of either yard can only receive cars moving within a very narrow speed range, auxiliary speed control devices must be installed just upstream of the cable device. In the Limmattal Yard, the auxiliary devices are electrodynamic retarders and Dowty retarders; the Maschen Yard uses rubber retarders and oscillating cable devices (for further details, see Appendix A). Despite these yard-unique features, the generic speed control system classifications are sufficiently general in that most state-of-the-art hump yards belong to one of the categories.

4.2 THE ADVANCED CLASP RETARDER SYSTEM

4.2.1 System Description

The system is named for the traditional clasp retarders used as speed control devices. Yards representative of this system are West Colton of the Southern Pacific line and Barstow of the Santa Fe line. Typically, this system employs a master retarder between the crest and the first switch, a number of group retarders in the switch area, and a tangent point retarder for each of

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*The term "target shooting" refers to the objective of getting a free-rolling car to a specific point on the track at either a "target" time or a "target" velocity.

the class tracks.* The master and the group retarders function (1) to ensure adequate headways between cars and, (2) to limit the speeds of cars on curves to below 15-17 mph. Satisfactory performance of these functions requires that the retarders be opened and closed on command, so full-control clasp retarders are ordinarily used. The task of the tangent point retarder is to ensure proper coupling speed. Once the car's rollability† on the class track is predicted and the distance-to-couple is known, proper coupling speed can be achieved by controlling the exit speed of a car from the tangent point retarder. Since the task of the tangent point retarder is comparatively simple, the less expensive weight responsive retarder, featuring a one-time release of retarder per car, is often used. Most yards prevent rollout by having negative grades at the end of the class tracks, where inert retarders are installed. The inert retarder can be considered more a safety device than a speed control device.

From the above discussion, it is clear that the control "points" in a conventional system are few and are spaced apart, necessitating the use of a target shooting scheme. Many measuring and feedback control schemes exist. In a sophisticated form of such a scheme, a car's rolling resistance is measured prior to its entry into the master retarder or the group retarder. This tangent track rollability is used to predict the rolling characteristic of the car when it reaches the bowl track. In addition, the rolling behavior of this car between the master and the group retarder is monitored; this "integrated" rollability is used to predict the car's behavior between the group and the tangent point retarder. Based on these predicted rollabilities, the retarder control algorithm calculates the amount of energy to be removed by each retarder so that the car under control will reach a point along the track at either a target time or a target speed.

4.2.2 Supplementary Equipment and Systems

The above description of the operating principle of the advanced clasp retarder system makes clear that the target shooting scheme requires a host of information. Many supplementary measuring devices, data transmitting and processing systems and control software, in addition to the more obvious clasp retarders along the tracks, are needed to gather that information. A list of these auxiliaries follows. A yard would not necessarily have all this equipment, but systems in other yards may contain supplementary equipment that is not listed here.

- Retarder power supply system--May contain an air compressor and air distributing system, a hydraulic oil supply system, and an electric power supply.
- Weigh scale or weigh rail--Measures the weight of a car to be used in the process control computer. It is usually installed near the crest.
- Photodetector--A beam interception optical device commonly used to measure car length from coupler to coupler. It is also installed near the crest.
- Wheel detectors--Usually magnetic devices triggered by a passing wheel. Hundreds of them are used in an automatic yard. Their functions range from measuring car rollability to initiation of speed measurement by a radar.
- Radars--Primarily used to determine speed of a car in the retarder section.
- Track circuits or presence detectors--Used to determine the presence of a car in a retarder or in a switch.
- Distance-to-couple track circuit--Provides the process control computer with the track fullness information when installed on a bowl track.
- Signal cables.
- Relays.
- Process computers--Backup computers are installed since most modern yards are too complex to operate manually. The computers are usually on hot standby.
- Software program--Developing a program which incorporates the control logic for the retarders is no trivial task. After the program is made to work, years of periodic "calibrations" are needed to improve the performance of a new speed control system.

4.2.3 Operation and Maintenance

Since the system is highly automated, the primary responsibilities of the operating personnel are monitoring and manual overriding in case of emergency. The complexity of the system, however, necessitates a high level of maintenance. While certain maintenance tasks are quantifiable (e.g., the periodic replacement of retarder brake shoes), others are not. As an example, consider the task of finding the source of and correcting an incorrect or poor quality signal from a wheel detector. The cause of this failure mode could be a defective detector, a broken cable, a poor contact in a relay, a defective signal processor, or an electromagnetic interference, among other possibilities. Depending on how critical the situation is, at least one of the yard personnel (most likely an electronic technician) will be assigned to the job. The task could take a few minutes or a few days to complete, so any attempt to make a quantitative statement about the maintenance of the system in terms of either cost or manpower would be futile. A survey of the numbers of maintenance crew relegated to the yard speed control systems in various existing yards would help, however, in estimating the overall economics of a system.

4.2.4 Qualitative Assessment

Major disadvantages of the clasp retarder system are the widely spaced control points of the system and the unpredictability of the car's rolling resistance. It is common knowledge among yard personnel that a car's rolling resistance from crest to couple is not a constant. The rollability measured in the switch area is often more than twice that experienced on a bowl track. Explanations range from wheel bearing warm-up to truck straightening by the tangent point retarder,

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*In this evaluation of state-of-the-art speed control systems, the focus has been on the advanced clasp retarder system, namely, one that employs master, group, and tangent point retarders. Most hump yards in the United States do not use tangent point retarders. For a smaller yard with less of a demand in performance, the latter practice could be more cost effective. A limited discussion of some of the low-cost speed control systems can be found in Appendix E.

†Used interchangeably with rolling resistance.

but definitive proof is nonexistent. The use of sophisticated computer control helps to alleviate the problem but does not eliminate it. If the car's rollability changes after the retarder, no correction can be made until the car reaches the next retarder, if there is one. The most advanced retarder control logic relies heavily on the statistical behavior of many cars. The problem it faces, however, can be compared to trying to predict a person's life span using statistical life expectancy data.

Another disadvantage of this system is the use of clasp retarders. The effectiveness of these retarders can be greatly reduced if foreign material gets trapped between the wheel rim and the retarder shoe resulting in a loss of friction. Contaminated wheels carrying such foreign material are encountered periodically, and in rail transport history a number of spectacular accidents in yards were caused by contaminated wheels. Government regulation now forbids cars laden with hazardous material to be released over the crest. Handling these special cars in a yard is expensive, but the cost of accidents is prohibitive.

The higher the automation of a clasp retarder system, the more it relies on sophisticated electronics. The system becomes more susceptible to electromagnetic interferences (EMI). This problem is well organized, and FRA has an on-going project to assess its extent.

Clasp retarders generate another well publicized problem--the high intensity wheel squeal noise. This noise not only is annoying to the communities surrounding a yard, but also could be damaging to yard crew who are exposed without proper ear protection. Federal noise standards have been anticipated for several years. The problem facing the railroad industry, however, is the lack of an effective solution to this problem other than erecting costly sound barriers or applying a messy and sometimes dangerous lubricant in the retarder section.

An advantage of the advanced clasp retarder system is that it generally requires a significantly low capital investment. This is particularly true in some of the small yard configurations in which fewer retarders and perhaps no automatic control systems are installed (see Appendix B). On the other hand, an elaborate system that constitutes a state-of-the-art conventional speed control system enjoys less of a cost advantage when compared with other optional systems available.

The clasp retarder system, however, is still favored in the United States. Because of the vast amount of experience with its operation, a clasp retarder system chosen for a new yard will involve fewer unknowns as far as yard performance, accessibility of vendors, yard operators training, and so on are concerned.

4.2.5 Potential Improvements

During the many years that the clasp retarder system has been used, the system has evolved and improved. Today's highly automated system is a dramatic contrast to the old manual system in which the retarder operator, from sheer experience, judges a car's rollability and the amount of retardation appropriate for that car. The research for this project exposed a number of existing problems with even the most current clasp retarder systems, however. These areas should be pinpointed for potential improvement. The solutions sought are not trivial or cost effective, otherwise they would probably have been implemented.

Despite the sophistication of the computerized system, cars are still misswitched and overspeed couplings happen in the yard on occasion. Part of the problem stems from the lack of appropriate rollability data and, more specifically, the inability to predict the car's rollability over a nonmeasuring section of the track from the rollability data of a measuring section. If the rollabilities of a large number of cars can be continuously monitored from crest to couple, statistical correlations could be established between the nonmeasuring and the measuring sections. It is not known if such a monitoring technique is available. The development of a technique that would provide continuous rollability data of a statistically meaningful number of cars in a cost-effective manner should represent a real challenge to researchers.

Even with the rollability data presently measured in a state-of-the-art yard, performance of the advanced clasp retarder speed control system could be improved if a more advanced retarder control algorithm is used. Several proposed schemes that are based on the fundamental idea of considering the relative motion of two consecutive cars instead of the motion of a single car (or cut) are presented in Appendix C.

As mentioned in Section 4.2.4, retarder squeal noise has become more of a problem in our environment-conscious society. Considering the number of people affected, from yard personnel to residents in the communities surrounding a yard, the amount of money spent on research seeking a solution to this problem has been minimal. A satisfactory solution to this problem has yet to be found.

The development of retarders that cost less is always desirable. In smaller yards, where the degree of automation is kept to a minimum, the cost of the retarders often becomes a major factor in making decisions. Even among big yards, the cost of the tangent point retarders has limited the installation of these retarders to only a handful of yards.

4.3 THE QUASI-CONTINUOUS CONTROL SYSTEM

4.3.1 System Description

In the 1960s revolutionary car retarding devices appeared in the European classification yards. Unlike the conventional clasp retarder, with which a large amount of a car's kinetic energy is dissipated in a relatively short section of track via friction, each new device absorbs only a moderate amount of energy. As a result, a large number of these devices must be installed along a track in order to keep the speed of a car within a design limit. This feature of closely spaced control points along a track is responsible for the name "quasi-continuous control system."

The pioneer of these devices was a hydraulic unit developed by the Dowty Corporation of England. The first generation of Dowty retarders, which was powered by a network of high-pressure (3,000 psi) hydraulic pipes, was installed in the Tinsley yard in England. The result was not totally successful because of the difficulty of containing leakage. Dowty has since developed three other generations of retarders, all of them self-contained hydraulic units. In the meantime, the Swedish firm of ASEA developed a spiral retarder which employs the same principle as the Dowty retarder but is capable of extracting seven times the energy from a passing wheel than a Dowty retarder can. More recently, a French company named Faiveley developed a sophisticated hydraulic retarder which can extract 16 times the energy of a Dowty retarder. In addition, its energy absorption is designed to be proportional to the axle load of the passing wheel. Detailed descriptions of these devices are found in Section 3. Also described in Section 3 is a simple hydraulic retarder called the Hydrabrake retarder. There is no evidence that this device has ever been used in a classification yard, mainly because it retards without taking into consideration a car's speed.

As discussed in Section 3, all of these innovative devices employ the same principle, namely, energy dissipation in a forced fluid flow. The devices are rail mounted and installed at close intervals from the end of the acceleration grade near the crest to a point well past the tangent point. Figures 4-1 through 4-3 are photographs of the Dowty, ASEA, and Faiveley retarders in their respective yards. It should be pointed out that the Faiveley retarders are still in their experimental stage. No yard is equipped exclusively with Faiveley retarders. The retarders seen in Figure 4-3 are units being field tested in Ambérieu Yard in France.

The operation of a quasi-continuous control system is best described by following a free rolling car from hump to couple. As in a clasp retarder yard, a car leaving the crest quickly accelerates on a steep grade. Such acceleration generates the headways between consecutive cars to allow switching operation. At the end of the accelerating grade, the car encounters the hydraulic retarders, all set at the same threshold speed. All cars moving faster than the threshold speed will be retarded until their speeds are, for all practical purposes, equal to the threshold speed. On the other hand, sufficient grade is maintained in the

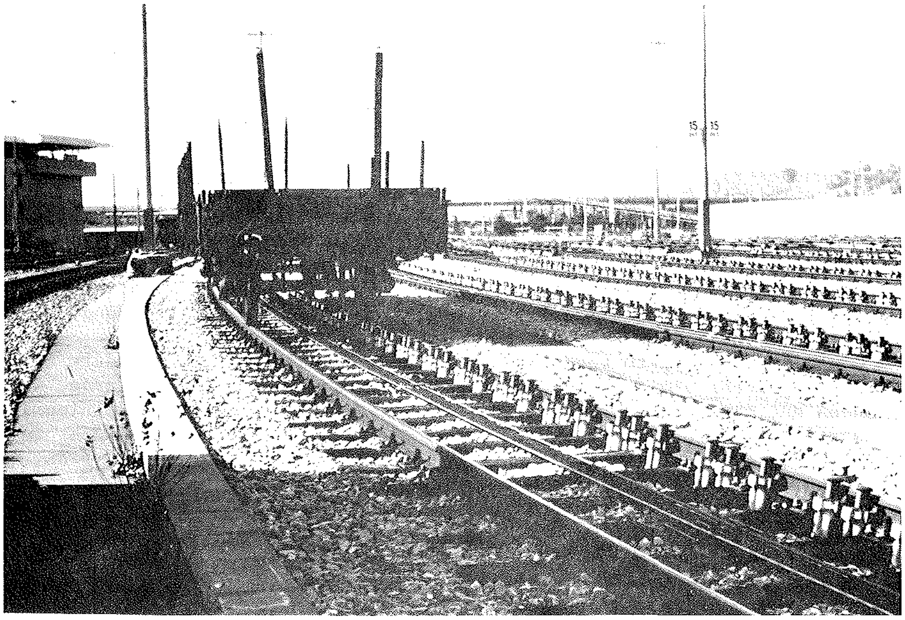
Figure 4-1. Dowty Retarders in Limmattal Yard

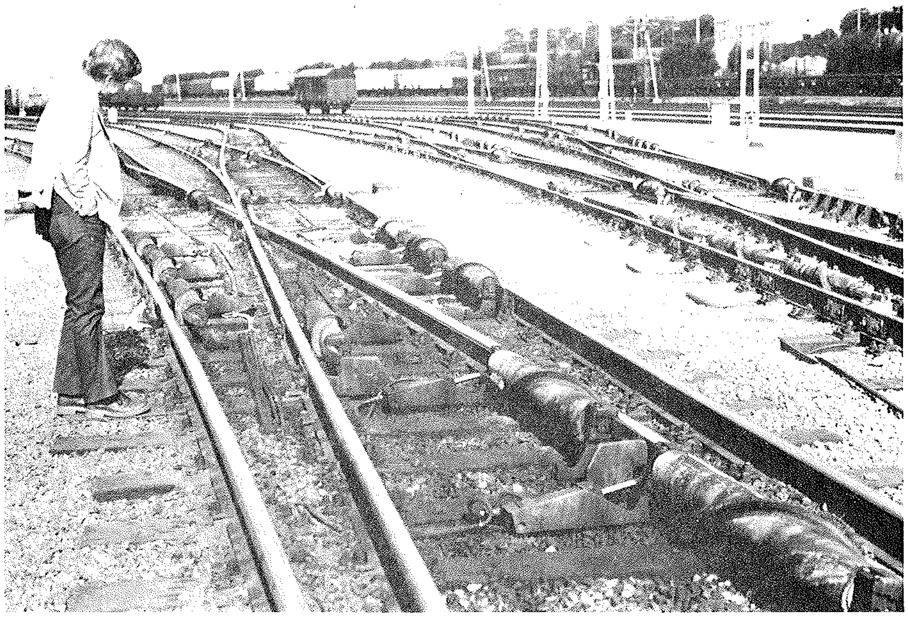
Figure 4-2. ASEA Retarders in Helsingborg Yard

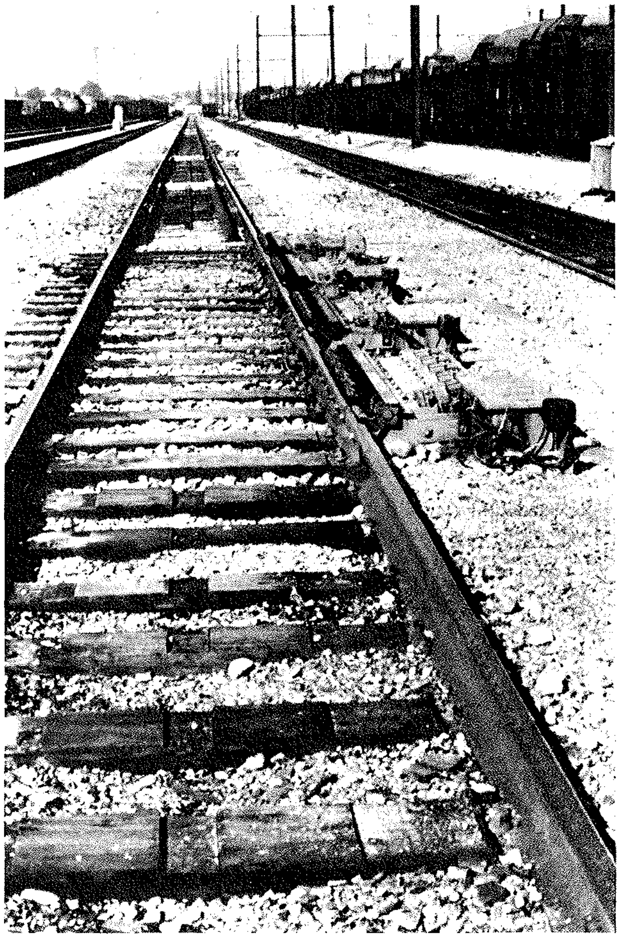

Figure 4-3. Faiveley Retarders in Ambérieu Yard

retarder section to keep the hard rollers moving at or near the threshold speed. (The uniform speed of all cars means that the original headways will be maintained throughout the constant speed zone.) Beyond the clearance point comes a short section of deceleration zone where densely packed retarders quickly slow the car from its switch area speed to the desired coupling speed.

Unlike the advanced clasp retarder system, the quasi-continuous system has a control zone that extends beyond the tangent point, usually to one-third or one-half the length of the class tracks. There are also two grades in the class yard. The upper portion of each of the class tracks has a steeper grade than the lower portion and has widely spaced retarders along that portion of the track. Here, all retarders have their threshold speeds set equal to the desired coupling speed. The density of the retarders is designed to keep the easiest rolling cars from exceeding a design maximum speed between retarders. The grade is chosen to prevent the hard rollers from stalling in this section. Except at the very end, the remainder of the class tracks are free of retarders. The grade in this portion is made to be nonaccelerating for an easy roller--just as in a clasp retarder yard. A short section of reverse grade is built in at the end of each class track to prevent rollout. As an added safety measure, retarders with zero threshold speed setting are usually installed there.

4.3.2 Supplementary Equipment and Systems

From the above description, it is clear that, with a quasi-continuous control system, the speed of each car through the yard is controlled by the internal "logic" of the retarders. They will retard cars having above threshold speeds but will offer little resistance to cars moving at less than the threshold speed. No external logic and control systems are needed, limiting the supplemental equipment needed to spare parts and maintenance shops. For some retarders, such as the ASEA spiral retarders, special inspection equipment in the form of an instrumented car is needed.

4.3.3 Operation and Maintenance

As in a fully automated clasp retarder yard, the responsibility of the operating personnel is primarily monitoring. Routine maintenance is expected to be simpler than that of a conventional system because there are no sophisticated electronics. All maintenance will be mechanical. There should be no signal work insofar as the speed control system is concerned.

4.3.4 Qualitative Assessment

The primary advantages of a quasi-continuous control system are:

- It is less affected by change in rollability.
- It is immune to contaminated wheels and electromagnetic interferences (EMI).
- There are potential savings in reduced car and lading damages due to improved coupling performance.
- Negligible yard downtime in the case of Dowty yard.

The primary disadvantages are:

- Higher capital cost.
- Little operating experience in the United States.
- Potentially greater operating cost if the system results in higher percentage of stalled cars.

Some of these advantages and disadvantages will be discussed in more detail below.

Because of its closely spaced control points, a quasi-continuous control system is less affected by changes in a car's rollability than a conventional system is. The extended control region along a class track reduces the free-roll length, which should potentially improve the coupling performance, but there are two opposing factors that could alter this expectation. The first is that the release speed from the last retarder in a quasi-continuous system is always equal to the threshold speed of that retarder and, therefore, is constant for all cars regardless of their rollabilities. In a clasp retarder system with tangent point retarders the release speed is calculated according to the anticipated rollability of the car and its distance to couple. However, according to the limited data collected, the anticipated rollability bears almost no relationship to the actual rollability on the class track. There is a question of how much benefit the advanced clasp retarder system reaps in attempting to compensate for differences in rollability.

When railroad personnel discuss the unpredictability of a car's rolling resistance on a class track, truck skewing and center plate friction are the major factors contributing to this unpredictability. Some railroad personnel believe that the use of tangent point retarders helps to alleviate the truck skewing problem, but it is not known whether the repeated pounding of the wheels going over the hydraulic retarders in a quasi-continuous system would also eliminate center plate sticking. If so, then the range of variation in rollabilities among cars is expected to narrow, and the coupling performance is expected to improve. In our quantitative analysis of the quasi-continuous system, the penalty due to constant release speed is accounted for, but the potential benefit of center plate loosening is not because there is no data to quantify this factor. Despite an enormous amount of effort expended in the quantitative analysis, the results should be viewed with caution because many factors affecting the performance of a system are unquantifiable at present.

Since a quasi-continuous control system does not rely on friction or on a host of electronic components to control the speed of cars, this system should be immune to wheels contaminated with slippery material and to electromagnetic interferences.

A more subtle advantage of the quasi-continuous control system, which applies more to the Dowty retarders than to either the ASEA or the Faiveley retarders, is that the system's performance is not noticeably degraded when a few retarders among the hundreds along a track are out of service. In the Dowty system, with the ease of inspection (visual) and replacement (by pulling out a defective capsule and replacing it manually with a functional one), downtime for the system is negligible. This advantage is significantly limited in the case of ASEA retarders: Fewer retarders per track mean the system's performance will be noticeably degraded when several retarders are out of service. Furthermore, the present method of detecting a nonfunctional ASEA retarder is to measure its energy absorption by a specially instrumented car. This checking procedure requires shutting down the yard one shift per month in a 24-class track yard. The Faiveley retarder, because of its much larger energy absorbing capability, approaches that of a discrete control system. As a result it loses many of the advantages of a quasi-continuous control system. Its maintenance characteristics are unknown since it is still in its developmental stage.

First on the list of potential disadvantages of a quasi-continuous control system is the high capital investment. Each retarder of a quasi-continuous control system, with its built-in logic and the accompanying requirements for precision parts and special alloys, is a relatively sophisticated mechanical device. The unit price of each retarder will always be high compared to other mechanical devices. Multiply the unit price by the thousands of units needed in a yard, and the initial purchase can easily amount to millions of dollars. The retarder hardware in a comparable clasp retarder yard would cost substantially less. However, by adding the costs of all the control-related sensors, cables, computers, and displays to the conventional system, the cost differential becomes less. An order-of-magnitude cost analysis and comparison will be discussed in Section 5. A comprehensive cost analysis is not within the scope of this report and may be useless since any realistic cost analysis must consider factors such as the amortization rate, the depreciation allowance, and so on, all of which constantly fluctuate in this inflationary age.

One concern of a quasi-continuous system designer is the possibility of a high percentage of stalled cars. This circumstance, should it occur, is not easily corrected, because in a quasi-continuous control system fine-tuning of the speed control system must be done in the design stage rather than the operating stage. If the problem is acute, trying a higher hump speed, a change of threshold speed settings in some of the retarders, or the removal of a number of retarders may or may not solve the problem. These measures should be considered only as a last resort. This problem and any other unforeseeable problems point to a fundamental disadvantage of any conventional system--the lack of operating experience in the United States.

4.4 HYBRID SYSTEM INCORPORATING QUASI-CONTINUOUS CONTROL

4.4.1 System Description

This hybrid system employs clasp retarders in the switch area and quasi-continuous control retarders on the class tracks. In such a system tangent point clasp retarders are superfluous.

4.4.2 Supplementary Equipment and Systems

This system requires the accessories and the maintenance facilities of both the conventional and the quasi-continuous control systems. The control algorithm for the clasp retarders should be simpler than that for the conventional system since the clasp retarders function solely to maintain headways.

4.4.3 Operation and Maintenance

Operation and maintenance should encompass the services required by both the conventional and the quasi-continuous control systems.

4.4.4 Qualitative Assessment

Because of its added complexity and therefore cost, this hybrid system is judged to be less cost-effective for a new yard. It becomes favorable mainly under certain circumstances of yard renovation; for example, in a clasp retarder yard with an unusually steep grade in the bowl resulting in high-speed impacts during coupling. Such yards are common because the average rolling resistance of the rolling stock has decreased since the introduction of roller bearings. Railroads using such yards are faced with the choice of (1) absorbing the cost of car and lading damages as a result of high percentage of overspeed couplings, (2) regrading the bowl area at substantial cost and for a prolonged period of loss of revenue, or (3) installing quasi-continuous control retarders on the class tracks. The relative merits of these three choices must be weighed case by case. For this reason, the quantitative analysis of this system (Section 5.5) is less involved than for either the conventional or the quasi-continuous control system.

Given such a hybrid yard, the principal advantage of it will be better coupling performance. Its disadvantages are high capital cost, high maintenance, squeal noise, vulnerability to EMI, and a possibility of contaminated wheels.

4.5 HYBRID SYSTEM INCORPORATING CAR MOVERS ON CLASSIFICATION TRACKS

4.5.1 System Description

This hybrid system uses clasp retarders before the clearance points. On each tangent track, a positive car-moving device is installed. One of three devices is used: (1) the ASEA or Hauhinco cable device, (2) the JNR linear-motor booster, or (3) the S.N.C.F. self-propelled car mover. Each device utilizes a low-profile car, often called a mule, that moves between the rails and below the cars. The mule may be propelled by a cable or self-propelled with power pickup from a power rail. Either way, the mule is capable of attaching itself to a free rolling car. Depending on whether the car is under speed or over speed at the time, the mule will accelerate or decelerate until a constant speed, usually the desired coupling speed, is achieved. The mule will move the car to within a specific distance (approximately 100 feet) from coupling, disengage itself from that car, and move swiftly back toward the tangent point for the rendezvous with the next car.

Two car movers, the JNR linear-motor booster and the S.N.C.F. self-propelled car mover, have sufficient power and speed to catch and engage with cars moving at a variety of speeds. Hence, only the clasp retarders and the car movers are needed for the speed control system. By contrast, the ASEA and Hauhinco cable devices can only receive cars moving within a narrow range of speeds. To use these devices effectively, additional retarders are needed before the entrance to the car mover section to ensure that fast-moving cars will be slowed to an acceptable speed. The additional retarders installed between the clearance point and the starting point of the car mover can be chosen from a variety of devices, as can be seen in the following examples.

An example of a yard that has supplemented its cable system with retarders is the Limmattal Yard of Switzerland, where an electrodynamic retarder is installed at the clearance point of each class track. As explained earlier, the retarder's function is to slow the car to a speed acceptable to the modified ASEA cable device on the tangent track. In Europe, the lack of automatic couplers on cars favors the release of long cuts at the hump. To accommodate the long cuts, distance is allowed between the electrodynamic retarder and the start of the cable device. The grade on this segment of the track, designed to be nonaccelerating to a hard rolling car, will cause easy rolling cars and short cuts to accelerate. Dowty retarders are installed in this section to maintain the speed of short cuts and easy rollers. This highly sophisticated speed control system of the Limmattal Yard produces the results its designer intended--uniform coupling speed and quiet operation. The cost of the yard, however, is more than three times that of a comparable conventional yard using an advanced clasp retarder system.

A second example is the Maschen Yard in West Germany. The speed control system in this yard consists of clasp retarders in the switch area, rubber retarders just beyond the clearance points, followed by Hauhinco oscillating cable systems and the Hauhinco cable devices. The rubber retarder slows the incoming cars to speed acceptable to the mule; the oscillating cable device prevents the long cuts from stalling. The system in the Maschen Yard is similar to that in the Limmattal Yard, but they differ in details. Additional information on these two yards can be found in Appendix A.

4.5.2 Supplementary Equipment and Systems

From the system description of Section 4.5.1, it becomes obvious that the supplementary equipment and subsystems needed to support this hybrid system are many. The underground tunnel in the Limmattal Yard illustrates this observation. The tunnel, which runs perpendicular to the tangent tracks just below the tangent points, accommodates the electric motor, the pulley with its safety cage, the counter weight, and the power conditioning equipment for each cable device. The capital investment of such a system is exorbitant.

4.5.3 Operation and Maintenance

Most yards employing this hybrid speed control system are automated. As with all fully automated yards, the operator's primary function shifts from direct control of cars to software improvement and hardware (computer as well as mechanical) maintenance. Although quantitative data are unavailable, the maintenance of any of the car-moving devices is costly both in terms of manpower and downtime.

4.5.4 Qualitative Assessment

Despite its superior performance, the clasp retarder-car mover hybrid system will not be adopted in the classification yards of the United States. The primary reason is its extraordinary cost. There is also less need for precision coupling because in the United States, all cars are equipped with automatic couplers. Furthermore, the added weight and length of an average U.S. car would make the design of a car mover system more demanding. In addition, this system shares many of the disadvantages of the conventional system, such as vulnerability to contaminated wheels and to EMI.

4.6 COMPARATIVE MATRIX OF THE FOUR SYSTEMS

The qualitative assessment of the four speed control systems elaborated in the previous sections is summarized in Table 4-1. In the remainder of this section conclusions will be drawn about the studied systems based on the qualitative assessment. The conclusions will be aimed at achieving the objective of this study--the recommendation of a potentially beneficial speed control system for railroads in the United States.

Of the four speed control systems, the advanced clasp retarder system must be given strong consideration. The shortcomings of this system, such as wheel squeal noise and over-speed couplings, are well known. Progress has been made in improving the performance of this system. With computers becoming faster and cheaper, the advent of more sophisticated retarder control logic should continue to upgrade the performance of this system. In addition, there is sufficient evidence that the capital cost for this system is and will remain lower than the other three systems.

The quasi-continuous control system--in particular, the Dowty system--is the most promising foreign system. The random nature of a car's rolling resistance dictates that, in theory, the only perfect control scheme is a continuous one. The Dowty system, with its closely spaced control points, approaches that ideal. Careful design is necessary for this system to achieve its desired performance. Unlike the advanced clasp retarder system, this system is not amenable to fine tuning once built. Because of the number of retarders needed in a yard, the capital cost of this system is high. Part

TABLE 4-1.-COMPARATIVE MATRIX OF THE FOUR IDENTIFIED SPEED CONTROL SYSTEMS

Speed control system	Advantages	Disadvantages
System 1 (clasp retarder)	Low capital cost Plenty of operating experience	Susceptible to change in rollability Vulnerable to contaminated wheels Squeal noise Susceptible to EMI
System 2 (quasi-continuous)	Less affected by change in rollability Immune to contaminated wheels Potential savings in reduced lading damage Potential savings due to zero system downtime	High capital cost Little operating experience in the United States Not entirely immune to noise problem
System 3 (clasp plus quasi-continuous)	Improved coupling performance Reduced risk of runaway cars	High capital cost Compounded noise problem
System 4 (clasp plus car-mover)	Superior coupling performance	Very high capital cost High maintenance Vulnerable to contaminated wheels Requires tangent point retarders or equivalent

of that initial investment may be compensated by its potentially low operating cost. The amount of compensation will depend on the size of the yard, its intended throughput, and the types of cargo. At this time, the Dowty system is rapidly gaining recognition worldwide.

The hybrid system incorporating Dowty retarders on the class tracks is much less attractive than the previous two systems where a new yard is concerned. The primary reason is that its cost is expected to be higher than either of the other two systems. This system may be cost effective, however, under special circumstances; for example, when renovating an old yard with steep grades in the bowl area. This circumstance is not uncommon because the older yards were built when the average rolling resistance of cars was higher.

The hybrid system incorporating car movers on the class tracks becomes a viable alternative only if cost is no object. This system is not expected to be incorporated in any classification yards in the United States.

SECTION 5 — QUANTITATIVE ANALYSES OF TWO SPECIFIC SYSTEMS

5.1 METHOD OF APPROACH

As stated in Section 2.4, the ultimate comparison of the various speed control systems must be made on an economic basis. Part of the economics should be the dollar benefits associated with improved performance. While the acquisition of capital, operating, and maintenance cost data of the various systems is no easy task, meaningful performance data are even more difficult to obtain. The difficulties of making quantitative performance comparisons of the various systems are illustrated in the following paragraphs.

A possible source for performance data is actual yard experience. The performance of a speed control system in a particular yard depends on many factors, including the size of the yard, the design goal (which reflects the operating philosophy of the railroad company), and the vintage of the system. A direct comparison of the performance data of, for example, an advanced clasp retarder yard in the United States with a Dowty yard in Great Britain is therefore inappropriate. Computer simulation affords the opportunity to compare speed control systems under identical conditions, but none of the existing computer models would do the job. The computer models developed by the vendors are simply design tools. The feasibility of a multi-track model using the Monte Carlo method was demonstrated by Kerr (reference 1).* Such a model could be modified to calculate the performances of several systems, but the cost of running the program would be prohibitive.

After many months of deliberation, a unique computer program was developed that would incorporate not only the dynamics of the rolling cars and the principal features of the retarder control logic, but also the stochastic nature of the classification process. This program, known as SPEEDCON, is described in Appendix D.

Briefly, the SPEEDCON program takes into account four random variables:

- Crest rolling resistance
- Random variations of rolling resistance along a track

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*A list of references can be found at the end of the report.

- Track fullness on the class track
- Probability that a car will be routed to a particular track.

The program determines the probability of stall and the distribution of coupling speed by analyses of single-car motions and calculates the percentage of misswitched cars by making pairwise comparisons.

With the development of the SPEEDCON program, the approach to making quantitative comparisons is simplified. First, for each speed control system that is qualified for quantitative analysis, a baseline yard is designed according to a set of common specifications. The specifications include the base rolling resistance distribution of cars; the number of classification tracks; the hump speed; the ranges of wheel sizes, car lengths, and car weights; and the curve and switch resistances. Relevant parameters of each baseline yard, such as the track geometry and the retarder locations, are then input to the SPEEDCON program, which in turn calculates the performance parameters of the corresponding speed control system. The calculated performance can then be used in the economic analysis of the system.

The quantitative evaluation procedures described are applied to three specific yards, one designed to use the advanced clasp retarder system, another to use the Dowty system, and a third to use a combination of the two. The selection of the three systems is based on the results of the qualitative analysis. The size of the baseline yard (32 class tracks), is an arbitrary choice. Each speed control system may have its optimum yard size, hump speed, and so on, so to determine the optimal values of these parameters the quantitative evaluation procedures must be applied repeatedly. Unfortunately, such an optimization investigation is beyond the allocated funds of this project. Nevertheless, the two examples given in Sections 5.3 and 5.4 demonstrate the methodology that was developed and the kind of results that can be expected. The results, however, are valid only if the many assumptions made in the analysis are taken into account. Most of these assumptions were necessary because of the lack of crucial data, but they should in no way invalidate the methodology.

5.2 ENGINEERING DESCRIPTION OF A 32-TRACK HUMP YARD

5.2.1 Background

The information necessary to evaluate a speed control system's performance in a yard consists of:

- The yard layout showing curves, locations of retarders and switches.
- The yard elevation showing the grades.
- The capacities of the retarders and the control algorithm.

The system's cost estimate will be based on the yard layout and hardware specifications.

A specification for a hypothetical yard was given to the manufacturers of each of the promising speed control systems since it was felt that the manufacturers would be able to show their systems most favorably. The specification was carefully written to avoid favoring one type of control system over another. The objective was to allow each system's advantages to be fully demonstrated along with its shortcomings. The specification and design information provided would put all the designs on the same basis and eliminate such factors as differences in real estate cost and car population that would be found in actual designs.

The specification consisted principally of:

- Requirements for the yard layout such as the number of class tracks and the length of the switching area. A medium-sized yard was specified because the trend in yard design seems to be away from small yards, and a large yard might represent too big a project for the manufacturers.
- Requirements for the minimum performance of the yard, such as the maximum percent misswitches, overspeed couplings and stalls at a specified humping speed. The performance requirements were strict enough to require an advanced speed control system.
- A description of the car population: the size of the cars, their weight and the rolling resistance probability function. (The last item was derived from data taken at Elkhart in December 1957.)

Additional information was supplied in the form of design information. The information encompassed clearance requirements between track-mounted equipment and freight cars, specifications for vertical and horizontal curves and the like.

The specification was written in two stages. A preliminary version was written and mailed to the potential designers: WABCO (representing the conventional system), Siemens, Dowty, ASEA, and Faiveley. Comments, criticisms and suggestions were solicited from vendors as well as from railroad personnel who acted as consultants. Their comments were used to revise and amend the original specifications and design information.

Only Dowty, ASEA and Faiveley agreed to participate in our effort and responded to our preliminary specification. WABCO declined to participate, citing a heavy work load. General Railway Signals (reached earlier by telephone) also declined. When the final specification was sent to the remaining vendors for their designs, ASEA also decided not to participate. Both Dowty and Faiveley produced yard designs to our specification using their speed control systems. (Both systems are of the quasi-continuous control type.) Since the Dowty system was judged more promising, it was selected as a candidate for quantitative analysis. An advanced clasp retarder controlled baseline yard was designed by SRI personnel for comparison purposes.

5.2.2 The Specification

Table 5-1 shows the complete specification and design information package used to design the yards in this report. Table 5-2 and Figures 5-1 and 5-2 show the SRI hypothetical yard rolling resistance distribution. Figure 5-3 presents a design information package.

5.3 THE ADVANCED CLASP RETARDER SYSTEM

5.3.1 Design and Description of the Baseline Yard

SRI designed an advanced clasp retarder control yard because the manufacturers of clasp retarders who were approached for assistance declined to participate. SRI was able to secure the services of a consultant from the railroad industry so that the methods used to design the yard are similar to those used by actual designers. Sophisticated computer programs developed at SRI under the sponsorship of FRA were used in the design of the yard.

TABLE 5-1.-FINAL SPECIFICATION FOR SRI INTERNATIONAL HYPOTHETICAL CLASSIFICATION YARD

YARD LAYOUT

- Thirty-two (32) classification tracks.
- Two (2) center tracks 3,500 feet long (from tangent point to end); track lengths taper evenly to 2,500 feet long at outer tracks.
- Maximum of 1,100 feet between hump crest and tangent point.
- Combination of retarders and/or adverse grades at the end of the class tracks is required to assure that cars or coupled strings of cars cannot roll past the end of the class tracks.

TRACK

- All track and switches must meet American Railway Engineering Association (AREA) standards.
- Switches will be selected by the vendor.
- U.S. practice requires that vertical curves be designed according to specifications given in Note A.

ROLLING STOCK

- All wheel dimensions must meet Association of American Railroads (AAR) standards.
- All track clearance dimensions must meet AAR standards.
- Axle loading of: heaviest car - 80,000 lb/axle; average car - 30,000 lb/axle; lightest car - 8,000 lb/axle.
- Overall coupler-to-coupler length of: longest car - 94 ft.; average car - 55 ft.; shortest car - 31 ft.
- Center-to-center distance between trucks for: longest car - 84 ft.; average car - 45 ft.; shortest car - 21 ft.
- Wheelbase of each truck: 5.5 ft.
- Static rolling resistance (see attached):

Cumulative distribution function Probability function	Plots, tables and equation

  (See Note B.)
- The SRI simulation of the yard performance will assume a constant initial "base" rolling resistance for each car to a point coinciding with the start of a group retarder. At that point the base rolling resistance will decrease to two-thirds of its initial value. It is assumed that rolling resistance does not vary with speed. (See Note C.)
- The effect of additional rolling resistance at:

  Curves - 0.045 ft. velocity head loss/°central angle.
  Switches - 0.060 ft. velocity head loss/switch.

DESIGN PARAMETERS

- Hump speed: 200 ft/minute.
- Throughput required: 3,000 cars/day.
- Single car cuts only.
- Cars and strings of cars must be able to be pulled back over crest for rehumping.
- Maximum train pullout speed from class tracks (either direction): 10 mph.
- Headway required between cars for proper switch operation (no misswitch) is set by switch design selected by vendor. (See Note D.)

WEATHER

- Ambient temperature: 65°F mean; -10°F minimum; 95°F maximum.
- Rail temperature may be assumed to be ambient plus 75°F.

PERFORMANCE

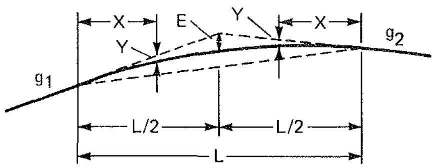
- 95% of cars couple at less than 6 mph.
- 98% of cars roll to 1,200 feet past the tangent point of the classification track.
- Less than 0.1% of cars are misswitched due to inadequate headway of switches.

TABLE 5-1.-CONCLUDED

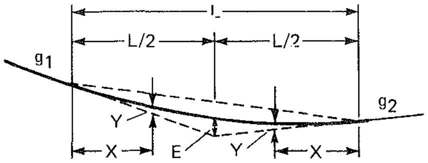
NOTES

A. Vertical curves are based on the algebraic difference in grades and are developed as follows (see Table 5-2):

SUMMIT



SAG



$A = |g_2 - g_2|$ $L = AC$ $E = \frac{AL}{800}$ $Y = \left(\frac{X}{L/2}\right)^2 E$

where

g_1, g_2 = gradients in percent
A = algebraic difference in percent
L = length of curve in feet
C = 15 (for hump crest)
= 40 (for summits)
= 60 (for sags)
E = external distance in feet
X = horizontal distance from beginning or end of vertical curve
Y = vertical distance between grade line and vertical curve in feet

B. The tabular probability function only goes to 28 lb/ton. The equation given for the cumulative distribution function can be used to determine the probabilities of cars of rolling resistances greater than 28 lb/ton occurring.

C. The rolling resistance is assumed to be independent of velocity in this simulation. A car's rolling resistance will remain constant during its run except for the specified decrease at the group retarder and increases through curves and switches. SRI feels that this represents the design assumptions used by the railroad industry.

D. Headway is defined as the distance between the last axle of the leading car and the first axle of the following car. If the vendor does not wish to specify the headway, a value of 50 feet (typical in the United States) may be used.

TABLE 5-2.-SRI HYPOTHETICAL YARD ROLLING RESISTANCE DISTRIBUTION

Zone, rolling resistance, pound/ton		Probability function[a]	Cumulative distribution function[b]
From	To		
0.000	.500	.002	.002
.500	1.000	.032	.034
1.000	1.500	.162	.196
1.500	2.000	.480	.676
2.000	2.500	1.078	1.753
2.500	3.000	2.023	3.776
3.000	3.500	3.322	7.098
3.500	4.000	4.880	11.978
4.000	4.500	6.483	18.461
4.500	5.000	7.847	26.309
5.000	5.500	8.715	35.023
5.500	6.000	8.958	43.981
6.000	6.500	8.618	52.599
6.500	7.000	7.854	60.453
7.000	7.500	6.865	67.318

TABLE 5-2.-CONCLUDED

Zone, rolling resistance, pound/ton		Probability function[a]	Cumulative distribution function[b]
From	To		
7.500	8.000	5.819	73.137
8.000	8.500	4.828	77.965
8.500	9.000	3.951	81.916
9.000	9.500	3.208	85.124
9.500	10.000	2.595	87.719
10.000	10.500	2.097	89.816
10.500	11.000	1.698	91.514
11.000	11.500	1.378	92.892
11.500	12.000	1.123	94.015
12.000	12.500	.919	94.934
12.500	13.000	.756	95.690
13.000	13.500	.625	96,315
13.500	14.000	.519	96,834
14.000	14.500	.433	97.267
14.500	15.000	.364	97.631
15.000	15.500	.307	97.937
15.500	16.000	.260	98.197
16.000	16.500	.221	98.418
16.500	17.000	.189	98.607
17.000	17.500	.162	98.769
17.500	18.000	.140	98.909
18.000	18.500	.121	99.029
18.500	19.000	.105	99.134
19.000	19.500	.091	99.225
19.500	20.000	.080	99.305
20.000	20.500	.070	99.375
20.500	21.000	.061	99.436
21.000	21.500	.054	99.491
21.500	22.000	.048	99.539
22.000	22.500	.043	99.581
22.500	23.000	.038	99.619
23.000	23.500	.034	99.653
23.500	24.000	.030	99.633
24.000	24.500	.027	99.710
24.500	25.000	.024	99.734
25.000	25.500	.022	99.756
25.500	26.000	.020	99.775
26.000	26.500	.018	99.793
26.500	27.000	.016	99.809
27.000	27.500	.015	99.824
27.500	28.000	.013	99.837
28.000	INFIN	.163	100.000
		100.000	

Equation for cumulative distribution: $F(R) = 1 - \dfrac{1}{1 + a\left(\dfrac{R}{10}\right)^{b}}$

$a = 7.14$

$b = 4.32$

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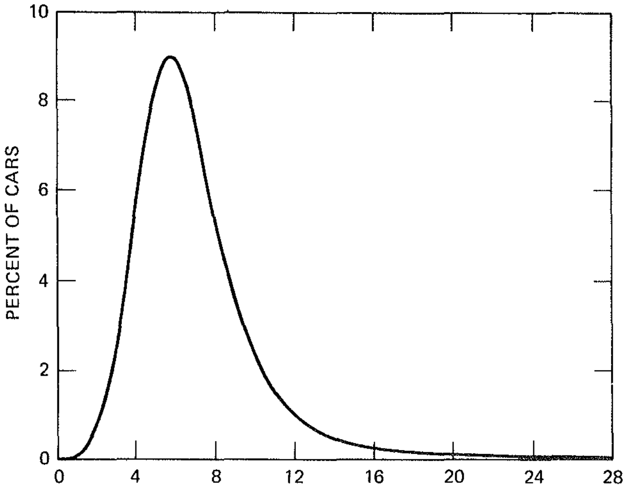
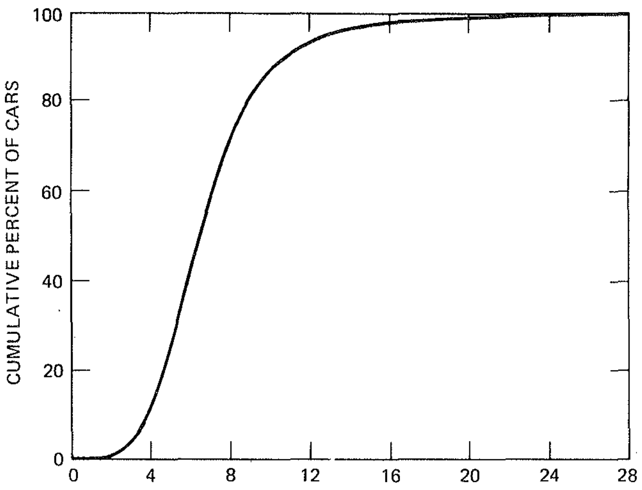
[a] Percent of cars.

[b] Cumulative percent to upperzone boundary



PROBABILITY FUNCTION — 0.5 lb/ton ZONE SIZE

Figure 5-1. Rolling Resistance Distribution (Probability Functions)



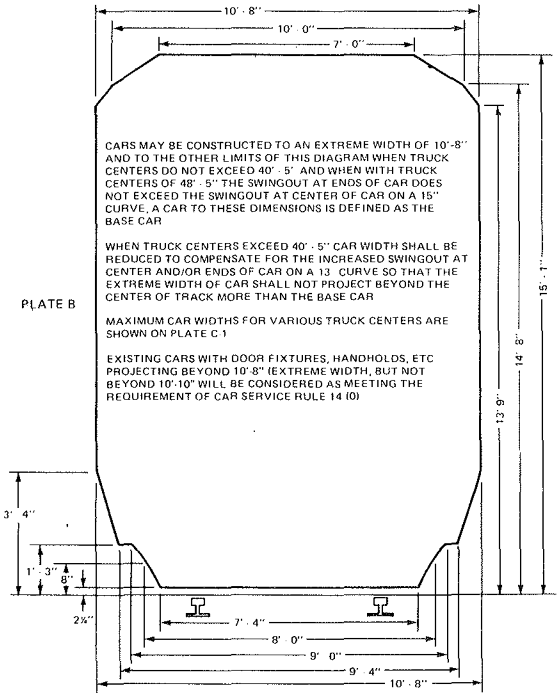
CUMULATIVE DISTRIBUTION FUNCTION

Figure 5-2. Rolling Resistance Distribution (Cumulative Distribution Functions)

This package contains additional design information that may be useful in your design efforts:

1. The spacing of the classification tracks may be assumed to be 14 feet (4.27 m) center-to-center. This is not required, however.
2. The spacing of the tracks following a switch at the "clearance point" may be assumed to be 14 feet (4.27 m) center-to-center as well.
3. AAR wheel drawings are enclosed. For design purposes, all wheels are assumed to be 36 inches (0.914 m) in diameter.
4. Drawings of switches used in classification yards are enclosed. These may be used in place of European designs, if desired.
5. An AAR standard car profile is enclosed.
6. The minimum radius of curvature in the yard is 350 feet (106.7 m).

PLATE B



CARS MAY BE CONSTRUCTED TO AN EXTREME WIDTH OF 10'-8" AND TO THE OTHER LIMITS OF THIS DIAGRAM WHEN TRUCK CENTERS DO NOT EXCEED 40' - 5' AND WHEN WITH TRUCK CENTERS OF 48' - 5" THE SWINGOUT AT ENDS OF CAR DOES NOT EXCEED THE SWINGOUT AT CENTER OF CAR ON A 15" CURVE, A CAR TO THESE DIMENSIONS IS DEFINED AS THE BASE CAR

WHEN TRUCK CENTERS EXCEED 40' - 5" CAR WIDTH SHALL BE REDUCED TO COMPENSATE FOR THE INCREASED SWINGOUT AT CENTER AND/OR ENDS OF CAR ON A 13 CURVE SO THAT THE EXTREME WIDTH OF CAR SHALL NOT PROJECT BEYOND THE CENTER OF TRACK MORE THAN THE BASE CAR

MAXIMUM CAR WIDTHS FOR VARIOUS TRUCK CENTERS ARE SHOWN ON PLATE C-1

EXISTING CARS WITH DOOR FIXTURES, HANDHOLDS, ETC PROJECTING BEYOND 10'-8" (EXTREME WIDTH, BUT NOT BEYOND 10'-10" WILL BE CONSIDERED AS MEETING THE REQUIREMENT OF CAR SERVICE RULE 14 (0)

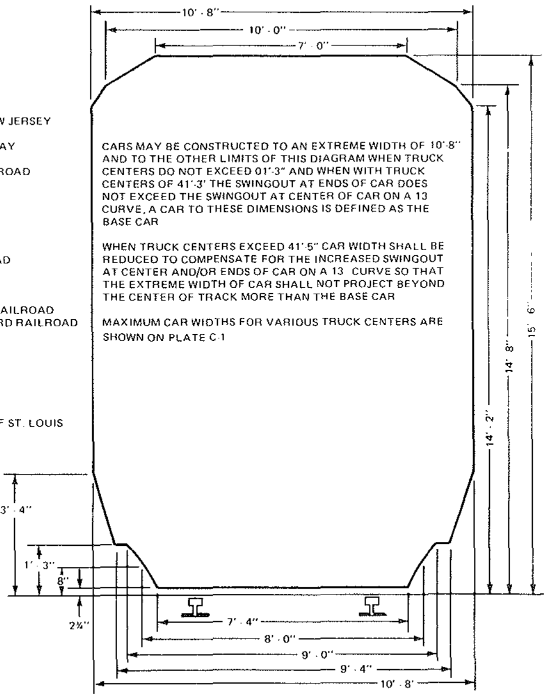
THE 2-1/2" ABOVE TOP OF RAIL IS ABSOLUTE MINIMUM UNDER ANY AND ALL CONDITIONS OF LADING, OPERATION, AND MAINTENANCE

ALL NEW OR REBUILT CARS SHOULD BE SO DESIGNED THAT NO PART OF CAR SHALL BE LESS THAN 2-3/4" ABOVE THE TOP OF THE RUNNING RAIL UNDER ALL ALLOWABLE WEAR AND SPRING DEFLECTION CONDITIONS THOSE ROADS USING MULTIPLE WEAR WHEELS MAY FIND IT NECESSARY IN MAINTAINING THE 2-3/4" MINIMUM CLEARANCE TO COMPENSATE FOR WHEELS WORN CLOSE TO THE CONDEMNING LIMIT BY REPLACING WHEEL AND AXLE SETS, BEARINGS OR WEDGES

ANN ARBOR RAILROAD COMPANY
BALTIMORE AND OHIO RAILROAD
BOSTON AND MAINE RAILROAD
CANADIAN NATIONAL RAILWAYS
CENTRAL RAILROAD COMPANY OF NEW JERSEY
CHESAPEAKE AND OHIO RAILWAY
CHICAGO AND NORTHWESTERN RAILWAY
DENVER UNION TERMINAL RAILWAY
DETROIT TOLEDO AND IRONTON RAILROAD
ERIE-LACKAWANNA RAILROAD
GULF MOBILE AND OHIO RAILROAD
KANSAS CITY SOUTHERN RAILWAY
LEHIGH VALLEY RAILROAD
LONG ISLAND RAILROAD
LOUISIANA AND ARKANSAS RAILWAY
LOUISVILLE AND NASHVILLE RAILROAD
MANUFACTURERS RAILWAY COMPANY
MISSOURI PACIFIC RAILROAD
NEW YORK CENTRAL RAILROAD
NEW YORK, CHICAGO, AND ST. LOUIS RAILROAD
NEW YORK, NEW HAVEN AND HARTFORD RAILROAD
NORFOLK AND WESTERN RAILWAY
NORTHWESTERN PACIFIC RAILROAD
PENNSYLVANIA RAILROAD
READING COMPANY
ST. LOUIS-SAN FRANCISCO RAILWAY
SOUTHERN RAILWAY SYSTEM
SOUTHERN PACIFIC COMPANY
TERMINAL RAILROAD ASSOCIATION OF ST. LOUIS
UNION RAILROAD COMPANY
WESTERN MARYLAND RAILWAY

UNRESTRICTED ON ALL ROADS EXCEPT ON CERTAIN ROUTES OF THOSE ROADS SHOWN FOR SPECIFIC RESTRICTED AREAS ON SUCH ROADS SEE "RAILWAY LINE CLEARANCES"

PLATE C



CARS MAY BE CONSTRUCTED TO AN EXTREME WIDTH OF 10'-8" AND TO THE OTHER LIMITS OF THIS DIAGRAM WHEN TRUCK CENTERS DO NOT EXCEED 01'-3" AND WHEN WITH TRUCK CENTERS OF 41'-3' THE SWINGOUT AT ENDS OF CAR DOES NOT EXCEED THE SWINGOUT AT CENTER OF CAR ON A 13 CURVE, A CAR TO THESE DIMENSIONS IS DEFINED AS THE BASE CAR

WHEN TRUCK CENTERS EXCEED 41'-5" CAR WIDTH SHALL BE REDUCED TO COMPENSATE FOR THE INCREASED SWINGOUT AT CENTER AND/OR ENDS OF CAR ON A 13 CURVE SO THAT THE EXTREME WIDTH OF CAR SHALL NOT PROJECT BEYOND THE CENTER OF TRACK MORE THAN THE BASE CAR

MAXIMUM CAR WIDTHS FOR VARIOUS TRUCK CENTERS ARE SHOWN ON PLATE C-1

THE 2-3/4" ABOVE TOP OF RAIL IS ABSOLUTE MINIMUM UNDER ANY AND ALL CONDITIONS OF LADING, OPERATION, AND MAINTENANCE

Figure 5-3. Design Information Package

The advanced clasp retarder control yard has master, group, and tangent point retarders and utilizes the most sophisticated control algorithm available. The layout of the plan view of the yard is the first part of the design. The required retarder lengths and locations are estimated, and straight track is allowed for them in the layout. The switches are selected to provide a relatively high maximum speed limit of 17 mph through the yard. A 7-8-9 lap switch is used as the king switch, and No. 9 lateral and No. 7 equilateral switches are used elsewhere. Track centers measuring 16 feet were selected for the classification tracks. The track layout fits within the 1,100 feet required between the hump crest and the tangent point. The yard layout establishes the location of all swtiches, retarders and horizontal curves.

For simplicity, one track (#31) is selected to design the grades. The initial design of the grades is done on a total head versus distance plot. The design's hard and easy rolling cars were selected at the 99 and 1 percent points on the cumulative distribution function, 18 and 2 pound/ton respectively. The specification calls for the design hard roller to roll 1,200 feet past the tangent point; its velocity head at that point is zero. The velocity head at the hump is set by the required hump speed. By plotting the total head of the hard roller and allowing for curve and switch resistance, the hump height relative to the stopping point of the hard roller is established. The grade in the class track is chosen to be nonaccelerating for the design's easy roller. A line is drawn at this grade from the point at which the hard roller stops to the tangent point, 1,100 feet past the hump crest, thus establishing the elevation of the tangent point. The grades connecting the hump crest and the tangent point are then selected to keep the maximum speeds below 17 mph and to accommodate all vertical curves. The retarder capacities are selected so that the easy roller will maintain a safe speed and an adequate headway between it and the hard roller.

The yard geometry is then programmed into the SRI PROFILE (reference 2). The program will simulate the behavior of the design's hard and easy rolling cars when they are humped in a hard-easy-hard sequence. The hard roller is unretarded, and retardation of the easy roller is selected to maintain adequate headway between the cars through the switching area and to maintain the speed of the car at the exit of the tangent point retarder at 6 mph (the maximum allowable coupling speed). Since the class track grade is equal to the easy rolling car's rolling resistance, this car should not accelerate. The PROFILE program permits detailed examination of a car's behavior in the yard, selection of adequate retarder lengths, and other information necessary for the next stage of design.

The retarder control algorithm selected is based on the algorithm described in the Budway patent. The algorithm controls cars so that they arrive at checkpoints in the yard at specified times. (This algorithm is described in Appendix E.) The control algorithm, along with the yard geometry, is then programmed into SRI's SPEEDCON program. This program simulates the behavior of a range of base rolling resistance cars, with retardation computed by the control algorithm; makes all the possible pairwise comparisons for headway; and examines the coupling speeds for a range of track fullness levels. The initial parameters for the control algorithm are chosen based on experience gained with the PROFILE simulations. These parameters are then optimized with the use of SPEEDCON to give the best yard performance. At this stage the yard design is complete.

The yard layout and final grade profile are shown in Figure 5-4.

5.3.2 Cost Estimate

5.3.2.1 Capital Cost. In this section the installation costs for an advanced clasp retarder system is estimated. The baseline yard speed control system described in Section 5.3.1 consists of:

- One master retarder
- Four group retarders (for four groups of eight tracks)
- Thirty-two tangent-point retarders (for 32 classification tracks)

Because U.S. manufacturers consider cost estimates proprietary and competitive, several railroads were asked to supply information needed to estimate the costs for the baseline conventional system considered here. The costs estimates are generally for "turn-key" installation of all signalling equipment from hump crest to the classification track. In particular, the estimates include:

- Labor, materials and installation
- Retarders
- Switch machines
- Process control computers
- Air compressors and electric power
- Cabling.

(Note that the Management Information System (MIS) yard computer is not included.) The information supplied by railroads on yard costs is described in the following four cases.

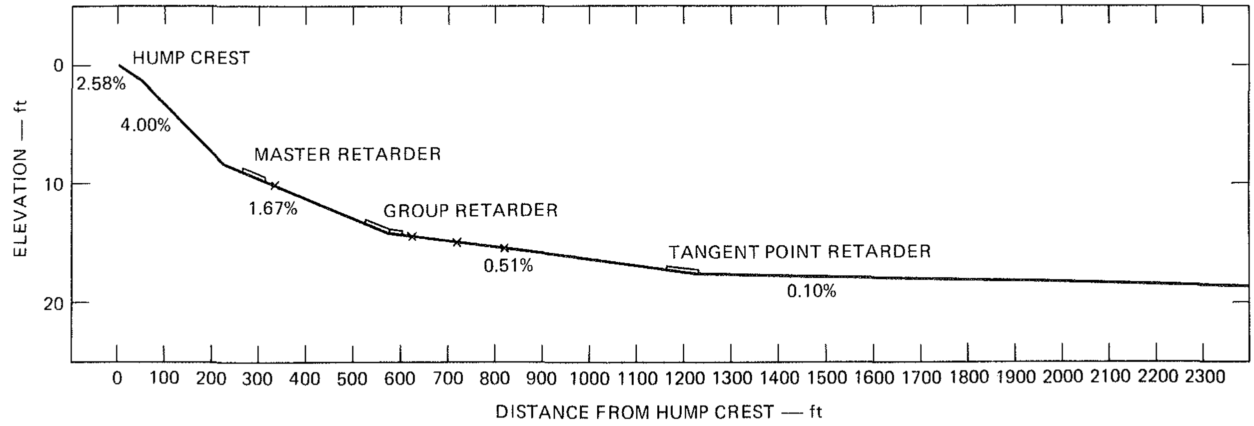


Figure 5-4. Plan View of Baseline Yard Using Advanced Clasp Retarder

Case 1: Master and 4 Group Retarders. Railroad A indicated that the 1978 estimated cost for a 1-master, 32-inert, 4-group retarder system is approximately \$3.4 million. The ratio of the 1979 to 1978 capital equipment price index is 217.9/199.1. Approximate 1979 cost: \$3.7 million.

Case 2: Tangent-Point Retarders. Railroad B indicated that the 1976 estimated cost for 32 tangent-point and 32 powered-skate retarders is approximately \$100,000 per track. Thus the 1976 cost for the entire system is approximately \$3.2 million. The ratio of the 1979 to 1976 capital equipment price index is 217.9/171.0. Approximate 1979 cost: \$4.1 million.

Case 3: 1 Master, 9 Group, and 56 Tangent-Point, Retarders. Railroad C indicated that the 1972 estimated cost for 1 master, 9 group, 56 tangent-point, and 56 powered-skate retarders is \$7.1 million. The ratio of the 1979 to 1976 capital equipment price index is 217.9/119.5. Approximate 1979 costs: \$12.9 million.

Case 4: 1 Master, 7 Group, and 50 Tangent-Point, Retarders. Railroad D indicated that the 1979 estimated cost for 1 master, 7 group, 50 tangent-point, and 50 powered skate retarders is \$12.8 million.

Based on the above data, three rough estimates for the baseline conventional system can be obtained; the final estimate is the average of the three estimates.

Estimate 1. A simple combination of Cases 1 and 2 is a rough approximation of SRI's baseline systems:

$$\text{Estimate 1} = \$2.7 \text{ million} + \$4.1 \text{ million}$$
$$= \$7.8 \text{ million}$$

Estimate 2. Scaling Case 3 from 56 to 32 classification tracks produces a rough approximation of SRI's baseline systems:

$$\text{Estimate 2} = \frac{32}{56} \times \$12.9 \text{ million}$$
$$= \$7.4 \text{ million}$$

Estimate 3. Scaling Case 4 from 50 to 32 classification tracks produces a rough approximation of our baseline system:

$$\text{Estimate 3} = \frac{32}{50} \times \$13.8 \text{ million}$$
$$= \$8.2 \text{ million}$$

Average Estimate

$$\text{Average Estimate} = \frac{\$7.8 + \$7.4 + \$8.2}{3}$$
$$\doteq \$7.8 \text{ million}$$

The 1979 cost estimate for the conventional retarder baseline system is \$7.8 million. This includes all labor, materials, and installation of signalling equipment (e.g., retarders, switches, and computers) from hump crest to classification track. This includes 1 master, 4 group, 32 tangent-point, and 32 powered-skate retarders. If simple inert retarders are used at the end of the classification track instead of the powered variety, the costs can probably be reduced by \$1 million from \$7.8 million to \$6.8 million.

5.3.2.2 Maintenance Cost. To estimate the maintenance cost of the retarders, certain assumptions must be made as to frequency of brake-shoe replacement, time needed for replacement, salary of maintenance personnel and cost of materials. The estimates that follow are based on those assumptions. It is assumed that the master and four group retarders must have their brake shoes replaced twice a year because of the high volume of cars passing through these retarders. Brake shoes and materials for each master and group retarder average \$6,000 per replacement. Each replacement requires 48 main-hours; the hourly rate of yard maintenance personnel is \$13.44 per hour (this includes wages, fringe benefits and a 30 percent allowance for general purpose maintenance equipment). Based on these assumptions, each replacement of brake shoes on a master or group retarder is estimated to cost \$6,650. Since ten brake shoe replacements are estimated to occur in a year, the annual maintenance for the master and four group retarders is approximately \$66,500.

Because of the low volume of cars through the 32 tangent-point retarders, it is assumed that their brake shoes need only be replaced every two years, or that 16 tangent-point retarders must have their brake shoes replaced in any given year. The tangent-point retarders are the less expensive hydraulic-weight responsive type which uses a special composition brake shoe costing approximately \$3,000 for the shoe and associated materials (rather than using second-hand rail for the braking surface). Each replacement takes 30 hours at an hourly cost of \$13.44 per hour. Based on these assumptions, each replacement costs approximately #3,400. Since 16 tangent-point retarder replacements are estimated ot occur in a year, the annual cost is \$54,400.

The total annual maintenance cost for the master, group, and tangent-point retarders is therefore approximately \$120,900 (i.e., \$66,500 + 54,400). This estimate does not include the loss of revenue while the maintenance is being performed.

The maintenance cost for the power supply system, the sensors and their associated equipment, and the process computers is not available. This cost is estimated to be about the same as the retarder maintenance cost.

It is assumed that one yard person (signal maintainer) is assigned to monitor and maintain the process control computers which control the retarders and switches. His wages plus fringe benefits are assumed to cost approximately \$25,000 annually.

5.3.3 Performance Estimate

The advanced clasp retarder system performance was simulated and estimated by the SPEEDCON program. (The SPEEDCON program and discussion of the program runs are described in Appendix D.) Essentially, the system's geometry was represented in SPEEDCON, and a car population of various rolling resistances was humped at the design speed of 200 feet per minute (approximately four cars per minute).

Because there is some controversy over the exact range of the U.S. rolling resistance car populations and because these assumptions greatly affect the performance of the speed control systems, it was decided to measure the performance of the speed control systems against two assumptions concerning the population of rolling resistance (see discussion in Appendix F):

Conservative Rolling Resistance Assumption

- Between the crest and group retarder (or equivalent location) the rolling resistances of the car population are assumed to be as shown in the Elkhart histogram (Figure F-1).

- After the group retarder (or equivalent location), the rolling resistances become easier; the Elkhart histogram (Figure F-1) is used, but all rolling resistance values are reduced to two-thirds (2/3).

Optimistic Rolling Resistance Assumptions

- Between the crest and group retarder (or equivalent location), the rolling resistances of the car population are assumed to be as shown in the Elkhart histogram (Figure F-1), except that all rolling resistance values are reduced to two-thirds (2/3).
- After the group retarder (or equivalent location), the rolling resistances become easier; the Elkhart histogram (Figure F-1) is used, but all rolling resistance values are reduced to four-ninths (4/9).

The SPEEDCON program provides for a rolling car to suddenly change its rolling resistance from its specified value; this change is unknown to the conventional speed control system. The model for this behavior is as follows:

- One-third (1/3) probability that a car will increase its specified rolling resistance by +19%
- One-third (1/3) probability that a car will decrease its specified rolling resistance by -19%
- One-third (1/3) probability that a car rolling resistance does not change from its specified value.

This provision was included to measure the "robustness" of the advanced clasp retarder system, i.e., the system's tolerance to either measurement errors in a car's rolling resistance or changes in the rolling resistance after a measurement is taken.

The key measures of performance as estimated by SPEEDCON for this clasp retarder system for both the conservative and optimistic rolling resistance assumptions are as follows:

1. Percent stalls in the switching area--The percentage of cars (from the assumed car rolling resistance population) that stall in the switching area (i.e., prior to entering the classification track). This performance measure reflects how well a balance is achieved between the cost of increasing the hump height to handle the hardest rolling cars and the corresponding cost of installing more retarder capability to handle the easiest rolling cars.
    - Conservative Rolling Resistance Assumption: Percent stalls = 0.03%
    - Optimistic Rolling Resistance Assumption: Percent stalls = 0.0%
2. Percent misswitched--The percentage of cars (from the assumed car rolling resistance population) that is misrouted to the wrong classification track because sufficient headway between cars was not maintained to throw the switch. (A misswitch usually occurs when car headway is less than 50 feet). This performance measure reflects the ability of the system to control headway in the switching area.
    - Conservative Rolling Resistance Assumption: Percent misswitch = 0.0%
    - Optimistic Rolling Resistance Assumption: Percent misswitch = 0.0%
3. Percent stopped short of coupling--The percentage of cars that stop short of coupling on the classification track. A car is defined as stopping short if it does not reach the specified target point with a velocity greater than zero. This performance measure reflects the ability of the system to control coupling speeds on the classification track. This measure is correlated with but not exactly the same as the percentage of uncoupled cars at the time the classification track is pulled, since a large percentage of cars stopping short get "bumped" along and finally couple. (A succeeding car enters the classification, hitting the car ahead which is stopped short and pushing it toward the coupling point.)
    - Conservative Rolling Resistance Assumption: Percent stop short = 15.8%
    - Optimistic Rolling Resistance Assumption: Percent stop short = 7.9%
4. Distribution of overspeed impact--The percentage of cars coupling at various speeds. This percentage is calculated from the speed distribution of cars arriving at a specified target point. This performance measure reflects the ability of the system to control coupling speeds on the classification track. The distribution for both the conservative and conservative and optimistic rolling resistance assumptions is given in Table 5-3.

TABLE 5-3.-CONVENTIONAL SYSTEM: DISTRIBUTION OF IMPACT SPEED ON THE CLASSIFICATION TRACK

Speed range, mph	Conservative rolling resistance assumption, percent	Optimistic rolling resistance assumption, percent
0-1	0.02	0.0
1-2	4.33	3.73
2-3	6.71	9.10
3-4	39.99	36.48
4-5	13.79	24.19
5-6	12.35	14.36
6-7	6.94	4.21
7-8	0.02	0.07
>8	0.0	0.0

The performance measures described above were obtained from the SPEEDCON computer model with assumptions concerning the car rolling resistance population. There are inaccuracies and approximations in the representation of any physical system by a computer model, and, currently, little definitive data exist on car rolling resistance in U.S. yards. Consequently, the performance numbers displayed above should be considered an estimate of performance. (The most accurate method would be to measure actual performance.) However, the approximations and inaccuracies should affect the Dowty and the advanced clasp retarder system equally, thus the relative performance difference in the performance measures for the Dowty and the conventional system should be fairly accurate. Section 5.4.2 describes the performance of the Dowty System; Section 5.6 compares the performance of the two systems.

5.4 THE DOWTY SYSTEM

5.4.1 Design and Description of the Baseline Yard

The design of the quasi-continuous control system used in the comparison was performed by Dowty Hydraulic Units, Ltd. The design procedure outlined here is based on the description give to SRI by Dowty. Computer programs are used by Dowty at several stages as a design aid.

The design effort begins with the compilation of basic design data that are traditionally supplied by a customer; in this case the information was contained in the specification:

- The percentage of the car population to be controlled and the base rolling resistance distribution.
- The curve, switch and wind resistance factors. (Wind resistance was assumed to be zero in this case.)
- The minimum and maximum axle loads and the minimum and maximum wheel diameters.
- The hump rate.
- The headway required for safe switching.

As with more conventional designs, the design begins with a plan view layout to establish the location of the curves and switches. Unlike a conventional yard design, this design need not accommodate clasp retarders; the yard can be made shorter.

The yard is divided into three areas for the design of the grades: the switch area, the deceleration area and the class tracks. The design's hard and easy rolling resistances are selected from the rolling resistance distribution. A light hard-rolling car followed by a heavy easy-rolling car is considered a worst case. Based on experience, a velocity that will maintain headway in the switch area, V_s, is chosen. A hump height and an initial grade are calculated to allow this speed to be achieved before the first switch. The switch area must have a grade adequate to maintain the light hard-rolling car's speed, allowing for switch and curve and wind resistances. The required number of retarder units to maintain the easy rolling car's speed is calculated assuming even distribution. The hump height and grades are adjusted to allow for idling speed losses.

To determine if the headway is adequate, the difference in time for the design-hard and the design-easy cars to reach V_s is calculated. In addition, the time losses in the switch area, from switch and curve losses, are calculated. These differences are subtracted from the time separation on the hump, resulting in a final time separation, Δt. At the last switch, the headway will be $\Delta t \cdot V_s$. If the headway is adequate then the switch area speed, V_s, is adequate.

A more detailed design stage follows in which the actual location of each retarder is established. Some sections of track will not have retarders (e.g., at switches), and a momentary overspeed will result. The density of the retarders following this gap must be increased to slow the cars quickly to V_s. Other sections of track will require a lower retarder density because of increased rolling resistance (e.g., on curves). At the completion of this stage, the switch area design is complete.

The deceleration zone is used to decelerate cars rapidly from switch area speed to an acceptable coupling speed. The deceleration zone begins at the clearance point. The grade is reduced to that for the maximum straight track rolling resistance plus the idling resistance of the retarders. Retarders are installed at maximum density to keep the section as short as possible and to gradually decrease speed settings so cars will not be decelerated too rapidly.

The classification tracks typically have retarders along one-third of their length. The grade is established so that 95 percent of the cars will leave the end of the control zone at the desired coupling speed. Retarders are installed to maintain the speed of the easy rolling car. The grade on the remaining two-thirds of the classification track is set equal to the rolling resistance of the easy rolling car.

The yard layout and grade profile are shown in Figures 5-5 and 5-6. Dowty did not conform to our specifications in designing their yard in several areas. The major instance of nonconformity involved the specified assumption of constant base rolling resistance of a car during its entire roll. SRI designed the clasp retarder yard so that the design hard roller starts out at 18 pounds/ton at the crest and decreases to 12 pounds/ton after passing the group retarder. Dowty designed a yard where a design-hard roller starts out at 12 pounds/ton,

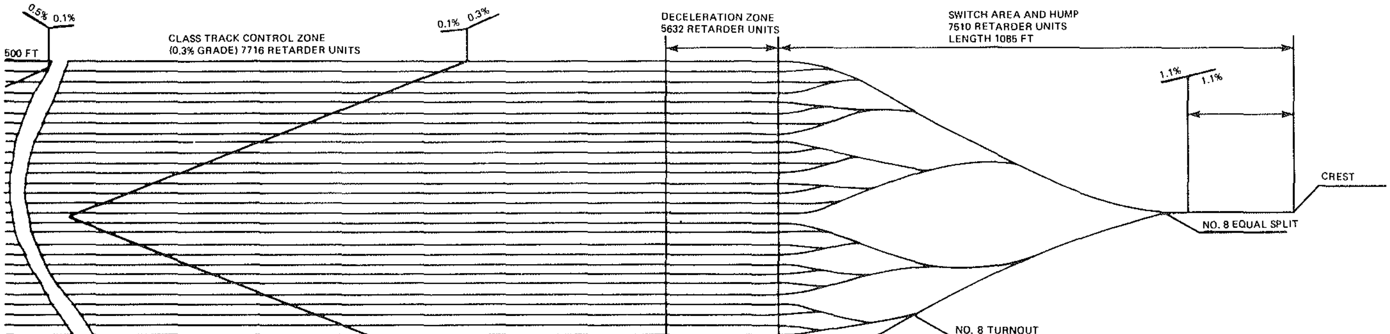


Figure 5-5. Dowty Yard Layout

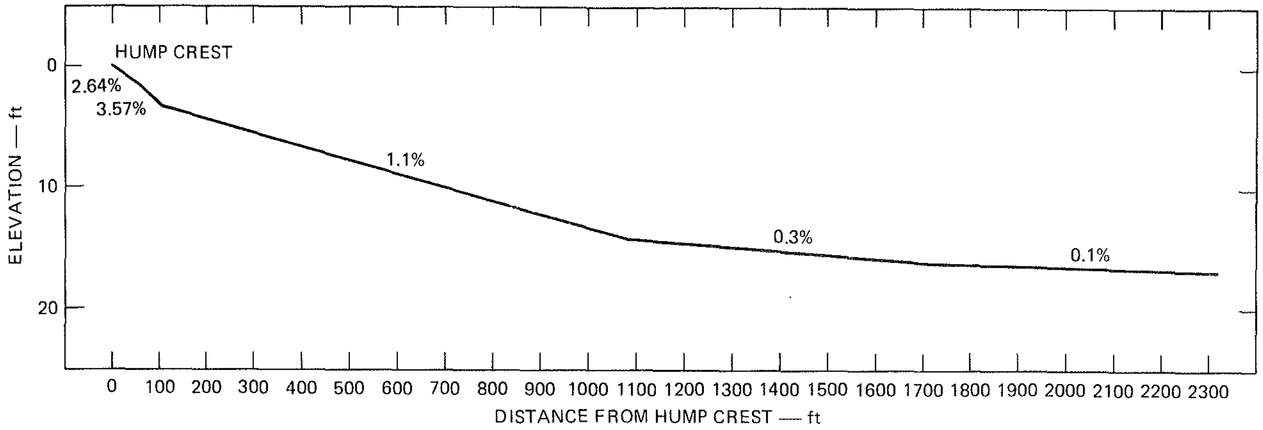


Figure 5-6. SRI Hypothetical Classification Yard, Dowty Hydraulic Units Design

decreases to 5.4 pounds/ton at the start of the deceleration zone on the class track, and decreases again to 4.4 pounds/ton at the end of the 0.3 percent grade on the class track. (The choice of the design-hard and design-easy rollers was left to the vendor.) When the Dowty yard was simulated using a base rolling resistance that changed as specified, the apparent performance suffered.

5.4.2 Dowty System Cost Estimates

5.4.2.1 Capital Cost. The SRI hypothetical yard consists of 32 classification tracks. The performance specifications and the design supplied by Dowty are described in Section 5.4.1. Table 5-4 (provided by Dowty) details the quantities, costs, and installation requirements of the Dowty retarder units. (Note that the Dowty design places retarders approximately one-third of the way into the classification tracks.)

TABLE 5-4.-QUANTITIES AND COSTS FOR DOWTY SYSTEM[a]

Retarder Quantities

The car speed control system described in Section 5.4.1 would comprise the following quantities of Dowty Hydraulic Retarders.

Location	Speed setting Meters per second	(mph)	Quantity
Hump	3.5	(7.83)	215
Switching Area	3.5	(7.83)	7,295
Deceleration Zone	2.5	(5.59)	3,040
	1.5	(3.35)	2,592
Class Tracks	1.5	(3.35)	7,716
Total			20,858

Estimated Costs

Current estimated budget costs for materials and installation are evaluated as follows:

1. Supply of the hydraulic retarders plus maintenance tools and design/support package = $8,667,504
2. The estimated labor requirement for rail drilling and installation is 4,800 man-hours.

Table 5-4 indicates that the SRI hypothetical yard requires 20,858 Dowty retarders at a cost of $8,667,504 (approximately $416 per unit).* For their Oklahoma City Dowty yard, the Santa Fe Railroad ordered an additional 5 percent spare retarders to facilitate replacement during maintenance of the Dowty units. This policy seems reasonable, therefore the total capital costs for the Dowty units, including 5 percent spares, becomes approximately $9.1 million.

Table 5-4 indicates that the estimated labor requirements for rail drilling and installation of the Dowty retarders is 4,800 man-hours. This amounts to approximately 15 man-minutes per unit. Some industry sources believe that this labor estimate may be too low, perhaps by as much as a factor of two. As of this writing, however, there is no empirical U.S. data on installing Dowty retarders in large quantities.† For the purposes of this study it is assumed that the Dowty estimate of 4,800 man-hours is correct. A large western railroad has indicated that it costs yard maintenance personnel at $13.44 per hour (1979 cost); this figure includes wages, fringe benefits, and a 30 percent allowance for general purpose maintenance equipment. Applying this hourly cost to the Dowty installation, the installation cost for 20,858 Dowty retarders totals approximately $64,500.

To put the Dowty design on a cost basis comparable to the conventional system, the costs of the following signal equipment plus installation must be included:‡

- Crest signal system
- Automatic switching
- Switch machines
- Track circuits for switches
- Power and cabling to switches.

An industry source indicates that the additional costs of this signal equipment plus installation is approximately $1.5 million for a 32 classification-track yard.

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[a] Source: "Car Control System for the SRI Hypothetical Classification Yars," prepared by Dowty Hydraulic Units, Ltd., February 21, 1980.

*All cost figures should be considered approximate since SRI did not ask for an exact quote on the hypothetical yard.

†As of April 1980, the Santa Fe's Oklahoma City Dowty Yard had not begun to install the Dowty retarders.

‡Note that the cost of the MIS yard computer is not included.

The total capital plus installation cost for the Dowty-equipped 32 classification-track yard described in Section 5.4.1 is approximately $10.7 million (see Table 5-5). Because the Dowty design does not include retarders at the pullout end, the $10.7 million cost of the Dowty system should be compared with the cost of the advanced clasp retarder system without powered-skate retarders (i.e., $6.8 million) discussed in Section 5.3.2.

TABLE 5-5.-DOWTY CAPITAL PLUS INSTALLATION COST

Dowty Retarders	$ 9,100,000
Dowty Installation	64,000
Additional Signalling	1,500,000
Total	$10,664,000

5.4.2.2 Maintenance Cost.* Routine maintenance involves checking the scraper ring and greasing the bearing periodically. Servicing of the capsules involves stripping and cleaning, fitting new seals, and charging with oil and nitrogen on assembly. If necessary, sliding cylinders or piston assemblies can be exchanged during this service to rectify any mechanical defaults. A mechanic and an assistant working a normal week should adequately maintain the retarders. A small room (approximately 150 square feet in area) containing benches, storage racks, maintenance tools and a wash tank will provide a suitable maintenance workshop. Information received from railway authorities using the Dowty System indicates an annual maintenance cost representing 2 to 3 percent of the initial capital cost of the system.

Assuming that the annual maintenance cost is 2.5 percent of the initial capital cost of the retarders, the estimated maintenance cost is approximately $217,000 (i.e., 0.025 × $8,667,504).

5.4.2.3 Operating Cost. The only operating cost seems to be the maintenance of the Dowty retarders, and that expense is accounted for in the annual maintenance cost. Because the process control computer required to throw the switches is considered to be a small simple computer system, we assume that no dedicated signal maintainer is required to monitor and maintain the small computer system.

5.4.3 Dowty System Performance Estimate

The Dowty system performance was simulated and estimated by the SPEEDCON program. (The SPEEDCON program and a discussion of the program runs are described in Appendix D.) Essentially, the Dowty system design was represented in SPEEDCON, and a car population of different rolling resistances was humped at the design speed of 200 feet per minute (approximately four cars per minute).

Because the exact range of the U.S. rolling resistance car population is not known and because these assumptions greatly affect the performance of the speed control systems, the performance of the speed control systems was measured against two assumptions concerning the population of rolling resistance:

Conservative Rolling Resistance Assumption

- Between the crest and group retarder (or equivalent location) the rolling resistances of the car population are assumed to be as as shown in the Elkhart histogram (Figure F-1).
- After the group retarder (or equivalent location) rolling resistances become easier; the Elkhart histogram (Figure F-1) is used, but all rolling resistance values are reduced to two-thirds (2/3).

Optimistic Rolling Resistance Assumptions

- Between the crest and group retarder (or equivalent location), the rolling resistances of the car population are assumed to be as shown in the Elkhart histogram (Figure F-1), except that all rolling resistance values are reduced to two-thirds (2/3).
- After the group retarder (or equivalent location), the rolling resistances become easier; the Elkhart histogram (Figure F-1) is used, but all rolling resistance values are reduced to four-ninths (4/9).

The SPEEDCON program provides for a rolling car that suddenly changes its rolling resistance from its specified value.† The model for this behavior is as follows:

- One-third (1/3) probability that a car will increase its specified rolling resistance by +19%
- One-third (1/3) probability that a car will decrease its specified rolling resistance by -19%
- One-third (1/3) probability that a car rolling resistance does not change from its specified value.

This provision was included to measure the "robustness" of the Dowty system to sudden changes in the rolling resistance of a car.

The key measures of performance as estimated by SPEEDCON for the Dowty system for both the conservative and optimistic rolling resistance assumptions are:

1. Percent stalls in the switching area--The percentage of cars (from the assumed car rolling resistance population) that stall in the switching area (i.e., prior to entering the classification track). This performance measure reflects how well a balance is achieved between the cost of increasing the hump height to handle the hardest rolling cars and the corresponding cost of installing more retarder capability to handle the easiest rolling cars.
   - Conservative Rolling Resistance Assumption: Percent stalls = 3%
   - Optimistic Rolling Resistance Assumption: Percent stalls = 0.46%
2. Percent misswitched--The percentage of cars (from the assumed car rolling resistance population) that are misrouted to the wrong classification track because sufficient headway between cars was not maintained to

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*This information supplied by Dowty.

†This does not happen in an actual yard. Due to the lack of quantitative data on how rolling resistance might vary, SRI modeled the variance as set forth. Since this same procedure was applied to all systems under study, it provides a relative measure of the "robustness" of the systems.

throw the switch. (A misswitch occurs when car headway is less than 50 feet.) This performance measure reflects the ability of the system to control headway in the switching area.

- Conservative Rolling Resistance Assumption: Percent misswitch = 0.15%
- Optimistic Rolling Resistance Assumption: Percent misswitch = 0.02%

3. Percent stopped short of coupling--The percentage of cars that stop short of coupling on the classification track. A car stops short if it does not reach the specified target point with a velocity greater than zero. This performance measure reflects the ability of the system to control coupling speeds on the classification track. This measure is correlated with but is not identical to the percentage of uncoupled cars at the time the classification track is pulled, since a large percentage of cars stopping short get "bumped" along and finally couple. (A succeeding car enters the classification, hitting the car ahead which is stopped short and pushing it toward the coupling point.) Unlike a clasp retarder yard, a Dowty yard has two grades on each class track. The first one-third of a class track has a much steeper grade (Figure 5-6). Bumping by subsequent cars significantly reduces the probability of a stall on the first one-third of the class track. (This effect is not reflected in the percentage values shown below.)

   - Conservative Rolling Resistance Assumption: Percent stop short = 41.1%
   - Optimistic Rolling Resistance Assumption: Percent stop short = 22.6%

4. Distribution of overspeed impact--The percentage of cars coupling at various speeds. The percentage is calculated from the speed distribution of cars arriving at a specified target point. This performance measure reflects the ability of the system to control coupling speeds on the classification track. The distribution for both the conservative and optimistic rolling resistance assumptions is given in Table 5-6.

TABLE 5-6.-DOWTY SYSTEM:
DISTRIBUTION OF IMPACT SPEED ON THE CLASSIFICATION TRACK

Speed range, mph	Conservative rolling resistance assumption, percent	Optimistic rolling resistance assumption, percent
0-1	1.63	0.26
1-2	4.48	2.72
2-3	5.81	6.73
3-4	9.33	7.93
4-5	17.77	20.26
5-6	13.83	29.15
6-7	2.50	8.60
7-8	0.51	1.33
>8	0.0	0.0

The above performance measures were obtained from the SPEEDCON computer model with assumptions concerning the car rolling resistance population. There are inaccuracies and approximations in the representation of any physical system by a computer model, and little definitive data currently exist on car rolling resistance in U.S. yards. The performance numbers displayed above are an estimate of performance. (The most accurate method would be to measure actual performance.) However, the approximations and inaccuracies are expected to affect the Dowty and the advanced clasp retarder system equally, making the relative performance difference in the performance measures for the Dowty and the advanced clasp retarder system fairly accurate. Section 5.6 compares the performance of the two systems.

5.5 HYBRID SYSTEM INCORPORATING THE DOWTY RETARDERS

5.5.1 Potential Configuration of the Baseline Yard

The hybrid yard incorporates the clasp retarder control system in the switching area and the quasi-continuous control system on the classification tracks.

The yard plan view layout would be similar to the advanced clasp retarder control yard but without the tangent point retarders. Master and group retarders would appear in the same locations and at approximately the same size.

The grade profile would be similar to that of the clasp retarder controlled yard up to the clearance point beyond the last switch. Starting at that point the yard would resemble the quasi-continuous yard from the deceleration zone through the class tracks.

The control logic for the master and group retarders would be similar to that used in the advanced clasp retarder system, except that the group retarder would try to deliver cars to the deceleration zone at speeds between the minimum coupling speed and the maximum speed the quasi-continuous retarders can safely handle. The deceleration zone would control all cars to within the minimum and maximum coupling speed. The retarders on the class tracks would maintain that speed.

The hybrid yard is foreseen as having two favorable applications: (1) in a large new yard designed for a high throughput while providing an accurate control on coupling speeds, and (2) as a renovation of an existing clasp retarder-controlled yard to improve the coupling performance.

5.5.2 Hybrid System Cost Estimate

5.5.2.1 Capital Cost. The SRI hypothetical yard consists of 32 classification tracks. A hybrid system consists of a clasp retarder system from the crest to the entrance of the classification tracks and a Dowty system on the classification tracks. From the crest to the entrance of the classification tracks, therefore, there is a master, four group retarders, and the associated signalling equipment. This portion of the system resembles Case 1 detailed in Section 5.3.2. (The capital and installation cost of Case 1 is $3.7 million.)

Referring to Table 5-4 (Section 5.4.2), the number of Dowty retarders on the 32 classification tracks is the total number of retarders in the deceleration zone (5,632) plus the number of retarders on the class tracks (7,716). The sum of those totals, or the total number of Dowty retarders on the classification track, is 13,348. As depicted in Table 5-5 (Section 5.4.2), 20,858 Dowty retarders (including 5 percent replacement) cost $9,164,000 for the units plus installation. Scaling this number by the ratio of 13,348/20,858 results in a cost of $5,864,000 for the 13,348 Dowty retarders (including 5 percent replacement) plus installation.

Adding the costs of the clasp retarder system in the upper part of the yard and the Dowty retarders on the class track indicates that the total cost of the hybrid system should be approximately $9,564,000. This cost estimate may be low; the hybrid system will probably require more Dowty retarders in the deceleration zone to regulate the varied speeds of cars arriving at the deceleration zone [the last point of control (retardation) is the group retarder]. The hybrid system is comparable in cost to the Dowty system described in Section 5.4.2, i.e., an estimated $10.7 million.

5.5.2.2 Maintenance Cost. Reviewing the discussion in Section 5.3.2.2, the annual maintenance cost of the master and four group retarders is $66,500. As in Section 5.4.2.2, the annual maintenance cost of the Dowty retarders on the classification tracks is assumed to be 2.5 percent of the initial capital cost. Based on that assumption, the Dowty retarder maintenance cost is $146,600 (0.025 × $5,864,000). The total annual maintenance cost of the hybrid system is $213,100 (i.e., $66,500 + $146,600).

5.5.2.3 Operating Cost. The operating cost of the hybrid system is based on a series of assumptions, as follows. A signal maintainer is required one shift per day to monitor and maintain the process control computers for switching and retarder operation. As in Section 5.3.2.3, an annual cost of $25,000 (wages plus fringe benefits) is estimated. As in Section 5.4.2.3, the only operating cost of the Dowty retarders is the maintenance cost, which is included in the annual maintenance cost estimated earlier.

5.5.3 Hybrid System Performance Estimate

Because the hybrid system was not simulated by the SPEEDCON program, no definitive performance estimates are available. However, since the hybrid system uses clasp retarders on the hump and switching area and Dowty retarders on the classification track, the following assumptions may be plausible:

- From crest to entrance of the classification tracks the hybrid system performs like the conventional system.
- On the classification track, the hybrid system performs like the Dowty system.

If the above assumptions are correct, the performance measures of the conventional system (Section 5.3.2) and Dowty system (Section 5.4.2) can be used to estimate the performance of the hybrid system.

1. Percent stalls in the switching area--The percentage of cars (from the assumed car rolling resistance population) that stall in the switching area (i.e., prior to entering the classification track). This performance measure reflects how well a balance is achieved between the cost of increasing the hump height to handle the hardest rolling cars and the corresponding cost of installing more retarder capability to handle the easiest rolling cars. (This measure is assumed to be the same as the conventional system.)
    - Conservative Rolling Resistance Assumption: Percent stalls = 0.03%
    - Optimistic Rolling Resistance Assumption: Percent stalls = 0.0%
2. Percent misswitched--The percentage of cars (from the assumed car rolling resistance population) that are misrouted to the wrong classification track because sufficient headway between cars was not maintained to throw the switch. (A misswitch occurs when car headway is less than 50 feet.) This performance measure reflects the ability of the system to control headway in the switching area. (This measure is assumed to be the same as the conventional system.)
    - Conservative Rolling Resistance Assumption: Percent misswitch = 0.0%
    - Optimistic Rolling Resistance Assumption: Percent misswitch = 0.0%
3. Percent stopped short of coupling--The percentage of cars that stop short of coupling on the classification track. A car stops short if it does not reach the specified target point with a velocity greater than zero. This performance measure reflects the ability of the system to control coupling speeds on the classification track. This measure is correlated with but not identical to the percentage of uncoupled cars at the time the classification track is pulled, since a large percentage of cars stopping short get "bumped" along and finally couple. (A succeeding car enters the classification, hitting the car ahead which is stopped short and pushing it toward the coupling point.) (This measure is assumed to be the same as the Dowty system.)
    - Conservative Rolling Resistance Assumption: Percent stop short = 41.1%
    - Optimistic Rolling Resistance Assumption: Percent stop short = 22.6%
4. Distribution of overspeed impact--The percentage of cars coupling at various speeds. This percentage is calculated from the speed distribution of cars arriving at a specified target point. This performance measure reflects the ability of the system to control coupling speeds on the classification track. (This measure is assumed to be the same as the Dowty system.) The distribution for both the conservative and optimistic rolling resistance assumptions is given in Table 5-7.

The hybrid performance assumptions are based on the theory that from the crest to the entrance of the classification track the yard is designed like the conventional design and that on the classification track it is like the Dowty design; in other words, the two appropriate halves of the conventional and Dowty design are simply "pieced" together. More likely, an optimum hybrid design would have a transition region where the design is like neither the conventional nor the Dowty design. More Dowty retarders probably will be needed at the beginning of the classification tracks (deceleration zone) to reduce the speed of cars which have accumulated excess velocity since leaving the group retarder. Lacking the detailed design, it is assumed that the yard will have performance characteristics identical to the clasp retarder yard from the hump to the tangent point (or start of the deceleration zone) and performance characteristics identical to the Dowty yard on the classification tracks.

TABLE 5-7.-HYBRID SYSTEM: DISTRIBUTION OF IMPACT SPEED ON THE CLASSIFICATION TRACK[a]

Speed range, mph	Conservative rolling resistance assumption, percent	Optimistic rolling resistance assumption, percent
0-1	1.63	0.26
1-2	4.48	2.72
2-3	5.81	6.73
3-4	9.33	7.93
4-5	17.77	20.26
5-6	13.83	29.15
6-7	2.50	8.60
7-8	0.51	1.33
>8	0.0	0.0

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[a] This performance measure is assumed to be the same as for Dowty system.

5.6 COMPARISON OF THE THREE SPECIFIC SYSTEMS

One difficulty in making quantitative comparisons between the conventional and Dowty designs is that, even given the same initial SRI specifications for the baseline yard (including a histogram of rolling resistance), the clasp retarder and Dowty yards were designed based on different assumptions on the hardest rolling car. SRI designed the clasp retarder yard using a design-hard roller which starts out at 18 pounds/ton at the crest but changes to 12 pounds/ton after the group retarder.* The Dowty corporation, on the other hand, designed the Dowty yard using a design-hard roller which starts out at 12 pounds/ton, changes to 5.4 pounds/ton at the start of the deceleration zone on the class track, and decreases further to 4.4 pounds/ton at the end of the 0.3 percent grade on the class track.

Because the actual rolling resistance distribution for U.S. cars are not known, it is a matter of conjecture as to which assumption (i.e., U.S. or Dowty) truly reflects U.S. car behavior. For this reason, to be fair to both designs, two different car populations of rolling resistances were simulated as being humped by the conventional and Dowty designs using SPEEDCON. One was a conservative rolling resistance assumption, the other was an optimistic rolling resistance assumption (see Appendix F). Tables 5-8 and 5-9 provide a comparison of the performance measures for the advanced clasp retarder, Dowty, and hybrid designs for the conservative and optimistic rolling resistance assumptions, respectively.

For the actual distribution of rolling resistances to be more difficult than the conservative assumptions, the performance measures should be worse than shown in Table 5-8. For the actual distribution of rolling resistances to be easier than the optimistic assumption, the performance measures should be better than shown in Table 5-9. However, for the actual distribution rolling resistances to fall between the conservative and optimistic assumptions, the performance measures should be between those found in Tables 5-8 and 5-9.

TABLE 5-8.-COMPARISON OF DESIGNS: CONSERVATIVE ROLLING RESISTANCE ASSUMPTIONS

Performance	Conventional, percent	Dowty, percent	Hybrid, percent
In switching area			
Probability of misswitch	0.0	0.15	0.0
Probability of stall	0.03	3.00	0.03
On class track			
Probability of stop-short	15.8	41.1	41.1
Distribution of overspeed impact			
0-1 mph	0.02	1.63	1.63
1-2	4.33	4.48	4.48
2-3	6.71	5.81	5.81
3-4	39.99	9.33	9.33
4-5	13.79	17.77	17.77
5-6	12.35	13.83	13.83
6-7	6.94	2.50	2.50
7-8	0.02	0.51	0.51
>8	0.0	0.0	0.0

TABLE 5-9.-COMPARISON OF DESIGN: OPTIMISTIC ROLLING RESISTANCE ASSUMPTIONS

Performance	Conventional, percent	Dowty, percent	Hybrid, percent
In switching area			
Probability of misswitch	0.0	0.02	0.0
Probability of stall	0.0	0.46	0.0
On class track			
Probability of stop-short	7.9	22.6	22.6
Distribution of impact speed			
0-1 mph	0.0	0.26	0.26
1-2	3.73	2.72	2.72
2-3	9.10	6.73	6.73
3-4	36.48	7.93	7.93
4-5	24.19	20.26	20.26
5-6	14.36	29.15	29.15
6-7	4.21	8.60	8.60
7-8	0.07	1.33	1.33
>8	0.0	0.0	0.0

In Tables 5-8 and 5-9 the performance in the switching area of the conventional system is always superior to the Dowty system. The discrepancy in the performance of the advanced clasp retarder and Dowty designs is reduced when the optimistic rolling resistance assumptions are made. The reduction occurs because the Dowty design is based on a relatively easy design-hard roller and performs better with an easier rolling population of cars. A Dowty design based on a hard rolling car would exhibit better performance in the switching area;

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[*] U.S. signal companies did not respond to invitations to submit designs.

however, the steeper grades on the hump and switching area would require more Dowty units. Because the Dowty units cost approximately $416 per unit, the total capital cost would be substantially affected. The clasp retarder design provides good headway control in the switching area, because the control algorithm is based on the passage times of a nominal car at various control points in its roll and does not depend directly on rolling resistance. In particular, if a car reaches a control point behind a nominal scheduled time, it is released from the retarder at a high velocity. If the car is ahead of schedule, it is released at a lower velocity. This algorithm appears to adapt and compensate for changes or errors in the measurement of the car's rolling resistance with respect to headway control in the switching area.

Tables 5-8 and 5-9 indicate that the Dowty design has better overspeed coupling performance on the classification track than does the advanced clasp retarder system. However, we see that the clasp retarder system also performs well; in particular, over 90 percent of the cars couple at less than 6 mph, and there are no couplings at speeds greater than 8 mph.* Although the Dowty system performs better than the advanced clasp retarder system with respect to overspeed coupling, the variance appears to be slight. The reason that Dowty performance is not significantly better is that the Dowty design places retarders only one-third of the way into the classification track; 67 percent of the length of the class track in a Dowty design is uncontrolled, compared to 100 percent of the length uncontrolled in the clasp retarder design. If the Dowty design were to be modified to have retarders distributed the length of the classification track, the cost of the Dowty yard would increase from $10.7 million to approximately $22.4 million (at a cost of $416 per Dowty retarder unit). From Tables 5-8 and 5-9 it appears that, in the Dowty design, more cars couple at greater than 6 mph under the optimistic assumption than under the conservative assumption. The higher number of high-speed couplings can be explained by the fact that, in the optimistic assumption, not only do the harder cars roll easier but the easier rolling cars also roll easier. The grades in the latter 67 percent of the class track in the Dowty design should be lowered to reflect the lowered rolling resistance of the easier rolling cars.

Tables 5-8 and 5-9 indicate that the advanced clasp retarder system is less apt to cause cars to stop short on the classification track than is the Dowty design. In the Dowty design the last 67 percent of the class track is uncontrolled, and cars are released from the last Dowty retarder into 67 percent of the length of the class track at a preset release speed, independent of the length of roll or the rolling resistance of the car. Although the clasp retarder design shows 100 percent of the length of the class track uncontrolled, cars are released from the tangent point retarders at variable release speeds depending on the length of roll and the car's rolling resistance.

From Tables 5-8 and 5-9 the hybrid design is assumed to perform in the switching area like the clasp retarder design and on the class track like the Dowty design. The tables reveal that the advanced clasp retarder design performs better than the Dowty design in three performance measures and performs only slightly worse with respect to overspeed coupling. Furthermore, the clasp retarder design performs better than the hybrid design in one measure, performs equally in two measures, and performs only slightly worse with respect to overspeed coupling. Because the capital cost of the advanced clasp retarder design appears to be considerably less than that of the Dowty and hybrid designs (i.e., approximately $3.8 million or 36 percent less), it appears that the advanced clasp retarder design for the baseline yard is more cost-effective than either the Dowty or the hybrid design.

The above results must be qualified. The comparison only relates to the specific designs evaluated for the 32 classification-track baseline yard, to the assumptions used in the SPEEDCON program, and to the two populations of rolling resistances assumed (i.e., conservative and optimistic assumptions). The only valid comparison of the system would be to use actual performance data rather than a computer simulation. Also, it is not clear whether for small hump yards (i.e., 8 to 12 class tracks) with low hump speeds (i.e., two cars per minute) the relative costs between a conventional and Dowty yard would be different.

SECTION 6 — CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Of the four generic state-of-the-art speed control systems discussed in this report, three are potentially viable:

- The conventional clasp retarder system employing advanced retarder control algorithm.
- The quasi-continuous control system (Dowty system).
- The hybrid system of clasp retarders and Dowty retarders.

The cost analyses of three baseline yards incorporating these three systems show that while the maintenance and operating costs of all three systems are comparable, the capital cost of either the Dowty system or the hybrid system is at least a third higher than that of the clasp retarder system. The quantitative performance evaluation of these three systems indicates that the advanced clasp retarder system has the best overall performance. The relatively poor performance of the Dowty system is at least partially the result of the use of unusually low design values for car rolling resistance.

While the quantitative analyses of three specific speed control systems yield some important information on the sensitivity of a system's performance to the assumed rolling resistance distribution, careful use should be made of the limited quantitative results in the future selection of speed control systems. One reason for this caution was mentioned earlier: The three baseline yards were not designed on exactly the same basis despite SRI's efforts to ensure uniformity. Another reason is that the relative merit of a speed control system depends on the size of the yard and the required throughput. For a certain size and throughput, the performance of one system may be far superior to the others. For this reason, when a new yard or a renovation project is contemplated, the three recommended systems must each be considered carefully; none of them can be automatically excluded.

6.2 RECOMMENDATIONS

Many potential improvements to the yard speed control system in general are identified in this report.

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*U.S. yards' desired coupling range is from 2 to 6 mph, with 4 mph as the desired nominal value.

The following list enumerates those improvements as recommendations for future work.

1. Fundamental Research on Car Rolling Resistance

There is a need for more fundamental research on car rolling resistance in yards, both for speed control and yard design. The conventional system performance might be improved by more sophisticated algorithms to control headway for switching and coupling velocities on the classification track. The key to most of these algorithms is the prediction of a car's rolling resistance.

The performance and cost of the Dowty system is critically dependent on a balance between the steepness of grades and the density of Dowty units. To achieve a balance, the rolling resistance distribution of the car population must be known.

2. Further Improvement of Retarder Control Algorithm

The current generation of retarder control algorithms does not take into consideration what the car ahead is doing. They are based on either a nominal (standard) velocity or on a time schedule for each car. "Second-generation" algorithms can be developed which control not only how a car is rolling but also what the car ahead is doing (see Appendix B). Coupled with variable hump speed, such second-generation algorithms are likely to produce higher hump speed (throughput). More research on second-generation control algorithms is needed.

3. Acquisition of Field Performance Data

The comparison of the performance of the conventional and Dowty systems was based on a computer model. The ideal situation is to compare the performance of such systems using actual field data. Unfortunately, at the time this report was written, Santa Fe's Dowty yard in Oklahoma City had not been completed. It is recommended that performance, cost, and maintenance data be monitored in the Oklahoma City yard and compared to data from a similar conventional yard. In this way system comparisons will be based on empirical data.

4. More Study of Hybrid System Alternatives

The hybrid system studied in this report consisted of a master retarder, group retarders, and Dowty units on the first third of the classification track. Other hybrid configurations are possible. For example, it may be more desirable to place the Dowty units in the middle third of the classification tracks instead of the first third. In such a configuration, the group retarder "target shoots" into the first third of the classification track. Speeds in the middle third are closely controlled by the Dowty units, and speeds in the final third are dictated by the preset release speed of the last Dowty units and by the grade. The advantage of such a hybrid system is that a car is released by the last Dowty unit into one-third rather than two-thirds of the classification track, as in the hybrid system studied in this report. The longer the distance of roll from the last control point, the poorer the coupling speed performance; it seems logical, therefore, to design a system that minimizes the distance between the last control point and the coupling point.

5. Noise Research

The noise behavior of the conventional and Dowty systems is not well understood, a lack of information that effectively impedes improvements to the various systems needing to meet future environmental standards. Fundamental research is needed to quantify the noise characteristics of various speed control systems and to suggest improvements.

6. Speed Control Test Track

New and innovative speed control research should be encouraged. One stimulus could be the development of a speed control test track at the FRA Transportation Test Center in Pueblo, Colorado. At this test track, railroads and vendors would be allowed to experiment and test new device and computer algorithm concepts.

Appendix A

SUMMARY OF DOMESTIC AND FOREIGN YARDS VISITED

A.1 DOMESTIC YARDS

A.1.1 West Colton Yard, West Colton, California

West Colton is the most advanced yard in the Southern Pacific system. Built in 1973 for $39 million, it is located at the junction of SP's mainline West Coast routes and its mainline Transcontinental route. It has 48 classification tracks and humps 2,000 to 2,800 cars per day for a 23 to 32% duty cycle. The normal hump rate is 3.4 mph (six 50-foot cars per min). Maximum car detention time is 12 hrs.

The speed control system was designed by WABCO and consists of full-control, clasp-type master, group and (on longer tracks) intermediate retarders. It also has weight-responsive tangent-point retarders to control the cars for coupling.

The retarder control algorithm attempts to make each car arrive at each of several reference points along its path within a specified time referenced to the time when the car passed the hump. The arrival times at each point are based on the rolling behavior of a "base" car. Repeated rollability measurements are made on each car to predict as accurately as possible the transit time of a car between reference points and to determine the retardation necessary to keep the car "on schedule." Sixty-three radar units are used in the yard. The constants used in the algorithm are updated every four months, based on statistics gathered on yard performance since the last update, to account for changes in the yard, car population, and seasonal differences.

The control computer was designed and installed by WABCO and is a Xerox SIGMA3 with the additional relay logic. No manual control of the yard is possible. Couplings over 6 mph are claimed to be less than 0.65%.

Up to four hump engines are used depending on the traffic load. A two-key trim end design is used. There is often a conflict between the trim engines working in each key, resulting in a bottleneck.

A.1.2 Barstow Yard, Barstow, California

Barstow Yard, built in 1976, is the most modern yard in the Santa Fe system. The yard has 44 classification tracks and humps 2,000 to 3,000 cars per day, for a duty cycle of 32 to 47%. In total, 4,000 to 6,000 cars pass through the yard each day. The normal hump rate is 2.5 mph (4.4 50-ft cars per min). The yard features a minihump with four sorting tracks for geometric blocking of trains and has only manual control.

The entire yard was designed, built, and programmed by Santa Fe personnel. WABCO and ABEX retarders were used and the computer system consists of four Data General "NOVA" minicomputers. Control algorithms have evolved since the initial installation, with modifications being made by Santa Fe personnel. The rollability of each car is measured with wheel detectors only once, just ahead of the master retarder. Manual control is possible at Barstow and the yard can also function without a computer by controlling the retarders with inputs from the radar units.

Two to three trim engines are normally used. Yard personnel claimed that the main bottleneck at the yard is lack of motive power.

A.2 FOREIGN YARDS

A.2.1 Dowty Equipped Yards

A.2.1.1 Dowty Test Facility, Cheltenham, England. Dowty Hydraulic Units, Ltd., maintains a test facility near their factory. The primary functions of the facility are to:

- Set up initial production units to specification.
- Spot-check production units.
- Perform continuing R&D on retarders.
- Determine empirical constants, such as orifice coefficients of prototype units.

During testing of prototype retarders, a car of known weight is pushed up to the desired speed and released just prior to reaching a section of track with the Dowty retarders under test. This section is instrumented to measure:

- The force (known as end-load) vs. deflection of the retarder piston.
- The change in velocity of the car as it passes over the retarders to determine the total energy extraction.
- The wheel lift of light cars.

The wheel lift is an important parameter. Wheel lift occurs on lightly loaded wheels if the end-load (vertical force applied by the retarder) is greater than the wheel loading. The end-load also determines the maximum energy extracted by the retarder and so should be set as high as possible while keeping wheel lift within the limits set by the railroad. These limits are between 6 and 8 mm (0.24 and 0.32 in).

A flow rig is used to set up a retarder's end-load. The Dowty piston is inserted into the rig which pumps oil at 60 gpm through the orifice valve. The valve can be adjusted to achieve the desired pressure in the capsule--the pressure determines the end-load which determines wheel lift.

Other tests performed include retarder operation at temperature extremes such as 102°C and -40°C.

A.2.1.2 Scunthorpe Yard, Scunthorpe, England. Scunthorpe Yard is located in a steel-producing area of England. The main cargo passing through the yard is structural steel products. The yard has 19 classification tracks and handles 250 cuts of cars per day. The speed limit in the yard is 10 mph.

The yard was updated in 1972 from a purely manual yard (using skatemen to control car speed) to a pure Dowty yard at a cost of $704,000 (£300,000). Updating consisted of installing 7,000 second-generation Dowty retarders and some regrading.

British Rail personnel are satisfied with the performance of the Dowty system. Shifted loads were common in the days of manual operation. The yard master stated that no shifted loads had occurred in the two years of his tenure while another official claimed that no shifted loads had occurred in the entire seven years of Dowty operation.

A.2.1.3 Healy Mills Yard, England. Healy Mills is a large, conventional yard with 50 class tracks used by Dowty for endurance testing.

The clasp retarder system is made by WABCO and consists of a master retarder on each of the double hump leads, and eight group retarders. The hump height is approximately 18 ft. Yard throughput is approximately 3,000 cars per day.

Dowty has installed eight booster-retarder units just past the hump crest, followed by 21 Dowty retarder units (12 on one lead, 9 on the other). The net energy input by the boosters is removed by the retarders so overall yard performance is not affected. The retarders boost car speed so that it is always above the retarder's activation speed.

Dowty uses the retarder section for testing prototype retarders as well as for endurance tests. Two of the prototype units present had gone over one million cycles. A Dowty representative remarked that a design is ready for production after withstanding one million cycles.

A.2.1.4 Limmattal Yard, Zürich, Switzerland. Limmattal is a modern yard in the Swiss Rail System presently having 32 classification tracks and is to be expanded to 64. The speed control system includes:

- Computer controlled hump locomotives that push the cars over the crest at 3.13 ±0.11 mph.
- A conventional clasp-type master retarder on each of the double hump leads. The retarder is 100 ft long and located one-third the distance between the hump and the last clearance point.
- Group retarders, one-half the size of the master retarder, each serving eight class tracks. These are located 300 ft past the master retarder.
- Electrodynamic siding retarders located just beyond the clearance point on each class track. The siding retarders release all cars at a 3.4 mph for the cable-operated mules.
- Dowty retarders mounted on the grade between the siding retarders and the mules beginning at about the tangent point. The Dowty retarders maintain the speed of short cuts on this section. (The yard is designed for long cuts of cars which are common in Europe, thus the long distance between the siding retarder and the start of the cable system.)
- Cable-operated mules on the classification tracks. The mule engages the wheels of the cars at the tangent point and propels tham at a constant 3.4 mph until just before coupling where it releases the car and returns. Wheel detectors and track circuits signal the computer when to start the mule and when to return it.

The rolling resistance of each cut is determined once just prior to the master retarder. The speed of the cut is measured at one point and compared with the speed computed for a cut of the same length but with the "worst" rolling resistance. The difference is a measure of the cut's rollability. Only this one rollability measure is used in the retarder control algorithm.

The retarders use a "ramp control" scheme in which the speed of a car is reduced evenly over the length of the retarder. The car's actual speed is monitored while the car is in the retarder and the retarding force (clasping pressure) is constantly adjusted. It is claimed that this constant variation prevents wheel squeal; no wheel squeal was heard during our visit.

The elaborate control system is expensive but justified by the need for ensured coupling as well as minimum operating noise. Low noise is important because the yard is located near a populated area. Since European cars do not have automatic couplers, the coupling speed (actually the buffering speed) must be low or the cars may bounce apart on impact, requiring the cars to be recoupled before the train can be made up. The cable-operated mules ensure a uniform, low coupling speed to minimize this problem. The total cost of the yard was $200 million in (approximately) 1973.

Dr. König, the principal Yard Designer, commented that if low noise were not a factor, he would have used a pure Dowty system; and that if European cars had automatic couplers, he would not have used the expensive cable system.

The process control system is similar to that used in the United States. The charges from the signaling contractor, Siemens, totaled $18 million (1973) approximately 10% of which was for computer hardware, and the remainder for outdoor equipment. Twelve man-years were required to develop the current software.

A.2.1.5 Nürnberg Yard, Nürnberg, West Germany. Nürnberg is an old (built in 1903) and very large yard with 106 classification tracks and is capable of handling 140 trains per day or 6,800 cars per day. The antiquated design has a continuous grade from the receiving yard to the start of the switch area. The grade eliminates the need for a hump locomotive. A manually-controlled clasp retarder at the head of the switching area holds the cars in the receiving area. When the headway is adequate between the previous car and the car in the retarder, the operator releases the car in the retarder and then stops the next car to repeat the sequence. Manually operated switches are used and skatemen control the car speed through the yard.

Modernization is planned which includes:

- Regrading
- Adding group retarders, each handling eight sidings
- Adding Dowty retarders in all the classification tracks below the group retarders. The gradient in the class tracks will be 0.8% and each track will have approximately 800 retarder units.

At present, six of the most heavily used tracks have been equipped with a clasp retarder and Dowty units to test the design. The clasp retarder is made by Thyssen and slows all cars to 9 mph. The Dowty retarders then slow the car in stages down to 2.2 mph for coupling. The speed, length, and weight of each cut of cars is measured prior to the clasp retarder to determine the retardation required. The retarders are controlled by a microprocessor.

The Dowty-Thyssen system was installed in May 1979; at the time of our visit in September 1979 approximately 27,000 cars had passed through the test section. Coupling performance was much improved over the performance of the skatemen.

A.2.2 ASEA Equipped Yards

A.2.2.1 Helsingborg Yard, Helsingborg, Sweden. Helsingborg yard is a continuous control yard using ASEA spiral retarders. It has 24 class tracks and currently handles 1500 cars per day at about 150 per hr. The performance is limited by the arrival sidings.

The yard was originally an 18-track, fully manual flat yard using skatemen. In 1965-1970, increased traffic necessitated converting it to a hump yard. The yard was regraded and 230 ASEA spiral retarders were installed in the switch area, the skatemen being maintained in the class tracks. In 1974 the yard was further updated with additional regrading and the addition of spiral retarders in the class tracks, bringing the total number to 700. Presently, the hump height is 9.6 ft (from crest to the last retarder), the hump grade is 4.5%, the switching area grade is 1.0% and the class tracks are at 0.28% grade. Switching is now done with relay logic. The cost of the most recent updating including regrading, additional retarders and modifications to other facilities, was $2.2 million (KR 8.98 million) in 1974.

Swedish rail personnel are happy with the performance of Helsingborg and plan to use ASEA retarders in other yard updating projects. The retarders are checked for proper operation monthly with a special locomotive equipped with an instrumented set of wheels that measure the retarding force. This typically required one shift/month. In a period of four months, two or three retarders will need to be replaced and taken out of service.

Service on a retarder requires machining the end of the spiral unit open for access to the pumping mechanism. When service is completed, the cylinder is rewelded. Two men can overhaul two retarders in eight hours. The local Swedish rail representative claimed that a retarder can withstand 500,000 wheel passages before requiring an oil change.

A.2.2.2 Malmö Yard, Malmö, Sweden. Malmö is a hybrid yard with three clasp retarders serving as group retarders and ASEA spiral retarders in the switch area below the clasp retarders and in the class tracks. There are 26 class tracks.

Like Helsingborg, Malmö has been recently updated. Originally it was a hump yard with only skatemen to control the car's speed. In 1972 clasp retarders were installed and the skatemen were maintained in the class tracks. In 1979 additional ASEA retarders were installed in the lower switch area and in the class tracks. Twenty-one skatemen were replaced. The control logic for the clasp retarders had to be modified and at the time of our visit this modification was being adjusted.

The clasp retarder outlet speed is computed from the car's weight, inlet speed and track destination (each path is different). The target speed at the spiral retarders is 6.7 ±1.1 mph. The speed setting of the retarders is stepped from 5.6 to 4.5 to 3.3 mph. The 19 retarders on each path have sufficient capacity to slow the heaviest car from 8.9 mph to 3.3 mph.

A.2.3 Other Yards

A.2.3.1 Maschen Yard, Hamburg, West Germany. Maschen Yard is a large, new and ultra-modern yard in the German Federal Rail System. Its 112 classification tracks are divided into a northbound and a southbound yard. The northbound yard with 18 arrival tracks and 64 classification tracks handles mostly short trains destined for Hamburg harbor. It has a design throughput of 6500 cars per day. The southbound yard with 16 arrival tracks and 48 classification tracks handles mostly long-distance trains bound for southern Germany. It has a design throughput of 6500 cars per day. Both yards use a maximum hump rate of 6 cars per min. The yard employs 1,700 people in three shifts. A car's typical residence time is two hours.

Construction began in 1970 and the southbound yard was completed in May 1977. A portion of the northbound yard was completed and put into operation in May 1979. When the yard is fully completed it will replace five yards in the Hamburg area. The cost of the yard is quoted as $402 million (DM 717 million) (1979) whereas the published value of $495 million (DM 884 million) includes the ultimate dismantling of the five yards it will replace.

The speed control system of each subyard is similar in complexity to Limmattal and includes:

- A Thyssen clasp-type master retarder.
- Thyssen clasp-type group retarders.
- Thyssen rubber rail siding retarders in each classification track used to slow all cars down to an acceptable speed for the cable system.
- Hauhinco oscillating cable system between the siding retarders and the cable-operated mules (about 150 ft long) to keep long cuts moving at a constant speed.
- Hauhinco cable-operated mules to move the cars down the classification track and ensure coupling. The mules push the cars at 2.8 mph and have a maximum travel of 2,230 ft.

The cars jump noticeably when they enter an activated rubber rail retarder which can only be deactivated once during the passage of a car. The cable system requires maintenance that averages one track down each day.

The yard also features an auxiliary hump in the southbound yard for secondary sorting. Each yard has arrival tracks but (it was claimed) has no departure tracks. However, aerial photographs show a half dozen departure tracks in each yard.

A.2.3.2 Ambèrieu Yard, Ambèrieu, France. Ambèrieu Yard, an old and conventional yard, is used by the French National Railroad as a test bed for new speed control devices. The yard has 41 classification tracks and uses manual switching. Two speed control systems were seen. The first is a self-contained car mover, installed on each classification track in 1973, and claimed to be the forerunner of the Japanese LIM system. The car runs on rubber tires on its own track between the rails. It is powered by a 48V, 350A electric motor in each car; its control system is unknown. The device is considered cost inefffective by railroad officials and no further development is intended.

In the second system, seven Faiveley hydraulic retarders were installed on one track in December 1978. They are distributed as follows: four are densely packed near the tangent point with a speed setting of 3.1 mph; and three are distributed on the class track with speed settings 2.7, 2.5 and 2.2 mph. Faiveley retarders are not only speed-responsive similar to the Dowty and ASEA retarders, but also weight-responsive and independent of wheel size. Operating noise is higher than the Dowty retarders and installation of the Faiveley retarders necessitated rail modification. These seven units are the only ones currently under field testing.

A.2.3.3 Shiohama Yard, Kawasaki City, Japan. The Shiohama Classification Yard is located in Kawasaki City, a heavily industrialized area. The yard consists of an inline type receiving yard, a parallel departure yard, a hump classification yard, a flat classification yard, and approximately 10 industry yards. The size of the yard is small by U.S. standards: 5 receiving tracks of approximately 1800 ft, 24 classification tracks ranging from 700 ft to 1300 ft (15 of these are hump classificaiton tracks, the remainder are flat classification tracks), 11 departure tracks of approximately 1800 ft, and other miscellaneous tracks.

The maximum grade between the hump and the classification tracks is 6%. The hump speed is approximately 2.2 km/hr (1.4 mph). One locomotive is used to operate the hump end and another to assemble trains at the departure end. One train usually consists of 30 to 50 cars, and 52 trains are made up in this yard per day according to the schedule.

The Shiohama Yard is unique because of the Linear Induction Motor (LIM) System installed there. The LIM works on the same principle as a cable-operated mule: the wheels of each car are engaged when entering the class tracks and the car is moved to coupling. The LIM is much more elaborate than a cable system. Since it can both accelerate and decelerate a car, it can operate faster than a cable system by moving a car down the class track at high speed, then slowing it to an acceptable speed just before coupling. The system was installed as part of an updating program in September 1974.

Before the LIM system became operational in the yard, the speed control of cars on the classification tracks was manually accomplished: a man jumped on to the oncoming car and braked it just prior to coupling. This method was both dangerous and costly. In comparison, the LIM system is safe and cost effective.

The linear motor car concept has been also applied to two other yards in Japan: the Fusotonda yard in the Kansai district and the Kitakami yard in the Tohoku district. While SRI project personnel did not visit these two yards it was learned that the Kitakami yard has a special feature to make operation feasible under snow conditions.

A dual computer system is installed to process classification information, retarding information, and linear motor system operation information. Each computer has a central processing unit of 16K words, two 32M words magnetic drums and input/output units. The classification information is sent from upstream terminals via a communication system. This information is then punched into cards and fed into the system manually for each train. The pin puller also receives printed classification information just prior to humping. The information required for retardation is obtained by measurement as the car rolls down the hump. The information obtained includes: car weight, speed of the car at the detector, wind velocity and direction, car type (box car, flat car, etc.), and the number of axles on the car.

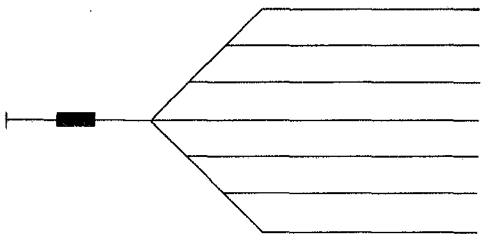
Appendix B

LOWER COST SPEED CONTROL SYSTEMS FOR MINI-HUMP YARDS[*]

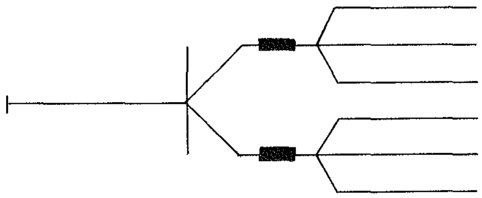
A flat yard is classified as a labor-intensive facility, whereas a hump yard is a capital-intensive facility. For this reason, it has been traditional to build flat yards for low-volume terminals (i.e., less than 1,000 cars per day), and to build hump yards for high-volume terminals (i.e., greater than 1,500 cars per day). However, traditional criteria need to be reexamined because of the rapid inflation of labor costs in the last decade and increasing innovation in the design of so-called "mini-hump" yards. In particular, Southern Pacific has pioneered the development of small mini-hump yards which it is claimed are economical for small- and medium-sized yards, i.e., those classifying from 500 to 1500 cars per day.

The performance of a mini-hump design should be specified in terms of a given humping rate (without misswitches and stalling) and a range of coupling impact speeds on the classification tracks for all cars between design-specified hardest and easiest rolling resistance cars (specified in pounds/ton or equivalent percent grade).

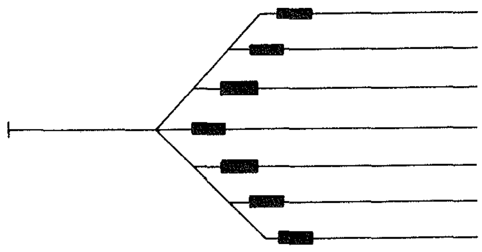
For small yards (i.e., 8 to 16 class tracks), Figure B-1 shows three alternatives for a mini-hump yard design.



a. MASTER-RETARDER-ONLY DESIGN



b. GROUP-RETARDER-ONLY DESIGN



c. TANGENT-POINT-RETARDER-ONLY DESIGN

Figure B-1. Mini-Hump Design Alternatives

The alternatives shown are master-retarder-only design, group-retarder-only design, and tangent-point-retarder-only design. Conventional hump yard designs for medium or larger yards normally contain a master and group retarders, and if a high hump rate is desired, may have in addition tangent point retarders (e.g., Southern Pacific's West Colton Yard).

The design of low-cost mini-hump yards was made feasible by the development of relatively inexpensive weight-responsive hydraulic retarders and low-cost speed measuring devices (i.e., doppler radar and sonic-notched-rail devices). Conventional hump yards traditionally use pneumatic, electric, or electro-hydraulic heavy duty retarders, which are considerably more expensive than weight-responsive hydraulic retarders.

The master-retarder-only design presented in Figure B-1(a) shows a single weight-responsive hydraulic master retarder. Because the distance to couple and the curves negotiated en route to the various classification tracks vary, additional sensors and computer logic to calculate rolling resistances, track fullness, and variable retarder release speeds based on distance to couple should be incorporated in order to achieve a high humping rate while maintaining proper coupling speeds. The need for this additional sophistication to maintain a high humping rate and proper coupling speeds becomes more acute as the number of classification tracks controlled by the single master retarder increases. As the number of classification tracks increases, the uncontrolled distance for a car's roll from the master retarder to the classification tracks increases, thus making it more difficult to achieve a high humping rate while maintaining sufficient headway between cars to throw switches; the extra distances and curvature to the outside tracks makes accurate coupling on the classification tracks difficult. In this design it is critical to bring all the clear points as close to the master retarder as possible to minimize the uncontrolled distance. However, a master retarder which is too close to the hump crest will constrain the humping rate, since not enough distance is allowed for cars to gain sufficient separation to avoid two cars being in the retarder simultaneously; normally the master retarder is placed at least 70 ft from the crest and preferably slightly farther.[†] The hump height for this design is approximately 7 ft for a 12-track classification yard; the actual height varies depending on the hardest rolling resistance for the design and the number of classification tracks.

To keep the uncontrolled distance of a car's roll from the retarder to the outside classification tracks within a reasonable limit so as not to let performance suffer, it is obvious that one solution is to limit the number of classification tracks being controlled by a given retarder. This philosophy gives rise to the group-retarder-only design shown in Figure B-1(b), in which two or more weight-responsive hydraulic retarders are used to control two or more groups of classification tracks. Thus, the group-retarder-only design can be considered as an evolution of the master-retarder-only design when the objective is to achieve higher performance by limiting the number of classification tracks under the control of a single retarder. In this design it is not only critical to minimize the uncontrolled distance from the group retarder to the clear point of the outside tracks, but it is also imperative to minimize the uncontrolled distance of a car's roll from the hump crest to each group retarder. The group retarders should be sufficiently close to the hump

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[*] Material in this Appendix will appear in an FRA-sponsored Yard Design Manual

[†] As a function of distance from the hump crest, the separation between cars increases to a maximum before decreasing.

crest to avoid the need for a master retarder ahead of the group retarders since this adds to the cost. In an attempt to place the group retarders as close to the hump crest as possible, the first-divide switch should not be so close as to constrain the humping rate. In particular, if the first-divide switch is too close to the hump crest, the humping rate will be limited because not enough distance is allowed for cars to gain sufficient separation to throw the switch; normally the first-divide switch is placed at least 70 ft from the crest and preferably slightly farther (see previous footnote). Again, the performance of this design can be enhanced by additional sensors and computer logic to calculate rolling resistances, track fullness, and variable retarder release speeds based on distance to couple.

The Southern Pacific (SP) has pioneered the development of the tangent-point-retarder-only design; they currently have six of these types of yards on their property.* Figure B-1(c) shows the design favored by SP in which weight-responsive hydraulic retarders are placed at each tangent point. The initial grades are designed to deliver the hardest rolling car to the tangent point at approximately 4 mph; the tangent point retarders are designed to slow and release easier rolling cars at a preset release speed of approximately 4 mph. The yards can achieve three cars per min over the hump. The key to the design (as claimed by SP) is that the tangent point retarders squeeze the wheels and straighten out the trucks, thus narrowing down the "band" of rolling resistances on the class tracks and giving superior coupling performance. The classification track grade is a "maintaining" grade for the easiest rolling car; therefore, no coupling impact speeds are greater than 4 mph. The hardest rolling car generally goes about a third of the way into the class track; because their wheels have been straightened they easily get "bumped" further into the class track by succeeding cars. An important factor for a successful operation is a "tight" design in which the uncontrolled distance of a car's roll from the hump crest to clear point on the outside track is kept to a minimum. However, again the first-divide switch should not be so close as to constrain the humping rate (see earlier discussion and the footnote). SP claims that a 24-track classification yard could be designed as long as the maximum distance from crest to clear can be kept at less than 550 ft. The hump for this design is approximately 6 ft high for a 12-track classification yard; the actual height varies depending on the hardest rolling resistance assumed for the design and the number of classification tracks. Because the tangent point retarders have a simple preset release philosophy, no sophisticated sensors or computers are needed to calculate rolling resistance, track fullness, or variable retarder release speeds to maintain high performance. Thus, even though there are more "feet" of retarders involved in this design as compared to the master-retarder-only or group-retarder-only designs. the costs of this design may not be substantially greater, especially if coupling performance is considered.

The assumptions of rolling resistance and the local operational environment will determine which of the above mini-hump designs is best for a given mini-hump performance specification. In any event, the detailed hump grade and retarder placement design is needed for the various design alternatives.

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*Mr. Barney Gallacher of the SP is designer of this type of yard.

Appendix C

AN ADVANCED RETARDER CONTROL SYSTEM* WITH LOOK-AHEAD CAPABILITY

BACKGROUND AND PHILOSOPHY

Current retarder control algorithms consider only the "characteristics" of the car to be controlled in determining how to control the car. This type of control policy is simple to implement, however, its performance is conservative since it is based on either nominal or worst-case assumptions about what the car ahead is doing.

Here, an attempt is made to conceptualize a retarder algorithm which has the following attributes:

1. Considers the rolling resistance of the car ahead, as well as the car to be controlled--We can release the second car from the retarder at high exit velocities if the car ahead is a fast rolling car; alternatively, we must release the second car at lower exit velocities if the car ahead is a slow rolling car.
2. Considers how far ahead the first car has traveled, when the second car enters the retarder--We can release the second car from the retarder at high exit velocities if the first car is far ahead; alternatively, we must release the second car at lower exit velocities if the first car is not far ahead.
3. Considers the joint distance that the first and second car travels over the same route, before one car is switched to another route--We can release the second car from the retarder at higher exit velocities if the distance of the common route traveled is short due to either car being switched early to another route; alternatively, the second car must be released at lower velocities if the two cars must travel together over a long common route.

The algorithm conceptualized here will not put any extra demands on measurement information; we will use the sensors which are already in place for a conventional retarder system. However, the algorithm will require more sophisticated data-processing of sensor input to achieve improvements of importance. Since process control computers have a great deal of capability, this should offer no problems.

A HEADWAY CONTROL PHILOSOPHY

If we had perfect state information (i.e., continuous position and velocity measurements) as well as complete control (i.e., continuous ability to extract or impart energy), then the problem can be treated as a problem of controlling the headway of a string of cars (with speed constraints) using modern control theory procedures (see reference 38). However, even though we do not have perfect state information and complete control, it is appropriate to examine the problem as primarily a headway control problem with "auxiliary" constraints. In particular, we want to choose the retarder exit velocity of the second car so that the headway at distance X (i.e., where switching occurs) is greater than a specified value.

INFORMATION PERTINENT TO CONTROL OF MASTER RETARDER

Figure C-1 shows the measurement information which is available and pertinent to the control of the master retarder. (The control of the group retarder is similar and is discussed later.) In particular:

- R_i -- Rollability of car i
- L -- Length of master retarder
- V_{i1} -- Retarder entrance velocity of car i
- T_{i1} -- Time car i enters retarder
- V_{i2} -- Retarder exit velocity of car i
- T_{i2} -- Time car i exits retarder
- X -- Joint distance of travel of cars 1 and 2 before either car is switched off common route.
- T_{i3} -- Time car i reaches distance X.

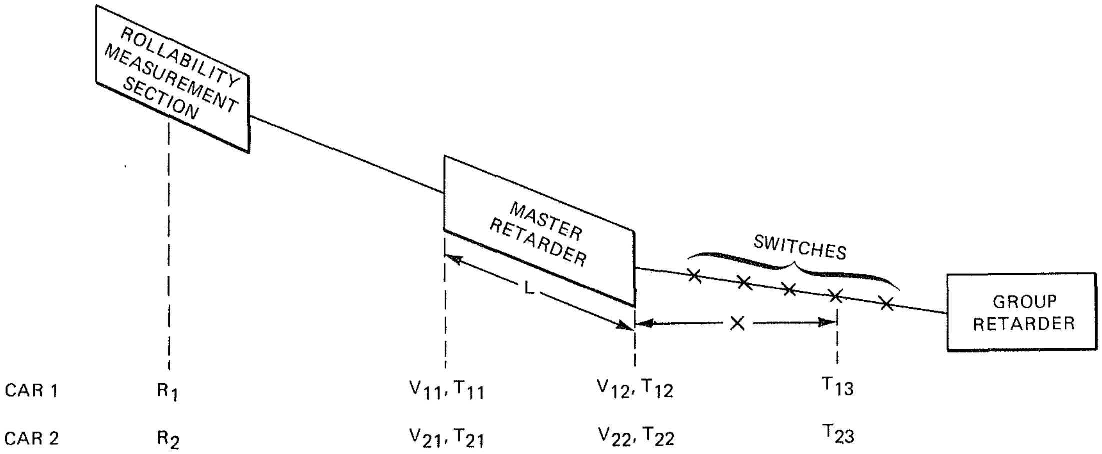

Figure C-1. Information Pertinent To Control of Master Retarder

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*These concepts were developed by Dr. Peter J. Wong; a patent is pending.

The availability of most of the above information is reasonably obvious. The parameter X is obtained by knowing the assigned class track for each car* and a "precalculated table" giving the joint distance of travel for two cars going to two specified class tracks. If the joint distance of travel is beyond the group retarder, then X is set equal to the distance to the group retarder.

The value of T_{13} is a calculated value.

BASIC EQUATIONS

There are two basic types of equations used in the algorithm to be presented. The first basic equation is derived from conservation of energy considerations, the second is based on a discrete velocity approximation.

Conservation of Energy

Referring to Figure C-1, the distance where either car 1 or car 2 is switched is designated X; the vertical drop in elevation from the end of the retarder to switch location X is called h. If car 1 is released from the retarder at exit velocity V_{12}, then the velocity over the switch, V_{13}, can be calculated using conservation of energy:

$$\frac{V_{13}^2}{2g} = \frac{V_{12}^2}{2g} + (h - R_1 \cdot X) \tag{1}$$

where g is the acceleration of gravity and R_1 is the rolling resistance of car 1 in units of percent grade. Equation (1) relates a car's velocity at two different points to the equivalent potential energy drop between those two points. Similar equations are used in the algorithm to be presented.

Discrete Velocity Approximation

Referring to Figure C-1, assume car 2 enters the retarder at velocity V_{21} at time T_{21} and exits the retarder at velocity V_{22}, then the time car 2 exits the retarder, T_{22}, is calculated using a discrete approximation to the average car velocity while in the retarder:

$$T_{22} \approx T_{21} + \frac{2L}{V_{21} + V_{22}} \tag{2}$$

where L is the length of the retarder. Equation (2) relates a car's passage time at two points to the velocity at these two points and the distance between these points. Similar equations are used in the algorithm to be presented.

ALGORITHM SPECIFICATION

The algorithm is an interactive search procedure in which the highest retarder exit velocity for the second car, V_{22}, is calculated subject to the constraint that sufficient headway exists at the point of switching. The highest release velocity is desired since this maximizes hump throughput. The algorithm is described with the following steps.

Step 1: Calculate V_{13} and T_{13}

The two cars will be switched to two different routes at a distance X from the end of the retarder. The drop in elevation at X from the end of the retarder is h; the value of h is stored in a table for each switch. The retarder exit velocity of the first car (V_{12}) and its exit time (T_{12}) are measured. The values of V_{13} and T_{13} are calculated from the following equations:

$$\frac{V_{13}^2}{2g} = \frac{V_{12}^2}{2g} + (h - R_1 \cdot X) \tag{3}$$

and

$$T_{13} = T_{12} + \frac{2X}{V_{12} + V_{13}} \tag{4}$$

where R_1 is the rolling resistance of the first car, and V_{13} in equation (4) is calculated in equation (3).

Step 2: Assume a Large Initial V_{22} and Calculate T_{22}, V_{23}, and T_{23}

The retarder entrance velocity of the second car (V_{21}) and its entrance time (T_{21}) are measured. The values of T_{22}, V_{23}, and T_{23} are calculated for an assumed large initial value of V_{22} using the following equations:

$$T_{22} = T_{21} + \frac{2L}{V_{21} + V_{22}} \tag{5}$$

where L is the length of the retarder,

$$\frac{V_{23}^2}{2g} = \frac{V_{22}^2}{2g} + (h - R_2 \cdot X) \tag{6}$$

and where R_2 is the rolling resistance of the second car.

$$T_{23} = T_{22} + \frac{2X}{V_{22} + V_{23}} \tag{7}$$

where T_{22} in equation (7) is calculated in equation (5) and V_{23} in equation (7) is calculated in equation (6).

Step 3: Calculate Headway at Point of Switching

The headway at point of switching is given by:

$$\text{Headway} = (T_{13} - T_{23}) \cdot \left[\frac{V_{13} + V_{23}}{2}\right] - (\text{length of first car}^{\dagger}). \tag{8}$$

Step 4: Try Lower Value of V_{22} if Headway Too Small

If headway given in equation (8) is too small, then Steps 2 and 3 are repeated with the assumed value for V_{22} decreased by a constant small amount Δ. We keep decrementing V_{22} by an amount Δ until the headway constraint in equation (8) is satisfied.

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[*] The assigned class track of each car is known to the process control computer, since the information is needed to throw the switches.

[†] The length of the first car can be a measured value, or taken from waybill data, or an assumed average car length.

APPLICATION TO GROUP RETARDER

Although the above discussion has focused on the application of the algorithm to the control of the master retarder, it can also be applied to the group retarder in a straightforward manner. Two cases are examined.

Case 1: In a retarder system containing master, group, and tangent-point retarders, the group retarders have the same function as the master retarder, that is to control headways between cars for switching. The role of the tangent-point retarders is to control coupling velocities on the classification track based on a distance-to-couple calculation. In this situation, because the group retarder has the same function as the master retarder, the retarder exit velocity, V_{22}, calculated by the algorithm can be directly applied to the group retarder without modification.

Case 2: In a retarder system containing master and group retarders (i.e., no tangent-point retarders), the group retarders have a dual role. First, to control headways between cars for switching, and, second, to control coupling velocities on the classification track based on a distance-to-couple calculation. In this case the calculation of the retarder exit velocity is slightly more complex. Assume that V_{22} is the retarder exit velocity calculated by the algorithm based on headway control considerations. Also, assume V'_{22} is the calculated retarder exit velocity based on distance-to-couple on the classification track. Then the selected retarder exit velocity should be the minimum of V_{22} and V'_{22}.

CONCLUDING REMARKS

In equations (4) and (7), the time a car takes to reach the switching point X is calculated as the distance X divided by the average velocity over the car's run. The average velocity over the car's run is approximated by averaging the two velocities at the beginning and end of the run for car i:

$$\text{Average Velocity} = \frac{V_{i2} + V_{i3}}{2} \qquad (9)$$

If there is a constant grade over the distance X, then equation (9) is accurate. However, if the grade changes then equation (9) is only approximate. The approximation in equation (9) can be improved by defining an experimentally determined fudge-factor K, so that:

$$\text{Average velocity} = K \cdot \frac{V_{i2} + V_{i3}}{2} \qquad (10)$$

The factor K can be a function of X (i.e., K can change with each track section that X occupies) and is determined by minimizing the least-square error in the approximation given by equation (10). This can be done by using an off-line hump grade simulation such as SRI's PROFILE model to calculate a car's speed profile over the distance X for various values of rolling resistance, and then determining exactly the average speed over the car's run.

Appendix D

DESCRIPTION, DOCUMENTATION AND APPLICATION OF SPEEDCON--A STOCHASTIC COMPUTER MODEL OF YARD SPEED CONTROL PERFORMANCE

D.1 INTRODUCTION

In rail hump yards, classification is performed by rolling a cut of cars down a grade and switching the cars on to 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 the headway maintained in the switching area (e.g., 50 ft) is sufficient to throw switches and prevent catch-up in retarders, that speed restrictions (e.g., 15 mph) at switches and curves are observed, and that proper coupling occurs on the class tracks within specified speed limits (e.g., 2-6 mph). Controlling headway and speeds would not be difficult if all cars had identical characteristics and rolling resistances (i.e., 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, type of car, and changes during the rolling of a car. Nonetheless, the profile designer must ensure that a large percentage (>95%) of the cars are delivered to the bowl tracks in a manner that satisfies the above design constraints. Moreover, because car speed directly translates into hump throughput, it is desirable that the fastest car speeds meeting these constraints are used.

In gradient design, achievement of these aims has usually been approached by considering design hardest (slowest) and easiest (fastest) rolling cars. It was implicitly assumed that it was only necessary to consider a hard rolling car followed by an easy rolling car followed by another hard rolling car traveling together from the crest to the last switch. The sizing and placement of retarder sections was determined from an analysis of this hard-easy-hard triplet of cars. However, implicit in this approach was the assumption that the retarder system could respond in a real-life situation to such a triplet of cars exactly as in the analysis on paper. This is not necessarily the case--most retarder control systems do not directly incorporate parameters which would allow the on-line logic to take account of the behavior of the design hard rolling and easy rolling cars in determining how to retard a real-life car. Additionally, even if the logic were to take account of the parameters of these design cars, errors in rollability measurement, plus changes in an individual car's rollability would tend to degrade the control system's capability to respond appropriately to control the cars. Finally, how the retarder control system should or will respond to cars with rolling resistances between the design values, or outside of the design limits is not considered in the profile design process at all. It has simply been assumed that if the design can be made to perform satisfactorily on paper for the design cars, at least those cars with rollability between the limits of rollability defined by the parameters of the design cars will perform satisfactorily. Such is not necessarily the case. In a series of simulation studies performed by CONRAIL using the PROFILE model (reference 2)* assuming a simple retarder logic, it was shown that a local minimum in headway occurs at an intermediate rolling resistance of 11 lb/ton for a situation where different rolling resistances were applied to the car following an easy rolling car of 4 lb/ton (see Figure D-1). This result shows that the response of the control system as car rollability changes may induce behavior which is not even monotonic, implying that system performance can be worse at an intermediate rolling resistance of 11 lb/ton (compared to typical design hard rolling resistances ranging from 12 to 18 lb/ton). Thus, ideally the hump profile design process should include the retarder logic as an inseparable part of the overall system.

Despite the weakness of the above design approach, the complexity of manually calculating cars' performance precluded any other design approach. Following this approach has led to usable, if not optimal, designs. Recently, the PROFILE model (reference 2) alluded to above has eased the labors of manual calculation involved in the traditional design process; however, the model's intended and actual use has generally been in the direction of permitting the designer to study more design alternatives, rather than in the direction of improving designs by addressing the above weaknesses. The SPEEDCON model has been developed, in part, as an extension of PROFILE model to address these weaknesses.

A related problem in yard design is the hump speed control system itself. Often, a significant improvement in hump profile performance can be achieved without modifying the geometric design at all, but simply by installing an improved retarder control logic. Thus, the designer could benefit considerably by being able to test different control logics, even if the geometry is not varied. In a more comprehensive design process, the designer might also wish to execute an interative design approach in which either the geometric design, the logic design, or both are varied. Finally, the designer/analyst might wish to attempt a design incorporating a quasi-continuous control retardation system, as offered by Dowty (England) and ASEA (Sweden). These systems can be used without any conventional retarders at all, or can be combined in a hybrid system in conjunction with conventional retarders. The SPEEDCON model is intended to be applicable to all of the above situations.

The SPEEDCON model was developed at SRI as a part of the Classification Yard Speed Control Project. In the context of this project, SPEEDCON is intended to serve the analyst as a tool in comparing the relative effectiveness of various speed control systems. It is capable of comparing different logic systems for conventional retarders, as well as analyzing distributed systems such as the Dowty and ASEA (either as standalone systems or combined in hybrid systems with conventional retarders.)

Table D-1 compares and contrasts the three methods of hump profile evaluation--manual, the PROFILE model, and the SPEEDCON model.

D.2 OVERVIEW OF THE MODEL

SPEEDCON is intended to estimate the overall expected performance of a rail hump yard gradient design. This performance is calculated in terms of the probabilities of occurrence of certain primarily undesirable events. These events fall into two categories:

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*References are listed at the end of this report.

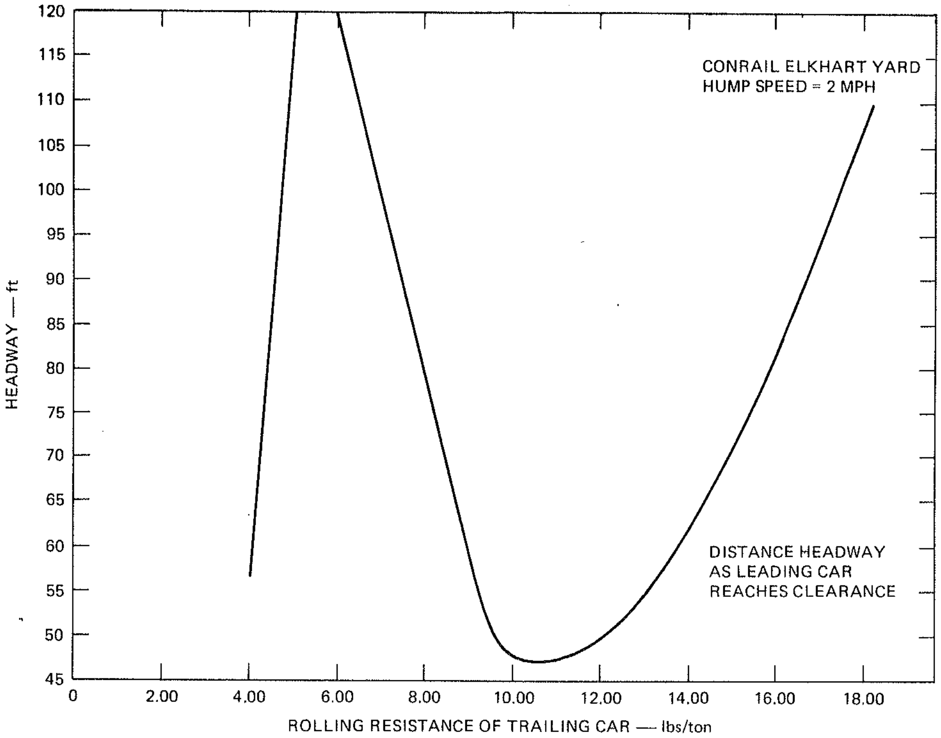

Figure D-1. Easy Rolling Car (4 lb/ton) Followed by Cars of Varying Resistance.

TABLE D-1.-COMPARISON OF THREE METHODS FOR HUMP PROFILE EVALUATION

	Method		
	Manual	PROFILE model	SPEEDCON model
Car rolling resistance levels	Easy and hard only	Easy and hard only	All
Conventional retarder policy	Fixed amount	Fixed amount	Various policies
Quasi-continuous retarder systems	Possible, with much effort	Not possible	Possible
Analysts' time required	Long	Medium--must make several runs	Short to medium
Computer time required	None	Small	Medium to high
Output produced	Medium to detailed--for 2 or 3 cars	Detailed--for 2 or 3 cars	In summary form for many cars--detailed optional

1. Events pertaining to a single moving car:
   a. Stalled cars prior to the tangent point.
   b. Stalled cars after the tangent point that fail to reach the target coupling point.
   c. Cars coupling at insufficient speed to couple properly.
   d. Cars coupling at excess speed.
2. Events pertaining to a consecutive pair of moving cars:
   a. Car pairs coupling prior to the tangent point.
   b. Car pairs with headways so small that they are in the same retarder section at the same time (catch-up in retarder).
   c. Car pairs with headways so small that they cannot be switched apart at a switch (misswitch).
   d. Car pairs colliding after being switched apart (catch-up prior to a switch's clearance point causing a cornering collision).

The single car events enumerated above are evaluated by comparing the motion of single cars to predefined numerical standards; the car pair events are calculated by comparing the positions of two consecutive cars over the hump (designated herein as a "car pair"; the related comparison is referred to as a "pairwise comparison"). No other car-by-car comparisons are performed; for example, catch-ups between the first and third cars over the hump, after the second car is switched out, are not checked.

The discussion of the structure of the SPEEDCON model can naturally be separated into two parts: Deterministic and Stochastic. The deterministic discussion deals with such items as the representation of the track geometry, the physics of car behavior, and the retarder logic. The stochastic discussion deals with the probabilistic model which is used to assess and accumulate the probabilities of the occurrence of events. These are addressed respectively in sections D.2.1 and D.2.2 below.

D.2.1 Deterministic Modeling in SPEEDCON

D.2.1.1 Portions of SPEEDCON Based on Existing PROFILE Model. The motion of each individual car is simulated by using the PROFILE model as a subroutine. Since SPEEDCON uses PROFILE as one of its basic building blocks, the structure of the physical representation of the system and car behavior largely follows on PROFILE. PROFILE is described in more detail elsewhere (references 2, 3, and 4); a brief description related to SPEEDCON will be given here.

PROFILE and therefore SPEEDCON are one-track simulations; 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 as a point mass for the purpose of its dynamics, the motion of which is assumed to be governed by the following differential equation:

$$\frac{d^2X}{dt^2} = \frac{dV}{dt} = \alpha \qquad (1)$$

$$\alpha = g_e(\tan\theta - R - C - W - \frac{S}{L} - \frac{E}{L} - \frac{U}{L}) \qquad (2)$$

$$g_e = \left[\frac{T}{T + I}\right]g \qquad (3)$$

where

X = distance from an arbitrary origin, ft

V = velocity of the car, ft/s

t = time, s

α = sum of all terms contributing to the car's acceleration, ft/s^2

g_e = effective acceleration of gravity used to account for energy stored in the rotating wheels of the car, ft/s^2

g = acceleration of gravity, ft/s^2

θ = angle of the grade below horizontal

$\tan\theta$ = grade (downgrades taken positive), ft/ft

R = static rolling resistance, lb/lb

C = curve resistance (if the track section is on a curve), lb/lb

W = wind resistance, lb/lb

S = velocity head lost in switch (if the track section is a switch), ft

E = velocity head extracted by retarder (if the track section is a retarder), ft

U = velocity head extracted by an individual unit of a continuous control system, ft

L = length of track section, ft

T = weight of the car, lb

I = additional weight of the car to account for the rotation of the wheels, lb.

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, when 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. As is obvious from the form of equation (2), cars within a retarder are assumed to be subjected to a uniform deceleration (i.e., energy is extracted uniformly within the retarder).

The solutions of the differential equation taking $V = V_o$ and $X = X_o$ at $t = 0$ yield the well known equations for a body subjected to a uniform acceleration:

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

and

$$X = X_o + V_o t + \tfrac{1}{2}\alpha t^2 \qquad (5)$$

Four major changes were made in PROFILE in incorporating it into SPEEDCON:

1. Most of the output was eliminated.
2. The option of specifying a velocity-dependent rolling resistance as an additional term in the differential equation (1) was eliminated.
3. Whenever a simulated car enters a conventional retarder, PROFILE calls a special subroutine which calculates a target exit velocity for the retarder, thus simulating the retarder control logic within the model.
4. The capability of optionally simulating a continuous control system was added.

Change 1 above is largely self-explanatory. The consequences of change 2 are twofold: first, it greatly simplified developing the stochastic part of the model (as will be obvious from subsequent discussions) and, second, the change conforms to the way most rail designers work (specifying only static rolling resistances, and ignoring any velocity dependence). The other changes will be discussed in subsequent sections.

D.2.1.2 Conventional Retarder Logic. Since SPEEDCON is intended to study yard speed control systems, incorporation of a retarder control logic is mandatory. Thus, whereas the PROFILE model previously required that the user input the required amount of retardation (in feet of velocity head), SPEEDCON's PROFILE subroutine dynamically requests a retarder target exit velocity (which is directly translatable to an amount of retardation) from a logic subroutine. However, retarder logics are fairly complex--sufficiently so that it is not possible to write a single subroutine capable of simulating all possible logics. Instead, it is necessary that a specialized subroutine be written for each separate logic to be studied. Two logics have currently been written for SPEEDCON; others can be written by users as the need arises. Each of the two available logics are described below. Both logics share a common "target shooting" distance to couple logic, which is therefore discussed separately in a third section below.

D.2.1.2.1 WABCO Target Travel Time Algorithm (reference 5). This algorithm is applied only in the switching area of the yard. Basically, the algorithm attempts to make the car being controlled arrive at a predetermined point following each retarder (excepting the tangent point retarder) according to a predetermined time schedule, normally the travel time of a hard-rolling reference car. The equation used to calculate the target let out speed for each car being controlled is based upon the assumption of uniformly accelerated motion (as was also assumed previously in equation (1)). As implemented in SPEEDCON and explained here, the logic has been simplified slightly (for clarity and to conform to SPEEDCON's treatment of the car as a point mass). The simplifications are (1) the cars are treated as points of zero length, (2) the control to be applied to a car is calculated instantaneously as the (point) car enters the retarder, and (3) the car is decelerated uniformly within the retarder. In this simplified form, the travel time of a car (see Figure D-2) from the crest to the reference point X downstream of the retarder is the sum of the travel times before the retarder (T_B), within the retarder (T_R), and after the retarder (T_A). The travel time for the reference car (T_{ref}) is a known predetermined parameter. Since it is desired that the controlled car travel from the crest to point X on the same schedule as the reference car, we have

$$T_B + T_R + T_A = T_{ref} \tag{6}$$

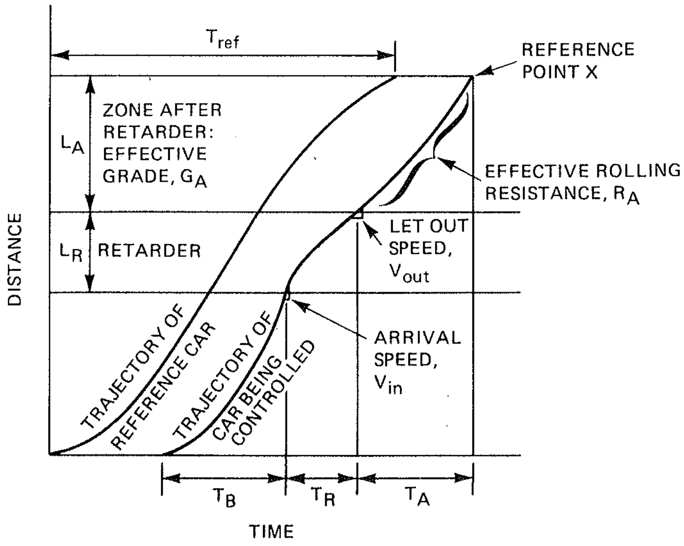

Figure D-2. Sketch of WABCO Target Travel Time Algorithm Definition

The control calculation should be conceptualized as being made at the instant the car enters the retarder. Therefore, T_B is no longer subject to control and also becomes a constant of the calculation. Since the control variable is the let out speed from the retarder (V_{out}), it is only necessary to express T_R and T_A as functions of V_{out}. For uniformly accelerated motion, and approximating a varying grade by the average grade, it can be shown that T_R and T_A are expressed in terms of V_{out} as:

$$T_R = \frac{2L_R}{V_{in} + V_{out}} \tag{7}$$

and

$$T_A = \frac{2L_A}{V_{out} + \sqrt{V_{out}^2 + 2g_e(G_A - R_A)L_A}} \tag{8}$$

where

L_R = length of retarder, ft

V_{in} = speed of the car at the entry of the retarder, ft/s

L_A = length of the control section downstream of the retarder

g_e = effective value of g as discussed previously

G_A = effective average grade in the control section downstream of the retarder (average grade compensated for known losses such as switches and curves)

R_A = rolling resistance after the retarder, lb/lb.

Putting equation (7) and (8) into equation (6) yields a relationship theoretically solvable for V_{out}. However, in practice the equation cannot be solved in closed form for V_{out}, and so it is solved using an iterative technique, both in the real-life implementation of the algorithm, as well as in its implementation for use in SPEEDCON.

In real life, the rolling resistance after the retarder, R_A, must be estimated from rollability measurements. This is called the expected rolling resistance and is used by the logic for its calculations. This resistance is not necessarily the same as the actual rolling resistance R'_A controling the car after the retarder; it is a prediction. As implemented for SPEEDCON, the expected resistance R_A is computed from rollability "measured" in test sections immediately preceding each retarder as:

$$R_A = a + bR_B \tag{9}$$

where

R_A = the predicted rolling resistance assumed by the retarder logic to govern the car's motion after it leaves the retarder.

R_B = rolling resistance "measured" immediately prior to the retarder (the actual rolling resistance governing the simulated car in the track section immediately preceding the retarder)

a,b = user-supplied adjustment factors relating R_A to R_B.

Thus, the resistance used by the simulated control system in calculating the schedule for a simulated car is entirely under user control. The parameters a and b can be set so that the retarder logic uses an expected rolling resistance R_A that conforms identically to the actual rolling resistance R'_A. This means that the retarder can control any simulated car within design bounds to conform perfectly to the desired schedule of the algorithm. On the other hand, the user can test the sensitivity of the yard performance against discrepancies between expected and actual rollability by setting parameters a and b so as to cause a divergence between expected and actual rollability.[*]

This algorithm is used to control the master and group retarders while a "target shooting" logic to achieve a desired coupling speed is used to control the tangent point retarders as discussed later. In yards without a tangent point retarder, the group retarder must also be used for target shooting. In SPEEDCON in such cases, whichever logic gives the more restrictive control (i.e., lower let out speed) is assumed to govern the tangent point retarder.[†]

D.2.1.2.2 <u>WABCO "Magic X" Retarder Control Algorithm.</u> The "Magic X" algorithm is based on an algorithm of the same name described in WABCO's promotional literature (reference 5). While simpler than WABCO's target travel time algorithm, it does not perform as well. As with the previous algorithm, "Magic X" is used in the switching area while a coupling speed target shooting algorithm is used for the classification track.

In using this algorithm it is 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 rolling car and a design hard rolling car.[§] From manual calculations or PROFILE simulation results, 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 relations shown in Figure D-3. 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_{in} of a car of arbitrary rolling resistance, the exit speed is uniquely determined from the "Magic X" by drawing the straight line shown dashed in Figure D-3 which goes from V_{in} through the crossing point of the "Magic X."[††] Mathematically, the exit speed can be computed from

$$V_{out} = V_{e,\,out} + (V_{h,out} - V_{e,out})\frac{V_{e,in} - V_{in}}{V_{e,in} - V_{h,in}} \qquad (10)$$

where

V_{out} = let out speed rom 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_{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.

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 consider both speed and headway

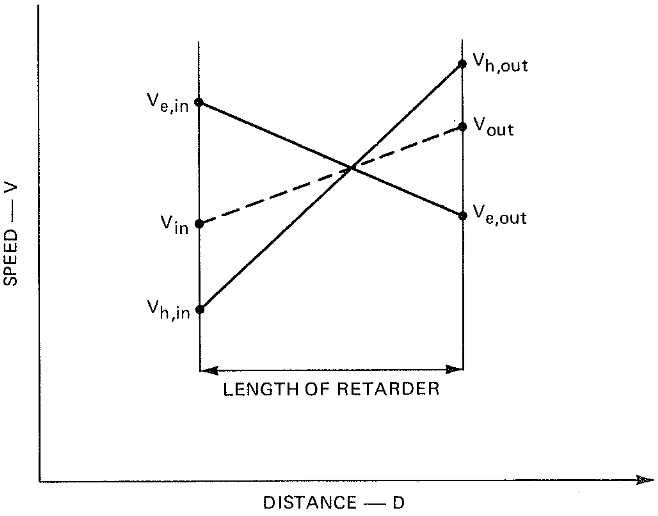

Figure D-3. Sketch of "Magic X" Algorithm Definition

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[*] As will be seen later, SPEEDCON can automatically make a series of runs which could include situations where the expected rollability is (1) overestimated, (2) correct, or (3) underestimated relative to the actual rollability.

[†] This generally yields a degraded performance relative to a master/group/tangent point retarder design.

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

[§] Methodologies to do this using PROFILE are given in references 2, 3, and 4.

[**] The speeds of the cars within the retarder are actually linear in the V^2 (speed squared) distance plane (as modeled in SPEEDCON).

[††] 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 is included in SPEEDCON to handle these limiting situations.

constraints to the extent that the control is derived from these parameters. However, as was seen in Figure D-1, the headway response of the system can indeed be highly nonlinear even though the control input is linear. On the other hand, this algorithm does not require on-line rollability measurement, and so is not sensitive to errors in measuring this parameter.

D.2.1.2.3 Target Shooting Coupling Speed Logic. In the previous sections algorithms for calculating a let-out speed from a retarder were described. However, in real world operations coupling speed is another constraint needing consideration. These previously described algorithms are used to control speeds in the switching area. However, in the tangent point retarder a different algorithm called "Target Shooting Coupling Speed" is used to control speeds on the class tracks. Basically, this algorithm takes into account how far the car must roll until it couples and tries to control the car to achieve a target coupling speed.

$V_{c,out}$ is designated as the let-out speed from the tangent point retarder which satisfies the coupling speed constraint. This let-out speed can be computed by applying equation (1) or by using energy considerations. Using such an approach, $V_{c,out}$ can be derived as:

$$V^2_{c,out} = V^2_{cd} - 2g_e L_c (G_c - R_A) \qquad (11)$$

where

$V_{c,out}$ = let-out speed from the retarder farthest downstream of the hump necessary to achieve a desired coupling speed

V_{cd} = desired coupling speed

L_c = distance to couple from the exit of the retarder

G_c = effective average grade from the retarder exit to the coupling point (average grade compensated for known losses such as switches and curves)

R_A = expected or estimated rolling resistance after the retarder (in lb/lb).

Note that this algorithm, like the Target Travel Time algorithm, requires an on-line estimate of rolling resistance, and so is also sensitive to discrepancies between a car's expected and actual rollability. Unfortunately, since the tangent point retarder is also the last point at which control can be exercised over the car, this does not provide an opportunity to correct for errors in the control caused by discrepancies in rolling resistance. Thus, the effects of discrepancies in rollability are especially important here; SPEEDCON allows the user to assess the effect of such discrepancies.

The above description assumes that tangent point retarders are used. However, when tangent point retarders are 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 switching area algorithm (Target Travel Time or "Magic X") and the class track algorithm (Target Shooting Coupling Speed) will generally be conflicting. To resolve this conflict, the let-out speed from the group retarder, in the absence of a tangent point retarder, is taken as

$$V_{g,out} = \min(V_{out}, V_{c,out}) \qquad (12)$$

where

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

V_{out} = let-out speed as computed by either the Target Travel Time or Magic X algorithm as applicable.

This equation simply specifies that whichever criterion yields the more restrictive let-out speed applies.

D.2.1.3 Continuous Control Retardation Systems. An important addition to SPEEDCON not available in PROFILE is the former model's capability to simulate quasi-continuous distributed control systems as offered by Dowty (England) and ASEA (Sweden). Each unit in these systems extracts a controlled amount of energy from the car using a purely mechanical analog logic self-contained within each unit. Thus, in a pure continuous control system, no centralized process control computer system is required to control the motion of cars. The key to controlling each car is the great number of such units encountered by a car in its roll from the hump to the bowl--in a typical Dowty system, 1000 units might be encountered by a car making such a roll.

Also common are hybrid designs combining a conventional electronically controlled clasp retarder system with a continuous control system. The typical design of this type uses the conventional system in the switching area with continuous control units on the bowl tracks. Such hybrid systems can be used in a "retrofit" attempt to improve the performance of an existing hump design. SPEEDCON is capable of analyzing both pure continuous control systems as well as hybrid systems.

Both the Dowty and ASEA systems use the same principal in retarding a car. Figure D-4 shows a sketch of the energy extracted from a car by a single quasi-continuous control unit when struck by the wheel of a car. The energy extracted is a function of car speed. Two energy extraction curves are associated with each unit. The upper curve in Figure D-4 (the Performance Curve) applies when the unit is extracting significant energy from the car. The lower curve (the Idling Curve) applies when only minimal energy is to be extracted

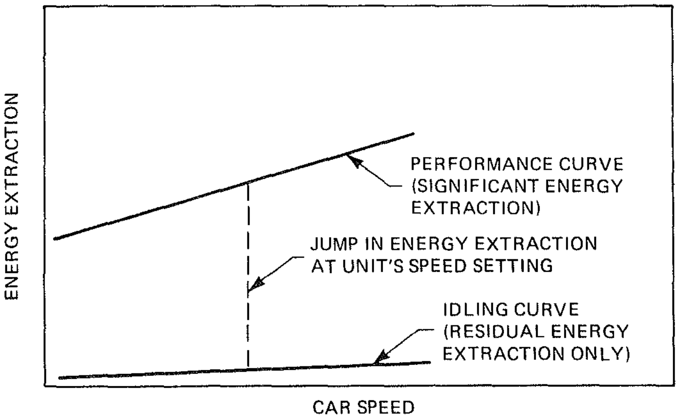

Figure D-4. Quasi-Continuous Control Retarder Energy Extraction Behavior

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*This discussion assumes a master/group retarder design. However, in the absence of tangent point retarders, to generalize one should consider what is referred to here as "group retarder" to mean the farthest retarder from the hump prior to the tangent point.

from the car.[*] For a single control unit, a jump between the lower and upper energy extraction curves occurs at a particular speed setting which is set during manufacture of the unit. The speed at which the jump occurs--herein called the critical speed of the unit--is specified as a part of the design process of a yard equipped with continuous control units. Generally, all the units within a given section of track will have a common critical speed setting. The typical performance behavior of a continuous control system yard is to control all cars within the bounds defined by the design hard- and easy-rolling cars to nearly the same speed--energy being extracted from easy rolling cars according to the Performance Curve by nearly every unit encountered; while only idling energy is extracted from the hard rolling cars by most of the units.

The user of SPEEDCON desiring to simulate the performance of a continuous control system must supply a small function subroutine that calculates the ft-tons of energy extracted when struck by one wheel of a car as a function of car speed and the critical speed setting of the unit (both in ft/sec). One such function subroutine has been written for SPEEDCON; it is calibrated for the relationships supplied by Dowty for the SRI hypothetical yard. As supplied, the relationships were in graphical form; the following computing formulas were fitted:

Performance or upper curve

$$E = .2775 + .0224\ V \qquad (13)$$

Idling or lower curve

$$E = .008595 + .00024366\ V + .00002772\ V^2 \qquad (14)$$

where

E = energy extracted, ft-tons

V = speed of car, ft/sec.

It should be noted that these formulas apply to a particular Dowty system, and may differ for other Dowty systems. They definitely will differ for ASEA systems, where the energy extraction on a per unit basis is approximately 7 times that for Dowty.

In SPEEDCON the critical speed settings at which the jump from the lower to the upper curve occur are handled as an input for the particular track section, and must be constant within that track section. The user must also specify the number of continuous control units within each track section.

The continuous control system in SPEEDCON is simulated axle strike by axle strike. SPEEDCON simulates these axle strikes as additional pseudotrack sections which are automatically created by the program. However, the track sections as seen by the user are not affected. The individual control units are arrayed uniformly by SPEEDCON within each track section.

D.2.2 Stochastic Modeling in SPEEDCON

SPEEDCON computes the probabilities of occurrence of certain, mostly undesirable events. The method of computing these probabilities is discussed in this section. Consideration was given to developing SPEEDCON as a Monte Carlo simulation model. However, except in cases of gross design error, the desired measures of effectiveness to be computed by SPEEDCON are all based on the occurrence of comparatively rare events. Under such circumstances, a prohibitively large number of car humpings would have to be simulated to obtain even a rough estimate of the probability of occurrence of these events--a million humpings could indeed be required to define these probabilities with even minimal confidence for a well-designed yard. Therefore, the use of a Monte Carlo approach was deemed impractical. Instead, SPEEDCON uses an approach based on probability theory.

Because the car motion itself must be simulated, a completely analytical (as opposed to simulation) approach is not possible. Instead, SPEEDCON deterministically simulates the motion of individual cars; when any of the previously enumerated events happen to a simulated car, or to a pair of cars in comparison, the probability of the occurrence of this event is incremented by an appropriate probability computed from the probability distributions of certain random variables.

D.2.2.1 Random Variables Used in SPEEDCON. There are four basic types of random variables considered in SPEEDCON. Three of these random variables are associated with the simulated cars while the fourth is associated with the track section where the event occurs. These random variables are shown in Table D-2.

The random variable R characterizes the rolling resistance (e.g., lb/ton) of a car picked at random from a large number of humped cars. While R in real life has a continuous distribution, in SPEEDCON the distribution of R is approximated by a discrete distribution. The probability $P(R^i)$ of each level of this approximating distribution (herein referred to as cell-probability) is input by the user directly in terms of probability, or if desired in terms of relative frequency.

Actually, R is interpreted as a "base" rolling resistance. Rolling resistance does not necessarily remain constant all along the course of a car's roll from crest to bowl; in design, therefore, it is usually customary to assume that rolling resistance decreases in some manner over this distance. Further, the rolling resistance will often change considerably in some, at least partially random manner, after it has been measured on-line for use in a retarder control algorithm.[†] This change can degrade performance considerably from that which would obtain if the retarder control algorithm had "perfect knowledge" of each car's rolling resistance. To address both of these problems, SPEEDCON uses the concept of a "rolling resistance transformation family." The transformation family of a random car is treated in SPEEDCON as a random variable, designated as T. The probabilities $P(T^i)$ of a random car belonging to a particular family are, like base rolling resistance, specified by the user. The actual value of T is arbitrary, since it serves only to denote a particular car's family of membership; therefore, the T^i (i.e., transformation families) are simply numbered 1, 2, ... N_T.[‡] Once a

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[*] Although the idling energy extraction is small, it must nonetheless be taken into account in designing a yard equipped with a continuous control system.

[†] The mean rolling resistance in subsequent track sections can often be estimated fairly accurately using techniques such as regression. However, individual cars can still differ significantly from this estimate.

[‡] i.e., $T^i = i$.

TABLE D-2.-RANDOM VARIABLES USED IN SPEEDCON

Random variable symbol	Description	Notation used to denote probability in ith cell of approximating discrete distribution	Notation used to denote probabilities for a pair of cars 1, 2
R	Car base rolling resistance	$P(R^i)$, $i = 1, N_R$	$P(R_1^i)$, $P(R_2^j)$
T	Rolling resistance transformation family number	$P(T^i)$, $i = 1, N_T$	$P(T_1^i)$, $P(T_2^j)$
F	Car's track fullness level	$P(F^i)$, $i = 1, N_F$	$P(F_1^i)$, $P(F_2^j)$
O_{cc}	Binomial variate associated with a specific car and track section: 1 if the car passes through the section, 0 if the car does not pass through the section	$P_{occ}(s)$, $i = 1, N_s$	Not applicable

Notes: N_R = number of cells used in approximating discrete rolling resistance distribution.

N_T = number of transformation families.

N_F = number of cells used in approximating discrete classification track fullness distribution.

N_s = number of sections of track entered in the track geometric data.

car's membership is specified, however, SPEEDCON will transform the car's base rolling resistance R using family-specific linear transformations of the form

$$R' = a + bR \qquad (15)$$

where

R' = transformed rolling resistance

a,b = user specified transformation parameters, specific to a particular family.

The parameters a and b are specific to a particular family and are assumed to apply only within a specific range of track sections.* These parameters are user-specified, and several transformations may be specified for an individual transformation family (for mutually exclusive sets of track sections). It should be noted that: (1) uniform scalings of rolling resistance are included in this concept, merely by specifying parameter "a" as zero; (2) that the transformation family can be employed to specify deterministic changes of rolling resistance without having any randomness merely by specifying only one transformation family, in which case $P(T^1) = 1$; and (3) that the transformation family concept, when employed in conjunction with the conventional retarder's rollability estimation (which is used in the retarder's control algorithm), can be useful in making SPEEDCON analyses that incorporate rollability measurement errors.

The third random variable employed in SPEEDCON is the track fullness level of a car picked at random from a large population of humped cars. This random variable is denoted by F. Like R, F is essentially a continuous random variable that is approximated discretely. Its cell probabilities $P(F^i)$ are also, like R, user inputs.

The last random variable employed in SPEEDCON is not used directly; however, its associated probabilities are quite important. These probabilities are associated with each track section s. The probability for a single track section, denoted by $P_{occ}(s)$, is the probability that a car, picked at random at the hump, will pass through track section s <u>on the simulated route</u>. At the hump crest $P_{occ}(s) \equiv P_{occ}(1)$ should be exactly 1 (i.e., all humped cars pass through the first track section or sections preceding the first switch). Immediately after the first switch, if half the cars take each track direction, $P_{occ}(s)$ will be 0.5. $P_{occ}(s)$ continues to drop at each switch until at the class track $P_{occ}(s) \equiv P_{occ}(N_s)$ is approximately equal to the reciprocal of the number of classification tracks. Indeed, in SPEEDCON, as will be discussed later, it is assumed that

$$P_{occ}(N_s) = \frac{1}{N_c} \qquad (16)$$

where

N_s = number of track sections on simulated route ≡ number of last track section (i.e., bowl track).

N_c = number of classification tracks.

Typical values of $P_{occ}(s)$ are shown in Figure D-5 for idealized and realistic 32-class track designs.

D.2.2.2 <u>Event Population Simulated in SPEEDCON</u>. At this point it will be convenient to discuss the interaction of the $P_{occ}(s)$ with the event population actually simulated in SPEEDCON. As mentioned previously, SPEEDCON only simulates the motion of cars on a single

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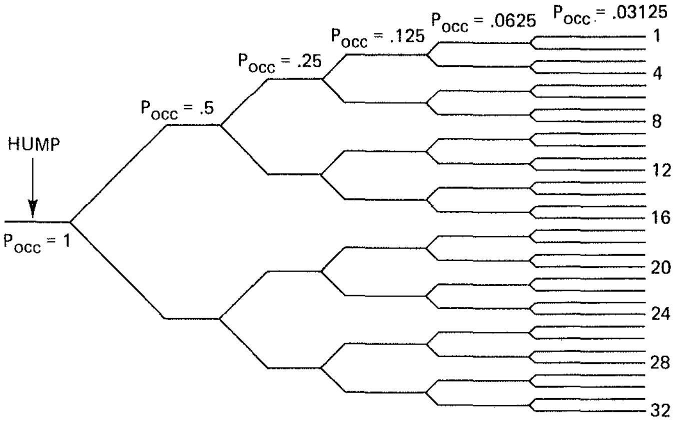
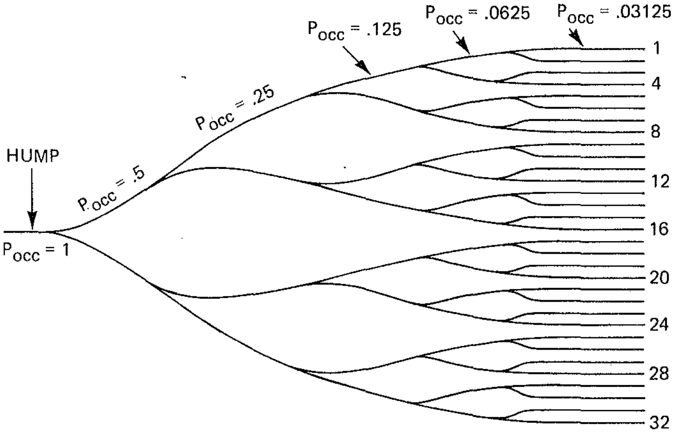
*Strictly speaking, a and b should be subscripted by transformation family number and by track section, although for simplicity this is not done here.



a. IDEALIZED, TOTALLY SYMMETRIC YARD



b. TYPICAL REAL-LIFE YARD

Figure D-5. Idealized and Typical 32-Class Track Yards

route into the bowl. A typical route which would be simulated would be the route leading to classification track 1 in Figure D-5 (a or b). This means that the actual population of events which can happen to the simulated cars faithfully reflect potential events happening to 100% of the cars as far as the first switch, then 50% of the cars as far as the second switch, and so on. Cars being shunted to the unsimulated routes are not, in actuality, simulated. However, if a yard were to be built in a perfectly symmetric manner as in Figure D-5(a), the simulation of a single route will suffice to portray all routes to the bowl.* In a totally symmetric yard, an event occurring on any one route would be mirrored (over an infinity of time) by identical events occurring on all other routes at the same distance from the hump crest.

Of course, totally symmetric yards as in Figure D-5(a) are never actually built. Figure D-5(b) shows a more realistic 32-classification track design. Although still fairly symmetric, Figure D-5(b) does show several deviations from perfect symmetry. For example, the locations and placements of curvature and distances from the crest to the tangent point may vary slightly from route to route (e.g., compare routes 1, 5, and 8). Other designs--particularly those which do not have a number of class tracks which is an integral power of 2--may deviate even more significantly from perfect symmetry. For these reasons, the probabilities associated with all events that happen to cars in SPEEDCON are output in two ways: (1) as probabilities of events occurring only on the true simulated route,† and (2) as probabilities "weighted" to reflect the overall yard,‡ assuming all events occur symmetrically. Since the latter probabilities are likely to be of the greatest interest to the analyst, emphasis here will be placed on these.

For the purposes of this discussion, it is important to distinguish between the incremental probability of the occurrence of an event, and the total probability of the occurrence of an event. The incremental probability of the occurrence of an event is designated here as $p_e(s)$ and the total probability as $P_e(s)$ (for the track section s) and as $\bar{P}_e$ for the entire yard. These are generic names that are used to refer to any of the event types considered in SPEEDCON. The incremental probability of the occurrence of an event is the contribution to the total probability for a specific simulated car (or car pair) at a specific track section s. When summed overall, cars (or car pairs) for which the event occurs within the specified track section s, one gets the total probability of the specified event within the track section, $P_e(s)$. Finally, the total probability of the event within the yard, $\bar{P}_e$, is the sum of the $P_e(s)$ across all track sections. The $P_e(s)$ and $\bar{P}_e$ are the output quantities reported by SPEEDCON. When the quantities $p_e(s)$, $P_e(s)$, and $\bar{P}_e$ are "primed" (i.e., $p'_e(s)$, $P'_e(s)$, and $\bar{P}'_e$), this designates that the probabilities have been weighted to reflect the overall yard, not just the simulated route. The "primed" quantities are summed in the same manner as their unprimed equivalents above.

The weighted probability reflecting the overall yard is computed on the incremental probability level by the relation

$$p'_e(s) = \frac{p_e(s)}{P_{occ}(s)} \quad . \qquad (17)$$

If the yard is reasonably symmetric, the $P'_e(s)$ and $\bar{P}'_e$ should be reasonably indicative of the overall yard performance; for asymmetric yards, at least a conservative evaluation of these probabilities can be made by selecting to simulate the worst behaving route to the bowl (usually one of the outside tracks).

D.2.2.3 Event Structure in SPEEDCON. The types of events simulated in SPEEDCON have already been enumerated previously (Section D.2). These events are again given in Table D-3 along with the related notation which is used to refer to them in this section, and the computing formulas used to compute and accumulate the incremental event probabilities.

As mentioned previously, SPEEDCON uses the PROFILE model to simulate the motion of cars. Each of these cars is simulated in total isolation from all other cars. At the completion of each single car simulation,

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*Assuming that the amount, but not direction, of curvature may play a role.

†Similar events which may happen on other routes not simulated in SPEEDCON are simply not "seen" by SPEEDCON in this case, and so are assigned a probability of zero (i.e., as if no events hsppen on other routes).

‡The probabilities in (2) can also be interpreted as the conditional probabilities of the events occurring, given that the car is on the simulated route.

TABLE D-3. EVENTS IN SPEEDCON AND COMPUTING FORMULAS

	Type of Event	Incremental Probability $[p_e(s)]$ Formula - Simulated Route Only	Incremental Probability $[p'_e(s)]$ Formula - Probability Reflecting Entire Yard	$\bar{P}_e, \bar{P}'_e$ Summed Over:	Comments
1. Events Involving a Single Car	1.a Car stalls prior to tangent point	$P(R^i) \cdot P(T^j) \cdot P(F^k) \cdot P_{occ}(s)$ s = track section of stall	$p_e(s)/P_{occ}(s)$	All cars for which event occurs and stall sections $i = 1,N_R$; $j = 1,N_T$; $k = 1,N_F$; $s = 1,N_S$	$\bar{P}'_e$(Event 1.a) + $\bar{P}'_e$(Event 1.b) + $\bar{P}'_e$(Event 1.c) + $\bar{P}'_e$(Event 1.d) + $\bar{P}'_e$(Event car couples in desired speed range) = 1 [Latter event not computed in SPEEDCON] (see Note 3)
	1.b Car stalls after tangent point	$P(R^i) \cdot P(T^j) \cdot P(F^k) \cdot P_{occ}(N_s)$ N_s = last track section number	$p_e(N_s)/P_{occ}(N_s)$ (see Note 1)	All cars for which event occurs $i = 1,N_R$; $j = 1,N_T$; $k = 1,N_F$ (see Note 1)	
	1.c Cars couple underspeed	As above	As above (see Note 1)	As above (see Note 1)	
	1.d Cars couple at excessive speed	As above	As above (see Note 1)	As above (see Note 1)	
	1.e Coupling speed distribution by 1 mile/hour increments	As above	As above (see Notes 1 and 2)	All cars for which event occurs by speed category v: $i = 1,N_R$; $j = 1,N_T$; $k = 1,N_F$ (see Notes 1 and 2)	$\bar{P}'_e$(Event 1.a) + $\bar{P}'_e$(Event 1.b) $+ \sum_{\text{all } v} \bar{P}_e^{v'}$ (Event 1.e) = 1 (see Note 4)
2. Events Involving Consecutive Pairs of Cars	2.a Car pairs coupling prior to tangent point	$P(R_1^i) \cdot P(R_2^j) \cdot P(T_1^k) \cdot P(T_2^\ell) \cdot P(F_1^m,F_2^n) \cdot [P_{occ}(s)]^2$ where $P(F_1^m,F_2^n)$ = joint distribution of track fullness level for a pair of cars (see Section C.2.2.4.2) $i,j = 1,2,\ldots N_R$ $k,\ell = 1,2,\ldots N_T$ $m,n = 1,2,\ldots N_F$	$p_e(s)/P_{occ}(s)$	All car pairs and sections for which event occurs $i,j = 1,N_R$; $k,l = 1,N_T$; $m,n = 1,N_F$; $s = 1,N_S$	Once a couple-up occurs for a car pair with specific characteristics, it cannot happen again later downstream for the car pair (i.e., the pair is considered coupled from that point on)
	2.b Car pairs with headways so small that they are in the same retarder section at the same time		As above	As above	Once a catch-up in retarder occurs for a car pair with specific characteristics, it cannot happen again later downstream for the car pair (because situation becomes indeterminate).
	2.c Car pairs with headways so small that they cannot be switched apart at a switch (misswitch)	$P(R_1^i) \cdot P(R_2^j) \cdot P(T_1^k) \cdot P(T_2^\ell) \cdot P(F_1^m) \cdot P(F_2^n) \cdot P_{sw}(s) \cdot [P_{occ}(s-1)]^2$ where $P_{sw}(s) \equiv$ Probability cars are switched apart at switch in section s (see Section D.2.2.4.3) $i,j = 1,2,\ldots N_R$ $k,\ell = 1,2,\ldots N_T$ $m,n = 1,2,\ldots N_F$	As above	As above	Automatically occurs for the car pair if the car pair coupled prior to the switch in section s
	2.d Car pairs colliding after being switched apart (catch-up prior to a switch's clearance point causing a cornering collision)		As above	As above	Cannot occur for the car pair if there was a misswitch at the switch in section s

Notes

1. Since these events only occur after the last switch, the section subscript may be dropped from $P_e \equiv \bar{P}_e$ and $P'_e \equiv \bar{P}'_e$.

2. Event further differentiated into separate speed categories (1 mile/hour increments) designated as v. Notation used is p_e^v and $P_e^v \equiv \bar{P}_e^v$, $p_e^{v'}$ and $P_e^{v'} \equiv \bar{P}_e^{v'}$.

3. Probability of event of coupling within desired speed range not computed in SPEEDCON, but can be computed by user by subtracting total event probabilities for events 1.a, 1.b, 1.c, and 1.d from 1 (also by summing $\bar{P}_e^{v'}$ values for appropriate v's).

4. Since the sum over v of the $P_e^{v'}$ is not generally 1 (because of stalls), an additional output is given with all the $P_e^{v'}$ normalized to sum to 1 (i.e., coupling speed distribution conditioned that the car couples).

SPEEDCON assesses and accumulates the incremental probability of occurrence of events 1a through 1e (i.e., the single car events) using the formulas given in Table D-3. In addition, a table of the car's motion over time is stored for later use. This table, referred to herein as the "trajectory table," consists of points generally at a uniform time spacing[*] containing

- The time in seconds since the car crested the hump
- The car's distance from the hump
- The car's speed
- The car's track section number.

These points are all referenced to the car's center of gravity.

The simulation is performed for all possible combinations of the set (R^i, T^j, F^k), a total of $N_R \cdot N_T \cdot N_F$ simulations. The computer time cost of performing even a fairly large number of simulations for a conventional yard is negligible; the cost for a continuous control system yard is somewhat more substantial.[†]

After the computations associated with single cars have been completed, SPEEDCON enters a second phase concerning events happening to pairs of cars. In this phase, called the "pairwise comparison phase," the trajectories of all possible pairs of cars are compared to seek out the occurrences of events 2a through 2d as indicated in Table D-3. These comparisons extend only as far as the tangent point. The comparisons are performed by retrieving car trajectories from the trajectory table a pair at a time. When the times in the trajectory table of the following car are offset by the hump time interval, the result is the same as if an individual simulation were done for the car pair. It is to be emphasized that the comparison of a trajectory pair with the specific characteristics as defined by the sextuplet $(R_1^i, R_2^j, T_1^k, T_2^\ell, F_1^m, F_2^n)$ represents the behavior of all such humped car pairs having this set of characteristics. Thus, it is quite reasonable to log a misswitch event for the pair of trajectories being compared at, say, switch 3 and another misswitch event at switch 4. In actuality, this represents two car pairs of <u>identical</u> characteristics, one pair scheduled to be switched apart at switch 3, and the other at switch 4.[‡] The probability formulas used in SPEEDCON have been constructed based on this concept.

The number of pairwise comparisons performed by SPEEDCON is thus $(N_R \cdot N_T \cdot N_F)^2$. This number could obviously grow quite large and consume much computer time.[§] However, these costs are entirely under user control; by judicious choice of the number of cells used to resolve R, T, and F, the user can exercise his specific trade-off between computer costs and accuracy. In the production SPEEDCON runs reported later, N_R was 19, and N_T and N_F both 3.

D.2.2.4 <u>Supporting Information Regarding Probability Formulas Used In SPEEDCON</u>. This section provides derivations of the probability formulas given in Table D-3 in the last section. It may be omitted by disinterested readers, and by readers unfamiliar with probability theory.

D.2.2.4.1 <u>Independence of Random Variables</u>. Each of the random variables associated with a single car is assumed to be mutually independent; therefore, the probability of a car being humped having the random variable triplet (R^i, T^j, F^k) is[**]

$$P(R^i, T^j, F^k) = P(F^i) \cdot P(T^j) \cdot P(F^k) \tag{18}$$

This assumption is the source of terms in the single car event formulas having these triple products.

For car pairs, the random variables R_1^i, R_2^j, T_1^k, T_2^ℓ are also assumed to be mutually independent, so that their joint probability is expressed by the similar product

$$P(R_1^i, R_2^j, T_1^k, T_2^\ell) = P(R_1^i) \cdot P(R_2^j) \cdot P(T_1^k) \cdot P(T_2^\ell) \tag{19}$$

However, the random variables F_1 and F_2 are correlated if the car pair may be destined to the same class track, and their joint distribution is intimately related to the track section occupancy, $P_{occ}(s)$. This is discussed in the next section.

D.2.2.4.2 <u>Joint Distribution for Fullness Levels of a Car Pair</u>. The joint distribution for the track fullness levels of the car pair, $P(F_1^m, F_2^n)$, cannot be considered to be the product of the marginal distributions when the car pair may be destined to the same class track, as is the case for events 2a and 2b, i.e.,

$$P(F_1^m, F_2^n) \neq P(F_1^m) \cdot P(F_2^n) \tag{20}$$

A little reflection reveals why. In the track section after the last switch on a route, only one fullness level can exist on that section during the time that two consecutuive cars roll through, since both cars are destined to the same bowl track, and it is assumed that one bowl track cannot have two different fullness levels during the period of time two consecutive cars roll into it.[††] Therefore, the joint probability

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[*] The time spacing is user-specified and in addition to the uniformly spaced time points contains points at irregular time intervals for every track section boundary crossing.

[†] Computer times on CDC 6400 are approximately (for a 1 sec simulation time step) 0.15 sec per simulation for a conventional yard and 2.5 sec per simulation for a Dowty yard having about 900 units on the simulated route.

[‡] Implicit in this process is the assumption that the behavior of the car on the simulated route is sufficiently close to that of a car on a diverging route that the behavior of the latter can be simulated by the former up to the switch's clearance point--this assumption is employed in checking for cornering collisions.

[§] An approximate relation for CP seconds to perform the pairwise comparisons on a CDC 6400 is

$$\text{CP. SEC} = .0373\ N_R N_T^2 N_F^2 + .0206\ N_R^2 N_T^2 N_F^2$$

The first term is due to certain efficiencies used in the programming; it is dominated by the second term in runs with a large number of rolling resistances.

[**] i.e., the joint distribution $P(R^i, T^j, F^k)$.

[††] This, of course, presupposes that the track is not pulled while these two cars are rolling into it. In reality, cars would not be permitted to enter the track while it was being pulled, due to safety considerations. Also, neglected in this analysis is the minor change in track fullness level "seen" by the second car due to the first car filling the track a little farther.

distribution of F_1 and F_2 after the last switch is

$$P(F_1^m, F_2^n) = \begin{cases} P(F_1^m) & \text{if } F_1^m = F_2^n \\ 0 & \text{if } F_1^m \neq F_2^n \end{cases} \tag{20}$$

However, the joint distribution $P(F_1^m, F_2^n)$ is desired all along the track, not just after the last switch. Intuitively, at the hump one would expect a joint distribution of F_1^m and F_2^n "close" to independence, due to the diversity of possible destinations. As a car pair proceeds along a specific track, the distribution should change discontinuously at each switch, each change moving the distribution closer to that in equation (20). Thus, the joint distribution of F_1^m and F_2^n is dependent upon the location of the specific track section involved. The joint distribution $P(F_1^m, F_2^n)$ dependent upon track section where the catch-up occurs will now be derived. The dependence upon the track section is expressed through the probability of occupancy of track section s, $P_{occ}(s)$.

Consider the track section $N_s - 1$ in Figure D-6, just prior to the last switch, where each car entering the section is shunted to one of two classification tracks. The probability of occupancy of track section $N_s - 1$ is $P_{occ}(N_s - 1)$;* the probability of occupancy of track section N_s, Class Track A, is $P_{occ}(N_s)$; and the probability of occupancy of track section N_s, Class Track B is, by subtraction, $P_{occ}(N_s - 1) - P_{occ}(N_s)$.

The joint probability distribution $P(F_1^m, F_2^n)$ of two consecutive cars in track section $N_s - 1$, conditioned on both cars being in track section $N_s - 1$, is then found in parts: If both cars are going to Class Track A

$P(F_1^m, F_2^n)\,|\,$both in $N_s - 1$ (for 1 to A and 2 to A)

$$= \begin{cases} \dfrac{P_{occ}(N_s)}{P_{occ}(N_s - 1)} \, \dfrac{P_{occ}(N_s)}{P_{occ}(N_s - 1)} \cdot P(F_1^m) & \text{if } F_1^m = F_2^n \\ 0 & \text{if } F_1^m \neq F_2^n \end{cases} \tag{21}$$

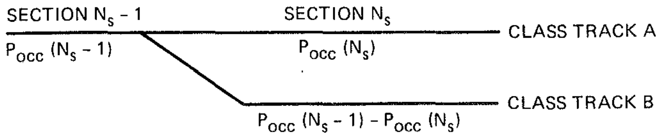

Figure D-6. Track Sections in Vicinity of Last Switch

If both cars are going to Class Track B

$P(F_1^m, F_2^n)\,|\,$both in $N_s - 1$ (for 1 to B and 2 to B)

$$= \begin{cases} \dfrac{[P_{occ}(N_s - 1) - P_{occ}(N_s)]}{P_{occ}(N_s - 1)} \cdot \\ \dfrac{[P_{occ}(N_s - 1) - P_{occ}(N_s)]}{P_{occ}(N_s - 1)} P(F_1^m) & \text{if } F_1^m = F_2^n \\ 0 & \text{if } F_1^m \neq F_2^n \end{cases} \tag{22}$$

If Car 1 is going to Class Track A and Car 2 to B

$P(F_1, F_2)\,|\,$both in $N_s - 1$ (for 1 to A and 2 to B)

$$= \frac{P_{occ}(N_s)}{P_{occ}(N_s - 1)} \left[\frac{P_{occ}(N_s - 1) - P_{occ}(N_s)}{P_{occ}(N_s - 1)}\right] \cdot P(F_1^m)P(F_2^n) \quad \forall^{\dagger} F_1^m, F_2^n \tag{23}$$

If Car 1 is going to Class Track B and Car 2 to A

$P(F_1, F_2)\,|\,$both in $N_s - 1$ (For 1 to B and 2 to A)

$$= \left[\frac{P_{occ}(N_s - 1) - P_{occ}(N_s)}{P_{occ}(N_s - 1)}\right] \frac{P_{occ}(N_s)}{P_{occ}(N_s - 1)} \cdot P(F_1^m)P(F_2^n) \quad \forall F_1^m, F_2^n \tag{24}$$

Equations (21) through (24) can be summed to yield

$P(F_1^m, F_2^n)\,|\,$Car 1 and 2 in Section $N_s - 1$

$$= \begin{cases} \dfrac{1}{[P_{occ}(N_s - 1)]^2} \Big[\Big\{ [P_{occ}(N_s)]^2 \\ \quad + [P_{occ}(N_s - 1) - P_{occ}(N_s)]^2 \Big\} P(F_1^m) \\ \quad + 2P_{occ}(N_s)[P_{occ}(N_s - 1) \\ \quad - P_{occ}(N_s)][P(F_1^m)]^2 \Big] & \text{if } F_1^m = F_2^n \\ \dfrac{1}{[P_{occ}(N_s - 1)]^2} \Big\{ 2P_{occ}(N_s)[P_{occ}(N_s - 1) \\ \quad - P_{occ}(N_s)]P(F_1^m)P(F_2^n) \Big\} & \text{if } F_1^m \neq F_2^n \end{cases} \tag{25}$$

Equation (25) is quite cumbersome to work with. However, the process by which it was derived is recursively generalizable to all the track sections extending upstream to the hump. Were this generalization to be done, the SPEEDCON user would also be required to specify track occupancy probabilities on all classification tracks in the yard (not just on the simulated route), together with detailed track geometry. Not only would this be cumbersome for the user, it would also be a level of detail inconsistent with the comparatively simple one-track simulation approach used in SPEEDCON. Therefore, the utility of the simplifying assumption in SPEEDCON that all classification tracks have the same

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*In this section we will briefly digress from the assumption of equal long term occupancy for all class tracks. By doing so, however, the derivation will be more general, and, due to its cumbersomeness, will also lend support to the assumption of equal occupancy of class tracks.

†Symbol ∀ ≡ for all.

probability of occupancy is apparent. This is equivalent to assuming that, over a long period of time, any one humped car has an equal likelihood to going to any of the classification tracks. This permits a considerable simplification of the derivation of $P(F_1^m, F_2^n)$; in the above derivation, for example

$$P_{occ}(N_s - 1) = 2P_{occ}(N_s) \tag{26}$$

and the occupancy on Class Track B simplifies as

$$P_{occ}(N_s - 1) - P_{occ}(N_s) = P_{occ}(N_s) \tag{27}$$

Making this simplification in equation (25) results in

$P(F_1^m, F_2^n)\,|$ Car 1 and Car 2 in Section $N_s - 1$

$$= \begin{cases} \frac{1}{2}P(F_1^m) + \frac{1}{2}P(F_1^m)P(F_2^n) & \text{if } F_1^m = F_2^n \\ \frac{1}{2}P(F_1^m)P(F_2^n) & \text{if } F_1^m \neq F_2^n \end{cases} \tag{28}$$

More importantly, $P(F_1^m, F_2^n)$ can now be generalized in a simple manner to all track sections from the hump to the bowl. Consider Figure D-7. The joint distribution $P(F_1^m, F_2^n)$ is desired for track section s, conditioned upon the car pair being in that section. The distribution is found, by analogy with the previous case, in parts. However, we avail ourselves of the simplification that all class track destinations are identical, insofar as occupancy is concerned. At track section s, call the number of possible class track destinations M. Then the joint probability distribution $P(F_1^m, F_2^n)$ of two consecutive cars in track section s, conditional on both cars being there, is again found in parts. If both cars are going to the same destination (any of the M possibilities)

$P(F_1, F_2)\,|$ both in s (for both 1 and 2 to same destination)

$$= \begin{cases} M\,\dfrac{P_{occ}(N_s)}{P_{occ}(s)}\,\dfrac{P_{occ}(N_s)}{P_{occ}(s)}\,P(F_1^m) & \text{if } F_1^m = F_2^n \\ 0 & \text{if } F_1^m \neq F_2^n \end{cases} \tag{29}$$

If the cars are going to different destinations

$P(F_1^m, F_2^n)\,|$ both in s (for 1 and 2 to different destinations)

$$= 2\binom{M}{2}\frac{P_{occ}(N_s)}{P_{occ}(s)}\,\frac{P_{occ}(N_s)}{P_{occ}(s)}\,P(F_1^m)P(F_2^n)\ \forall F_1^m, F_2^n \tag{30}$$

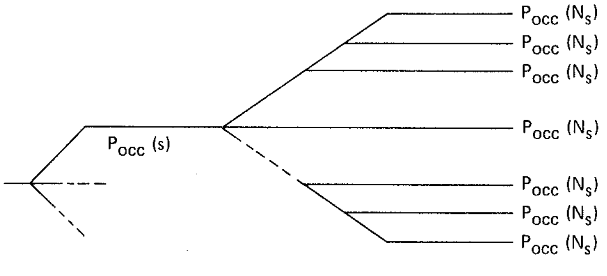

Figure D-7. Track Section Leading to Many Classification Tracks

Here the quantity $\binom{M}{2}$, "M combinatorial 2," denotes the number of possible ways M objects (destinations) can be selected[*] two at a time.

The factor of 2 multiplying $\binom{M}{2}$ is necessary because we wish to count Car 1 to destination A and Car 2 to destination B as a separate case from Car 1 to destination B and Car 2 to destination A. $\binom{M}{2}$ is defined as

$$\binom{M}{2} = \frac{M!}{(M-2)!\,2!} \tag{31}$$

which simplifies to

$$\binom{M}{2} = \frac{M(M-1)}{2} \tag{32}$$

Further, since all destinations are identical,

$$M = \frac{P_{occ}(s)}{P_{occ}(N_s)} \tag{33}$$

Finally, putting equations (29) through (33) together and simplifying results in the desired expressions:

$P(F_1^m, F_2^n)\,|$ both in s (for 1 and 2 to same destination)

$$= \begin{cases} \dfrac{P_{occ}(N_s)}{P_{occ}(s)}\,P(F_1^m) & \text{if } F_1^m = F_2^n \\ 0 & \text{if } F_1^m \neq F_2^n \end{cases} \tag{34}$$

$P(F_1^m, F_2^n)\,|$ both in s (for 1 and 2 to different destinations)

$$= \left[1 - \frac{P_{occ}(N_s)}{P_{occ}(s)}\right] P(F_1^m)P(F_2^n)\quad \forall F_1^m, F_2^n \tag{35}$$

Equations (34) and (35) are the actual relations used in SPEEDCON. Computationally, they are easy to use: regardless of fullness level, $P(F_1^m, F_2^n)$ is first assigned the value given by equation (35). Then F_1^m is checked against F_2^n, if they are unequal, the computation of $P(F_1^m, F_2^n)$ is complete; however, if $F_1^m = F_2^n$, the additional amount specified by equation (34) must be added, completing the computation. The relation for $P(F_1^m, F_2^n)$ behaves as expected: if the car pair is in track section N_s (i.e., on the class track) only equation (34) applies and $P(F_1^m, F_2^n)$ is zero if $F_1^m \neq F_2^n$. Near the hump, the ratio $P_{occ}(N_s)/P_{occ}(s)$ is small, so $P(F_1^m, F_2^n)$ is approximately $P(F_1^m) \cdot P(F_2^n)$.

D.2.2.4.3 Probability a Car Pair is Switched Apart at a Switch. The formulas for misswitch and cornering events (Events 2c and 2d) in Table D-3 use an expression for the probability of two consecutive cars being switched apart at a switch. Designating the switch section as s, this probability is conditioned on the car pair having travelled together as far as s on the specific simulated route.

Consider Figure D-8. There are four possible combinations of routings for a car pair (Cars 1 and 2): (1) Both 1 and 2 to A; (2) Both 1 and 2 to B; (3) Car 1 to A and Car 2 to B; and (4) Car 1 to B and Car 2

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[*] Selection is done without replacement, in agreement with the constraint that the cars have different destinations.

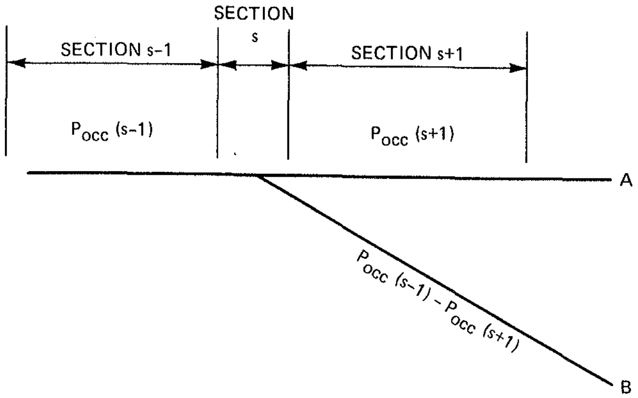

Figure D-8. Track Occupancies in the Vicinity of a Switch

to A. The probability of a car pair being switched apart at the switch in section s (on the simulated route) is then the sum of the conditional probabilities of (3) and (4) above, namely

$$P_{sw}(s) = \frac{P_{occ}(s+1)}{P_{occ}(s-1)} \; \frac{[P_{occ}(s-1) - P_{occ}(s+1)]}{P_{occ}(s-1)} + \frac{[P_{occ}(s-1) - (P_{occ}(s+1)]}{P_{occ}(s-1)} \; \frac{P_{occ}(s+1)}{P_{occ}(s-1)} = \frac{2 \cdot P_{occ}(s+1)[P_{occ}(s-1) - P_{occ}(s+1)]}{[P_{occ}(s-1)]^2} \tag{36}$$

In practice, this relation is simplified by using the $[P_{occ}(s-1)]^2$ in the denominator to cancel the similar term in Table D-2 for events 2c and 2d.*

D.2.2.4.4 Car Pair Formulas for Incremental Probability. The proper incremental probability $p_e(s)$ for cair pair events 2a and 2b is the probability of the occurrence of the characteristics of the pair

$$P(R_1^i) \cdot P(R_2^j) \cdot P(T_1^k) \cdot P(T_2^\ell) \cdot P(F_1^m, F_2^n) \tag{37}$$

multiplied by the probability that the cars follow each other to section s, which is

$$[P_{occ}(s)]^2 \tag{38}$$

Referrring back to Table D-3, for events 2c and 2d, in computing $p_e(s)$ we may take

$$P(F_1^m, F_2^n) = P(F_1^m) \cdot P(F_2^n) \tag{39}$$

i.e., we may treat F_1^m and F_2^n as uncorrelated. This is because cars 1 and 2 are always going to different tracks† (because they are being switched apart), so it is reasonable to assume the tracks' fullness levels, over the long term, are independent. Then the probability of the occurrence of the characteristics of the pair becomes

$$P(R_1^i) \cdot P(R_2^j) \cdot P(T_1^k) \cdot P(T_2^\ell) \cdot P(F_1^m) \cdot P(F_2^n) \tag{40}$$

Finally, p_e is computed by multiplying the above product by the probability that the cars are switched apart, $P_{sw}(s)$, and by the probability that the cars have followed each other as far as section s‡ $[P_{occ}(s-1)]^2$.

D.3 THE SPEEDCON PROGRAM

This section describes the structure of the SPEEDCON program, the input the user must prepare, and the output produced by the program.

D.3.1 The Structure of SPEEDCON

Previous sections have already alluded to the structure of SPEEDCON to some extent. This section briefy structures the overall program in relation to user input and output.

Figure D-9 shows a flowchart of the overall structure of SPEEDCON. First the program reads various forms of input data that instruct the program on the nature of the SPEEDCON run to be performed (the input will be discussed in detail in Section D.3.3). Next, the single car phase is initiated. The nature of this phase was described in Section D.2.2.3. After completion of the single car phase, the pairwise comparison phase is initiated (also discussed in Section D.2.2.3). After the pairwise comparison phase is complete, SPEEDCON proceeds to output its results. Details of the output may be found in the next section.

SPEEDCON is written entirely in near ANSI standard FORTRAN. A few machine dependent syntaxes (CDC) had to be used in order to build the model at all, however. These are

- Use of a random-access mass storage scratch file. This is used to store the cars' trajectory tables.
- The system utility SECOND is called, in order to keep track of computer time consumed in various phases. This proved very useful in estimating run costs.
- The ENCODE utility is used to build a complex printed output table in the WABCO target travel time logic module.

Most of these features are supported in the new FORTRAN 77 standard, and the program can easily be converted to this. References to SECOND can simply be deleted, as this is not critical to most users. One final machine dependence is that certain variables will have to be made DOUBLE PRECISION on smaller (e.g., 32 bit) word machines; this is largely a carry-over from PROFILE.

Figure D-10 lists all the SPEEDCON subprogram modules by name and purpose, together with their calling hierarchy. Not shown are any additional subprograms the user may install as a part of the retarder logic modules.

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[*] For a switch section s SPEEDCON uses $P_{occ}(s) \equiv P_{occ}(s-1)$ since $P_{occ}(s)$ when s is a switch would otherwise be indeterminate. SPEEDCON does not allow two adjacent sections to both be switches, so s - 1 is always determinate.

[†] Events 2a and 2b inherently consider a situation where the cars may indeed by traveling to the same classification track.

[‡] Same as $[P_{occ}(s)]^2$ (see footnote in previous section).

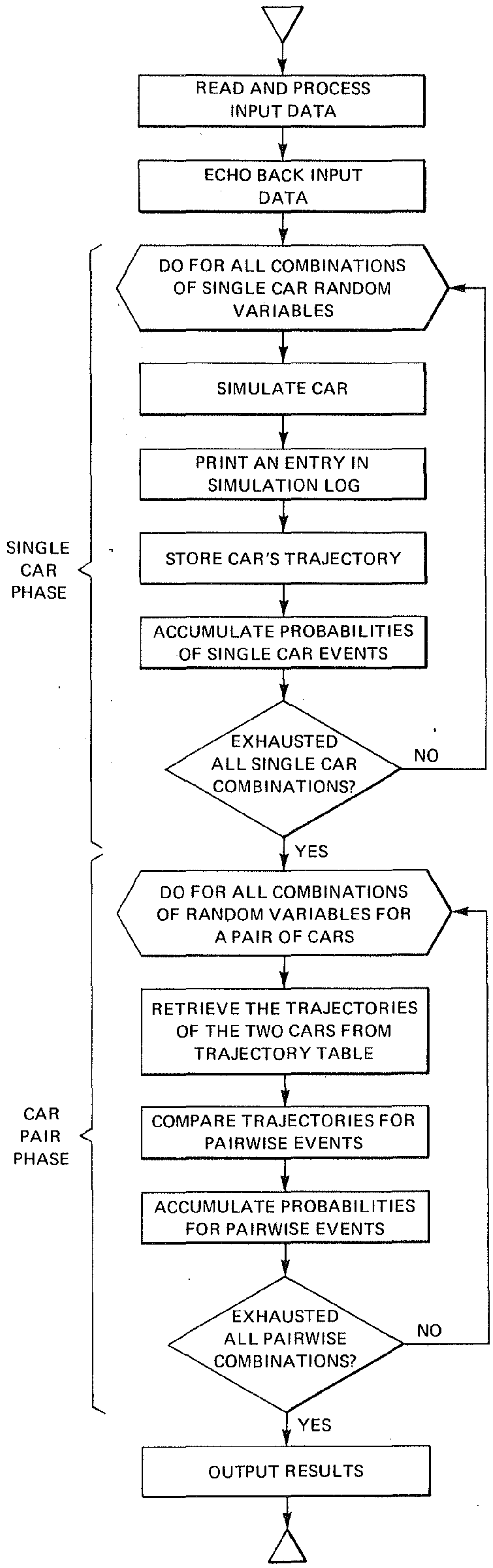

Figure D-9. Flowchart of Overall Structure of SPEEDCON

D.3.2 SPEEDCON Output

This section discusses the nature of the output produced by SPEEDCON, illustrated by two small example runs. Although logically the model's input precedes its output, the output is presented first here because it is felt that this order will enable the potential user to make a more informed selection among the various input options.

Exhibit 1 shows the complete output for a SPEEDCON run for the SRI-designed hypothetical yard; Exhibit 2 similarly shows the complete output for a pure Dowty yard, designed by Dowty as a hypothetical yard in conjunction with the current SRI project. It must be emphasized that neither of these runs is to be considered the production evaluation runs which compare the performance of the two types of yard designs. Although based on the same yard design, the production evaluation runs use 3 rolling resistance transformation families, and 3 class track fullness levels; the demonstration runs shown in Exhibits 1 and 2 use only one level of each (i.e., the randomness of these parameters is not assessed). The production evaluation runs will be discussed in Section D.4.

The first portion of the SPEEDCON output consists of several pages of "echo-back" information, documenting the input data. The first page of output documents several run parameters--the simulation time step, hump speed, car length, etc. Also included are several program logical "switches" that allow the user several options regarding the amount of output, and also permit certain portions of the program--e.g., the pairwise comparisons--to be bypassed.

The next several pages of the output--still a part of the echo-back--present the distributions of the three random variables. These distributions are input by the user. The echo-back presents them in the form of histograms showing the frequency in 1000 represented by each cell (the actual probabilities used in SPEEDCON are these frequencies divided by 1000). In the example runs shown in Exhibits 1 and 2, the track fullness levels and the rolling resistance transformations each have only one cell in their histograms, in conformance with the assumption mentioned previously. The base rolling resistance distribution is represented by 28 cells at 1 lb/ton increments; the distribution used was fitted from data taken in CONRAIL's Elhart, Indiana yard.*

The histograms are followed by an echo-back page displaying the input parameters for the rolling resistance transformations.

After this comes a page echoing-back the track geometric data input by the user. This data basically specifies the design of the yard. In addition to the obvious geometric information such as section lengths and grades, this data also includes information such as the distances from the end of each switch section to the switch's clearance point, and the probability that a humped car uses the track section (i.e., the P_{occ}(s) of Section D.2.2). In addition, the user may optionally append alphanumeric identification data to each track section.

Finally, the last echo-back is printed by the routine that reads the retarder logic input parameters. As mentioned earlier, this routine is a module that may be

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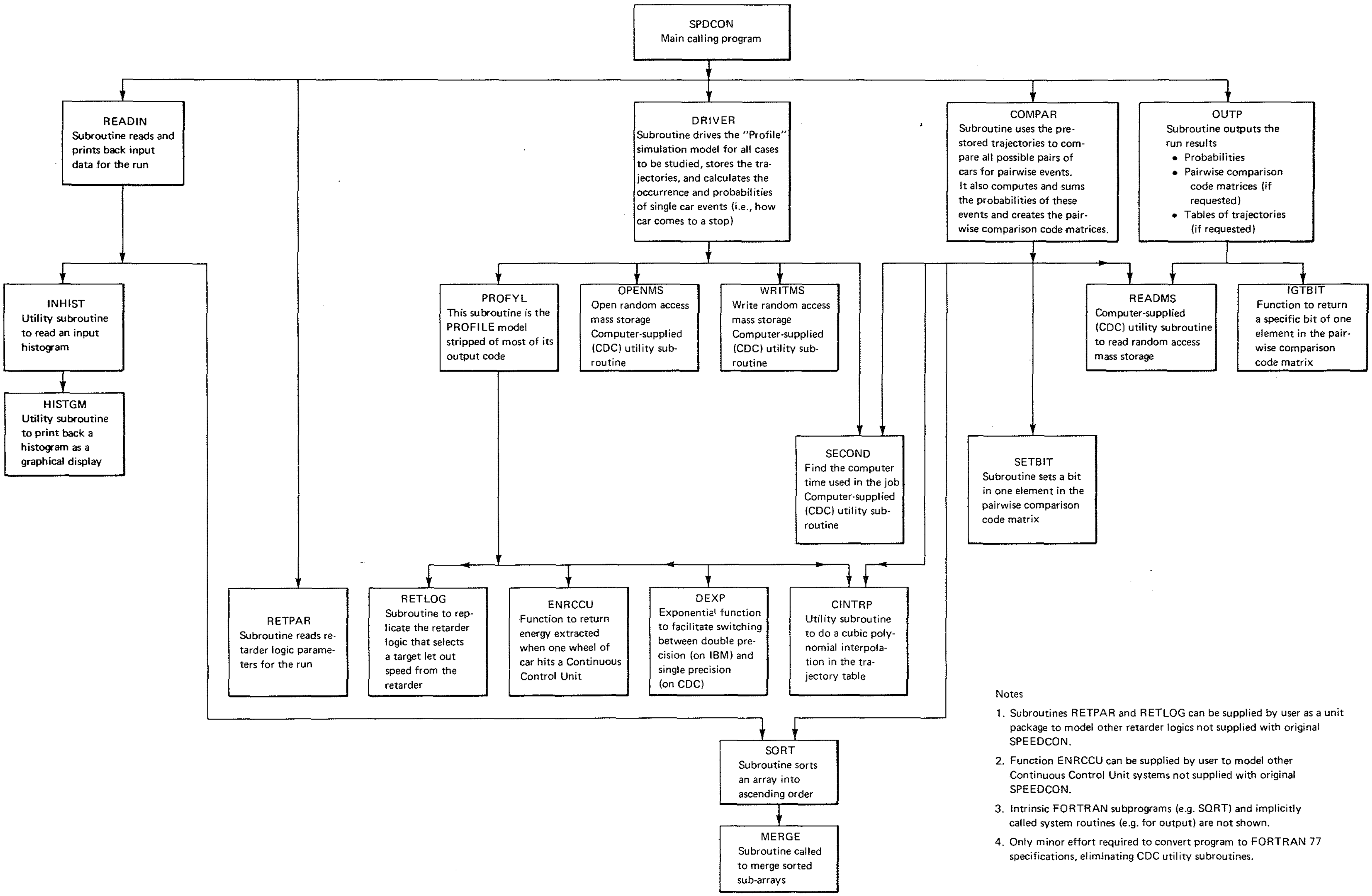
*More detail on this distribution can be found in Section D.4 and Appendix F.



Notes

1. Subroutines RETPAR and RETLOG can be supplied by user as a unit package to model other retarder logics not supplied with original SPEEDCON.
2. Function ENRCCU can be supplied by user to model other Continuous Control Unit systems not supplied with original SPEEDCON.
3. Intrinsic FORTRAN subprograms (e.g. SQRT) and implicitly called system routines (e.g. for output) are not shown.
4. Only minor effort required to convert program to FORTRAN 77 specifications, eliminating CDC utility subroutines.

Figure D-10. Block Diagram of SPEEDCON Subprogram Calling Hierarchy provided at user option; the routine used in these SPEEDCON demonstration runs is for the WABCO Target Travel Time Algorithm[*] (see Section D.2.1.2.1).

The next portion of the output is a simulation log, with one entry (of several lines) for each combination of base rolling resistance, rolling resistance transformation family, and track fullness level--a total of $N_R \cdot N_T \cdot N_F$ entries.[†] This table lists such information as:

- Base rolling resistance of each simulated car.
- Rolling resistance as transformed and applicable sections.
- Variables associated with the car's retardation (if the yard is equipped with conventional retarders).
- A code giving the "fate" of the car (i.e., stalls or couples--see the stop code tables later in the output).

The next section of the output is a table giving the legend for the optional "pairwise comparison code matrices;" this is followed by the matrices themselves. A total of $N_T^2 \cdot N_F^2$ matrices will be printed, so the user is cautioned that the potential for a large volume of output exists when N_T and/or N_F are large. Nonetheless, these matrices are quite useful for obtaining a "feel" for the results of the pairwise comparisons.

Each matrix is parametrized by base rolling resistance values--along the rows for the lead car, and across the columns for the following car. The entire matrix represents a single rolling resistance transformation family for the lead car, and another single rolling resistance transformation family for the following car. Similarly, this entire matrix also represents single classification track fullness levels for the lead and following cars.

Each matrix also presents the stop codes that came from the single-car-at-a-time analysis in a position adjacent to the lead car/following car base rolling resistance labeling. This information is convenient in manually correlating each car's isolated behavior with its behavior in conjunction with another car.

Finally, each entry or cell of the matrix contains a code which represents what happens to a car pair having the specified set of characteristics. This code is called the "pairwise comparison code." Generally speaking, the higher this code, the worse the set of events that can happen between such a car pair. In examining this table, it should be recalled that the pairwise comparison represents the behavior of <u>all</u> such car pairs humped having the specified set of characteristics (see Section D.2.2.3).

Referring to the comparison code matrices in Exhibits 1 and 2, it can be seen that the conventional retarder yard (Exhibit 1) only has pairwise problems when the lead car is an extreme hard roller (as evidenced by the nonzero codes across the lowest rows). The problems taper off as the following car also becomes an extreme hard roller (as evidenced by the zero entries on and above the diagonal in the lower right portion of the matrix). Comparing this comparison code matrix to that of the Dowty yard (Exhibit 2) reveals quite a difference. The Dowty yard, generally speaking, has problems whenever a lead car of about 7.5 lb/ton or harder is followed by an easier rolling car.[‡] It is felt the differing performances exhibited here are due to different design assumptions used in designing each of the hypothetical yards--an 18 lb/ton hard rolling car for the conventional yard versus a 12 lb/ton hard rolling car for the Dowty yard. This is discussed in greater detail in Section 5.

Finally, the last portion of the SPEEDCON output shown in the exhibits consists of two pages of tables giving the total probabilities of the occurrence of various mostly undesirable events. These probabilities are computed according to the formulas given in Table D-3.

The first column of probabilities (labeled as "Prob. on Simulated Route only") are the $P_e(s)$ and $\bar{P}_e$ of Section D.2.2.2; the second column of probabilities (labeled as "Prob. Weighted to Approximate Overall Yard") are the $P_e'(s)$ and $\bar{P}_e'$ of that section. Refer to that section for a precise definition of these probabilities; however, most users will want to use the probabilities given in the second column. The $P_e(s)$ and $P_e'(s)$ are the event probabilities broken down by specific track section s; their totals (labeled "Overall") give the probability summed over the entire route ($\bar{P}_e$, first column) or over the entire yard ($\bar{P}_e'$, second column).

The first page of event probability output tables pertains to events associated with single, isolated cars, and gives information relating to how the car stopped or coupled. Also given is the coupling speed distribution for cars that actually rolled to a coupling. An extra set of two columns is included for the coupling speed distribution--in this second set of columns, the coupling speed distribution is adjusted to sum to 1.0.[§] In the first set of columns, stalls are included in the total probability.

The second page of event probability output tables gives the probability of events for a consecutive pair of cars over the hump crest. It should be noted that "consecutive pair" are the operative words here--in its present stage, SPEEDCON does not consider catch-ups between 3, 4, or more consecutive cars, or the eventual couple-up or collision that is bound to occur when a lead car stalls and some subsequently humped car impacts it.[**]

Comparing these probabilities for the conventional and Dowty yards, the trend implied by the comparison code matrix is seen to continue, that is, the probability of undesirable events for the Dowty yard is much higher than for the conventional yard.

One additional output, not shown in exhibits, is available. This is an abbreviated, PROFILE-like car history table for <u>every</u> simulated car. This is essentially the car trajectory table, and consists of:

- The time in seconds since the car crested the hump.
- The car's distance from the hump in feet.

---

[*] Actually, this routine is irrelevant for the Dowty yard run (Exhibit 2).

[†] See Section D.2.2 for a definition of these terms.

[‡] The cut-off does not follow the diagonal precisely, so the above statement is only approximate. The comparison code matrix should be consulted for specifics.

[§] The event space consists only of coupling cars.

[**] In actuality, were a car to stall, the hump (or at least the track of the stall) would be closed while an engine would be sent to retrieve it.

- The car's speed in ft/sec.
- The car's track section number, with track section boundaries indicated as the negative of the preceding track section.

This output is primarily useful in very small runs such as investigating the details of the headway problems between a few specified car pairs. The user is cautioned that this option has the potential to produce an enormous quantity of output for even medium sized runs.

Exhibit 1

SAMPLE SPEEDCON DEMONSTRATION RUN FOR A CONVENTIONAL YARD

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR BASE ROLLING RESISTANCE      --

   RANGE     FREQ.
   (LB/T)     IN
             1000
----------- ----

                  ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   0 -    1.    1 +*
   1.-    2.    6 +****
   2.-    3.   31 +********************
   3.-    4.   82 +****************************************************
   4.-    5.  144 +********************************************************************************************
   5.-    6.  177 +*****************************************************************************************************************
   6.-    7.  165 +*********************************************************************************************************
   7.-    8.  127 +*********************************************************************************
   8.-    9.   88 +********************************************************
   9.-   10.   58 +*************************************
  10.-   11.   38 +************************
  11.-   12.   25 +****************
  12.-   13.   17 +***********
  13.-   14.   11 +*******
  14.-   15.    8 +*****
  15.-   16.    6 +****
  16.-   17.    4 +***
  17.-   18.    3 +**
  18.-   19.    2 +*
  19.-   20.    2 +*
  20.-   21.    1 +*
  21.-   22.    1 +*
  22 -   23.    1 +*
  23 -   24.    1 +*
  24 -   25.    1 +*
  25.-   26.    1 +*
  26.-   27.    1 +*
  27.-   28.    1 +*

NOTE -- SOME CELLS ABOVE HAVE BEEN ROUNDED TO 1 RATHER THAN 0 TO MAKE THEM APPARENT
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR CLASS TRACK PERCENT FULLNESS --

   RANGE     FREQ.
   (PCT.)     IN
             1000
----------- ----

                  ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   0 -  100. 1000 +*****************************************************************************************************************
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SIMULATION CONTROL PARAMETERS FOR THE RUN --

 SIMULATION TIME STEP, DELTA T, SEC.                                  1.000
 INTERVAL OF SIMULATED CAR HISTORY TABLE, SEC.                        1.000
 SIMULATE CARS IN BOWL TRACKS (1. = SIM.)                             0.
 PERFORM PAIRWISE COMPARISONS (1. = PERFORM)                          1.
 COMPARISON CODE MATRICES OUTPUT SWITCH (1. = PRINT)                  1.
 CAR HISTORY TABLE OUTPUT SWITCH (1. = PRINT)                         0.
 COLLAPSE TRACK FULLNESS DIMENSION (I>0 = COLLAPSE INTO CELL I)       0.

PHYSICAL PARAMETERS FOR THE RUN --

 HUMP SPEED, MPH                                                      2.270
 LENGTH OF SIMULATED CARS, FEET                                      55.000
 WEIGHT OF SIMULATED CARS, TONS                                      60.000
 EXTRA WEIGHT OF CARS DUE TO WHEEL ROTATION, TONS                     2.870
 CRITICAL HEADWAY AT SWITCHES, FEET                                  50.000
 SPEED BELOW WHICH COUPLINGS ARE UNDERSPEED, MPH                      2.000
 SPEED ABOVE WHICH COUPLINGS ARE OVERSPEED, MPH                       6.000
 CONTINUOUS CONTROL UNIT LENGTH, FEET                                  .750
 TRUCK WHEELBASE, FEET                                                5.500
 CENTER TO CENTER TRUCK SPACING, FEET                                45.000
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR ROLL. RES. TRANSFORMATIONS  --

 TRANSF.   FREQ.
 FAMILY     IN
   NO.     1000
----------- ----

                +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      1.   1000 +**********************************************************************************************************************************
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

ROLLING RESISTANCE LINEAR TRANSFORMATIONS FROM BASE ROLLING RESISTANCE (TRANSFORMATION FAMILY   1) --

          SECTIONS                        TRANSFORMATION
          --------      ---------------------------------------------------------

          13 - 50       ROLL. RES.(TRANSF.) =   .6670 * ROLL. RES.(BASE) + 0.0000

          NOTE -- ANY TRACK SECTIONS FOR WHICH A TRANSFORMATION IS NOT SPECIFIED WILL USE THE BASE ROLLING RESISTANCE VALUES.
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

 TRACK    LENGTH    CUM.    PERCENT   HORIZ.   SWITCH    DIST.     MAX.    NUMBER    SPEED    PROB.        DESCRIPTION
SECTION   (FEET)   LENGTH    GRADE    CURVE     LOSS    END SW.   RETAR-     OF     SETTING    CAR
NUMBER             (FEET)             RESIS.   (FT OF  TO CLEAR   DATION   CONTIN.  CONTIN.   USES
                                      (LB/T)    HEAD)    POINT    (FT OF   CONTROL  CONTROL   TRACK
                                                        (FEET)    HEAD)    UNITS    UNITS   SECTION
                                                                                    (MPH)

    1      52.5      0.0     2.58     -0.00    -0.00     -0.0     -0.00     -0.      -0.00   1.0000   CREST TO EVC
    2     172.5     52.5     4.00     -0.00    -0.00     -0.0     -0.00     -0.      -0.00   1.0000   EVC TO GRCH1
    3      40.0    225.0     1.67     -0.00    -0.00     -0.0      0.00     -0.      -0.00   1.0000   GRCH1 TO MRET1
    4      50.0    265.0     1.67     -0.00    -0.00     -0.0      5.25     -0.      -0.00   1.0000   MRET1
    5      10.0    315.0     1.67     -0.00    -0.00     -0.0     -0.00     -0.      -0.00   1.0000   MRET1 TO SWO
    6       1.0    325.0     1.67     -0.00      .00    139.7     -0.00     -0.      -0.00    .5000   SWO
    7       8.5    326.0     1.67     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .5000   SWO TO SW1
    8       1.0    334.5     1.67     -0.00      .06    171.8     -0.00     -0.      -0.00    .2500   SW1
    9      61.1    335.5     1.67     12.00    -0.00     -0.0     -0.00     -0.      -0.00    .2500   SW1 TO PT
   10      35.0    396.6     1.67     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .2500   PT TO BHC1
   11      83.8    431.6     1.67      9.49    -0.00     -0.0     -0.00     -0.      -0.00    .2500   BHC1 TO EHC1
   12      10.0    515.3     1.67     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .2500   EHC1 TO GRET1
   13      49.7    525.3     1.67     -0.00    -0.00     -0.0      5.21     -0.      -0.00    .2500  GRET1 TO GRCH2
   14      30.4    575.0      .50     -0.00    -0.00     -0.0      3.19     -0.      -0.00    .2500   GRCH2 TO GRET2
   15      20.0    605.3      .50     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .2500   GRET2 TO SW2
   16       1.0    625.3      .50     -0.00      .06    171.8     -0.00     -0.      -0.00    .1250   SW2
   17      71.3    626.3      .50      7.95    -0.00     -0.0     -0.00     -0.      -0.00    .1250   SW2 TO PT
   18      20.0    697.6      .50     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .1250   PT TO SW3
   19       1.0    717.6      .50     -0.00      .06    171.8     -0.00     -0.      -0.00    .0625   SW3
   20      71.3    718.6      .50      7.95    -0.00     -0.0     -0.00     -0.      -0.00    .0625   SW3 TO PT
   21      30.0    789.9      .50     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .0625   PT TO SW4
   22       1.0    819.9      .50     -0.00      .06    171.8     -0.00     -0.      -0.00    .0313   SW4
   23      71.3    820.9      .50      7.95    -0.00     -0.0     -0.00     -0.      -0.00    .0313   SW4 TO PT
   24      83.0    892.2      .50     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .0313   PT TO BHC2
   25     167.6    975.2      .50     12.50    -0.00     -0.0     -0.00     -0.      -0.00    .0313   BHC2 TO EHC2
   26      20.0   1142.8      .50     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .0313   EHC2 TO TRET
   27      70.0   1162.8      .50     -0.00    -0.00     -0.0      4.60     -0.      -0.00    .0313   TRET
   28      28.0   1232.8      .07     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .0313   SIM. CLASS TRACK
   29   -2418.0   1260.8      .07     -0.00    -0.00     -0.0     -0.00     -0.      -0.00    .0313   UNSIM. CLASS TRACK
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

RETARDER LOGIC INPUT PARAMETERS FOR WABCO TARGET TRAVEL TIME ALGORITHM -

                           REFERENCE POINTS                        ADJUSTMENT TO           ESTIMATION OF ROLLING
                         --------------------                    AVERAGE GRADE(PCT)     RESIS. (LB/T) AFTER RETARDER
                         UPSTREAM   DNSTREAM    TRAV. TIME,        AFTER RETARDER      ------------------------------
                         PT. - END  PT. - END    REF. CAR        ------------------              MEAS.RES.             TARGET
RETARDER      TRACK      OF TRACK   OF TRACK   BETWEEN REF      ADDITIVE  MULTIPL.    ADDITIVE   PRIOR TO   MULTIPL.   COUPLING
GROUP NO.   SECTION(S)   SEC. NO.   SEC. NO.   POINTS, SEC.      CONST.    CONST.      CONST.   RET.GR.NO.   CONST.    VELOCITY
---------   ----------   --------   --------   ------------     --------  --------    --------  ----------  --------   --------

    1            4           0         12         31.000          0.000     1.000       0.000        1        1.000

    2           13           0         26         65.980          0.000     1.000       0 000        1         .667
                14                                                                                   2        0.000

    3           27           0          0         -0.000          0.000     1.000       0.000        1         .667      4.00
                                                                                                     2        0.000
                                                                                                     3        0.000

INPUT/INITIALIZATION COMPLETE.  CP SECS. =       .769
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SIMULATION LOG FOR PERCENT FULLNESS OF CLASS TRACKS = 50.00   (1209.00 FEET FROM TANGENT POINT TO COUPLING POINT)
ROLLING RESISTANCE TRANSFORMATION FAMILY  1


PROFYL CALLED WITH BASE ROLL. RES. =    .500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =    .334 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.567 FPS, TARGET VEL. OUT =  23.409 FPS
RET. GRP.  1, TRK. SEC.  4, RET.     .943 FT., VEL. IN  23.567 FPS, TARGET VEL. OUT  23.409 FPS, ACHIEVED VEL. OUT  23.409 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  26.646 FPS, TARGET VEL. OUT =  16.484 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  26.646 FPS, TARGET VEL. OUT  16.484 FPS, ACHIEVED VEL. OUT  20.982 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   2.891 FT., VEL. IN  20.982 FPS, TARGET VEL. OUT  16.484 FPS, ACHIEVED VEL. OUT  16.484 FPS
IMPOSSIBLE TO RETARD CAR SUFFICIENTLY TO ACHIEVE TARGET CPL. VEL. - TARGET LET OUT VEL. 0. FPS USED
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.     .010 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   4.600 FT., VEL. IN  17.644 FPS, TARGET VEL. OUT    .010 FPS, ACHIEVED VEL. OUT   7.042 FPS
END SIM., CP SECS. =    .113, PTS. ADDED TO TABLE =   105, ENDING CODE =  0, STOP CODE =  4
```

```
PROFYL CALLED WITH BASE ROLL. RES. =  1.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  1.001 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.394 FPS, TARGET VEL. OUT =  23.889 FPS
RET. GRP.  1, TRK. SEC.  4, RET.    .416 FT., VEL. IN  23 394 FPS, TARGET VEL. OUT  23.889 FPS, ACHIEVED VEL. OUT  23.889 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  26.949 FPS, TARGET VEL. OUT =  16.638 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  26.949 FPS, TARGET VEL. OUT  16.638 FPS, ACHIEVED VEL. OUT  21.342 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   3.045 FT., VEL. IN  21.342 FPS, TARGET VEL. OUT  16.638 FPS, ACHIEVED VEL. OUT  16.638 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.   4.661 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   4.600 FT., VEL. IN  17.463 FPS, TARGET VEL. OUT   4.661 FPS, ACHIEVED VEL. OUT   6.465 FPS
END SIM., CP SECS. =    .119, PTS. ADDED TO TABLE =   106, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  2.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  1.668 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.218 FPS, TARGET VEL. OUT =  24.388 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  23.218 FPS, TARGET VEL. OUT  24.388 FPS, ACHIEVED VEL. OUT  24.219 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  27.123 FPS, TARGET VEL. OUT =  16.826 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  27.123 FPS, TARGET VEL. OUT  16.826 FPS, ACHIEVED VEL. OUT  21.538 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   3.069 FT., VEL. IN  21.538 FPS, TARGET VEL. OUT  16.826 FPS, ACHIEVED VEL. OUT  16.826 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.   6.861 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   4.408 FT., VEL. IN  17.316 FPS, TARGET VEL. OUT   6.861 FPS, ACHIEVED VEL. OUT   6.861 FPS
END SIM., CP SECS. =    .112, PTS. ADDED TO TABLE =   105, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  3.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  2.335 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL  IN =  23.042 FPS, TARGET VEL. OUT =  24.908 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  23.042 FPS, TARGET VEL. OUT  24.908 FPS, ACHIEVED VEL. OUT  24.018 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  26.824 FPS, TARGET VEL. OUT =  17.125 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  26.824 FPS, TARGET VEL. OUT  17.125 FPS, ACHIEVED VEL. OUT  21.135 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   2.614 FT., VEL. IN  21.135 FPS, TARGET VEL. OUT  17.125 FPS, ACHIEVED VEL. OUT  17.125 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.   8.509 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   3.954 FT., VEL. IN  17.284 FPS, TARGET VEL. OUT   8.509 FPS, ACHIEVED VEL. OUT   8.509 FPS
END SIM., CP SECS. =    .118, PTS  ADDED TO TABLE =   104, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  4.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  3.002 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.865 FPS, TARGET VEL. OUT =  25.450 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  22.865 FPS, TARGET VEL. OUT  25.450 FPS, ACHIEVED VEL. OUT  23.816 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  26.521 FPS, TARGET VEL. OUT =  17.426 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  26.521 FPS, TARGET VEL. OUT  17.426 FPS, ACHIEVED VEL. OUT  20.725 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   2.156 FT., VEL. IN  20.725 FPS, TARGET VEL. OUT  17.426 FPS, ACHIEVED VEL. OUT  17.426 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.   9.887 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   3.499 FT., VEL. IN  17.249 FPS, TARGET VEL. OUT   9.887 FPS, ACHIEVED VEL. OUT   9.887 FPS
END SIM., CP SECS. =    .106. PTS. ADDED TO TABLE =   104. ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  5.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  3.669 LB/T
RET. GRP   1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.686 FPS, TARGET VEL. OUT =  26.017 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  22.686 FPS, TARGET VEL. OUT  26.017 FPS, ACHIEVED VEL. OUT  23.612 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =, 26.215 FPS, TARGET VEL. OUT =  17.730 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  26.215 FPS, TARGET VEL. OUT  17.730 FPS, ACHIEVED VEL. OUT  20.307 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   1.693 FT., VEL. IN  20.307 FPS, TARGET VEL. OUT  17.730 FPS, ACHIEVED VEL. OUT  17.730 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  11.095 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   3.050 FT., VEL. IN  17.226 FPS, TARGET VEL. OUT  11.095 FPS, ACHIEVED VEL. OUT  11.095 FPS
END SIM., CP SECS. =    .115, PTS. ADDED TO TABLE =   103, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  6.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  4.335 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.506 FPS, TARGET VEL. OUT =  26.610 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  22.506 FPS, TARGET VEL. OUT  26.610 FPS, ACHIEVED VEL. OUT  23.406 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  25.906 FPS, TARGET VEL. OUT =  18.037 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  25.906 FPS, TARGET VEL. OUT  18.037 FPS, ACHIEVED VEL. OUT  19.881 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   1.225 FT., VEL. IN  19.881 FPS, TARGET VEL. OUT  18.037 FPS, ACHIEVED VEL  OUT  18.037 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  12.184 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   2.614 FT., VEL. IN  17.225 FPS, TARGET VEL. OUT  12.184 FPS, ACHIEVED VEL. OUT  12.184 FPS
END SIM., CP SECS. =    .113, PTS. ADDED TO TABLE =   103, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL  RES. =  7.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  5.002 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.325 FPS, TARGET VEL. OUT =  27.233 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  22.325 FPS, TARGET VEL. OUT  27.233 FPS, ACHIEVED VEL. OUT  23.199 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  25.592 FPS, TARGET VEL. OUT =  18.348 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  25.592 FPS, TARGET VEL. OUT  18.348 FPS, ACHIEVED VEL. OUT  19.444 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .751 FT., VEL. IN  19.444 FPS, TARGET VEL. OUT  18.348 FPS, ACHIEVED VEL. OUT  18.348 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  13.183 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   2.171 FT., VEL. IN  17.212 FPS, TARGET VEL. OUT  13.183 FPS, ACHIEVED VEL. OUT  13.183 FPS
END SIM., CP SECS. =    .117, PTS. ADDED TO TABLE =   103, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  8.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  5.669 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.142 FPS, TARGET VEL. OUT =  27.888 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  22.142 FPS, TARGET VEL. OUT  27.888 FPS, ACHIEVED VEL. OUT  22.990 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  25.275 FPS, TARGET VEL. OUT =  18.664 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   5.210 FT., VEL. IN  25.275 FPS, TARGET VEL. OUT  18.664 FPS, ACHIEVED VEL. OUT  18.998 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .272 FT., VEL. IN  18.998 FPS, TARGET VEL. OUT  18.664 FPS, ACHIEVED VEL. OUT  18.664 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  14.111 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   1.738 FT., VEL. IN  17.216 FPS, TARGET VEL. OUT  14.111 FPS, ACHIEVED VEL. OUT  14.111 FPS
END SIM., CP SECS. =    .110, PTS. ADDED TO TABLE =   102, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  9.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  6.337 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.957 FPS, TARGET VEL. OUT =  28.579 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21 957 FPS, TARGET VEL. OUT  28.579 FPS, ACHIEVED VEL. OUT  22.778 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  24.953 FPS, TARGET VEL. OUT =  18.984 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   4.939 FT., VEL. IN  24.953 FPS, TARGET VEL. OUT  18.984 FPS, ACHIEVED VEL. OUT  18.984 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .057 FT., VEL. IN  18.984 FPS, TARGET VEL. OUT  18.984 FPS, ACHIEVED VEL. OUT  18.984 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  14.982 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   1.319 FT., VEL. IN  17.247 FPS, TARGET VEL. OUT  14.982 FPS, ACHIEVED VEL. OUT  14.982 FPS
END SIM., CP SECS. =    .116, PTS. ADDED TO TABLE =   102, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. = 10.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  7.004 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.770 FPS, TARGET VEL. OUT =  29.309 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21.770 FPS, TARGET VEL. OUT  29.309 FPS, ACHIEVED VEL. OUT  22.564 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  24.628 FPS, TARGET VEL. OUT =  19.308 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   4.458 FT., VEL. IN  24.628 FPS, TARGET VEL. OUT  19.308 FPS, ACHIEVED VEL. OUT  19.308 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .047 FT., VEL. IN  19.308 FPS, TARGET VEL. OUT  19.308 FPS, ACHIEVED VEL. OUT  19.308 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  15.805 FPS
RET. GRP.  3, TRK. SEC. 27, RET.    .896 FT., VEL. IN  17.269 FPS, TARGET VEL. OUT  15.805 FPS, ACHIEVED VEL. OUT  15.805 FPS
END SIM., CP SECS. =    .116, PTS. ADDED TO TABLE =   102, ENDING CODE =  0, STOP CODE =  0
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PROFYL CALLED WITH BASE ROLL. RES. = 11.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  7.671 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.583 FPS, TARGET VEL. OUT =  30.083 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21.583 FPS, TARGET VEL. OUT  30.083 FPS, ACHIEVED VEL. OUT  22.349 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  24.298 FPS, TARGET VEL. OUT =  19.639 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   3.969 FT., VEL. IN  24.298 FPS, TARGET VEL. OUT  19.639 FPS, ACHIEVED VEL. OUT  19.639 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .037 FT., VEL. IN  19.639 FPS, TARGET VEL. OUT  19.639 FPS, ACHIEVED VEL. OUT  19.639 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  16.588 FPS
RET. GRP.  3, TRK. SEC. 27, RET.    .482 FT., VEL. IN  17.308 FPS, TARGET VEL. OUT  16.588 FPS, ACHIEVED VEL. OUT  16.588 FPS
END SIM., CP SECS. =     .113, PTS. ADDED TO TABLE =   102, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. = 12.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  8.337 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.393 FPS, TARGET VEL. OUT =  30.906 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21.393 FPS, TARGET VEL. OUT  30.906 FPS, ACHIEVED VEL. OUT  22.131 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.963 FPS, TARGET VEL. OUT =  19.975 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   3.473 FT., VEL. IN  23.963 FPS, TARGET VEL. OUT  19.975 FPS, ACHIEVED VEL. OUT  19.975 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .027 FT., VEL. IN  19.975 FPS, TARGET VEL. OUT  19.975 FPS, ACHIEVED VEL. OUT  19.975 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  17.335 FPS
RET. GRP.  3, TRK. SEC. 27, RET.    .079 FT., VEL. IN  17.366 FPS, TARGET VEL. OUT  17.335 FPS, ACHIEVED VEL. OUT  17.335 FPS
END SIM., CP SECS. =     .112, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. = 13.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  9.005 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.202 FPS, TARGET VEL. OUT =  31.782 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21.202 FPS, TARGET VEL. OUT  31.782 FPS, ACHIEVED VEL. OUT  21.912 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.624 FPS, TARGET VEL. OUT =  20.318 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   2.970 FT., VEL. IN  23.624 FPS, TARGET VEL. OUT  20.318 FPS, ACHIEVED VEL. OUT  20.318 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .017 FT., VEL. IN  20.318 FPS, TARGET VEL. OUT  20.318 FPS, ACHIEVED VEL. OUT  20.318 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  18.051 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.432 FPS, TARGET VEL. OUT  18.051 FPS, ACHIEVED VEL. OUT  17.500 FPS
END SIM., CP SECS. =     .118, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. = 14.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. =  9.671 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.009 FPS, TARGET VEL. OUT =  32.720 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  21.009 FPS, TARGET VEL. OUT  32.720 FPS, ACHIEVED VEL. OUT  21.690 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  23.280 FPS, TARGET VEL. OUT =  20.668 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   2.457 FT., VEL. IN  23.280 FPS, TARGET VEL. OUT  20.668 FPS, ACHIEVED VEL. OUT  20.668 FPS
RET. GRP.  2, TRK. SEC. 14, RET.    .007 FT., VEL. IN  20.668 FPS, TARGET VEL. OUT  20.668 FPS, ACHIEVED VEL. OUT  20.668 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  18.740 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.516 FPS, TARGET VEL. OUT  18.740 FPS, ACHIEVED VEL. OUT  17.542 FPS
END SIM., CP SECS. =     .115, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 15.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 10.339 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.814 FPS, TARGET VEL. OUT =  33.726 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  20.814 FPS, TARGET VEL  OUT  33,726 FPS, ACHIEVED VEL. OUT  21.465 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.930 FPS, TARGET VEL. OUT =  21.026 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   1.934 FT., VEL. IN  22.930 FPS, TARGET VEL. OUT  21.026 FPS, ACHIEVED VEL. OUT  21.026 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  21.026 FPS, TARGET VEL. OUT  21.026 FPS, ACHIEVED VEL. OUT  21.021 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  19.404 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.612 FPS, TARGET VEL. OUT  19.404 FPS, ACHIEVED VEL. OUT  17.597 FPS
END SIM., CP SECS. =     .118, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 16.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 11.005 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.618 FPS, TARGET VEL. OUT =  34.809 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  20.618 FPS, TARGET VEL. OUT  34.809 FPS, ACHIEVED VEL. OUT  21.238 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.575 FPS, TARGET VEL. OUT =  21.393 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   1.401 FT., VEL. IN  22.575 FPS, TARGET VEL. OUT  21.393 FPS, ACHIEVED VEL. OUT  21.393 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  21.393 FPS, TARGET VEL. OUT  21.393 FPS, ACHIEVED VEL. OUT  21.374 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  20.047 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.711 FPS, TARGET VEL. OUT  20.047 FPS, ACHIEVED VEL. OUT  17.655 FPS
END SIM., CP SECS. =     .117, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 17.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 11.673 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.419 FPS, TARGET VEL. OUT =  35.979 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  20.419 FPS, TARGET VEL. OUT  35.979 FPS, ACHIEVED VEL. OUT  21.009 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  22.215 FPS, TARGET VEL. OUT =  21.771 FPS
RET. GRP.  2, TRK. SEC. 13, RET.    .857 FT., VEL. IN  22.215 FPS, TARGET VEL. OUT  21.771 FPS, ACHIEVED VEL. OUT  21.771 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  21.771 FPS, TARGET VEL. OUT  21.771 FPS, ACHIEVED VEL. OUT  21.737 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  20.669 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.830 FPS, TARGET VEL. OUT  20.669 FPS, ACHIEVED VEL. OUT  17.735 FPS
END SIM., CP SECS. =     .120, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 18.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 12.339 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.219 FPS, TARGET VEL. OUT =  37.249 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  20.219 FPS, TARGET VEL. OUT  37.249 FPS, ACHIEVED VEL. OUT  20.778 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.849 FPS, TARGET VEL. OUT =  22.159 FPS
RET. GRP.  2, TRK. SEC. 13, RET.    .301 FT., VEL  IN  21.849 FPS, TARGET VEL. OUT  22.159 FPS, ACHIEVED VEL. OUT  22.159 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  22.159 FPS, TARGET VEL. OUT  22.159 FPS, ACHIEVED VEL. OUT  22.112 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  21.273 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.969 FPS, TARGET VEL. OUT  21.273 FPS, ACHIEVED VEL. OUT  17.834 FPS
END SIM., CP SECS. =     .125, PTS. ADDED TO TABLE =   101, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 19.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 13.007 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.017 FPS, TARGET VEL. OUT =  38.633 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  20.017 FPS, TARGET VEL. OUT  38.633 FPS, ACHIEVED VEL. OUT  20.543 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.477 FPS, TARGET VEL. OUT =  22.560 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  21.477 FPS, TARGET VEL. OUT  22.560 FPS, ACHIEVED VEL. OUT  22.189 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  22.189 FPS, TARGET VEL. OUT  22.560 FPS, ACHIEVED VEL. OUT  22.128 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  21.861 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  17.609 FPS, TARGET VEL. OUT  21.861 FPS, ACHIEVED VEL. OUT  17.492 FPS
END SIM., CP SECS. =     .117, PTS. ADDED TO TABLE =   102, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 20.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 13.673 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.812 FPS, TARGET VEL. OUT =  40.149 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  19.812 FPS, TARGET VEL. OUT  40.149 FPS, ACHIEVED VEL. OUT  20.306 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  21.097 FPS, TARGET VEL  OUT =  22.975 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  21.097 FPS, TARGET VEL. OUT  22.975 FPS, ACHIEVED VEL. OUT  21.798 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  21.798 FPS, TARGET VEL. OUT  22.975 FPS, ACHIEVED VEL. OUT  21.722 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5 867 FPS, RETARDER LET OUT VEL.  22.433 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  16.821 FPS, TARGET VEL. OUT  22.433 FPS, ACHIEVED VEL. OUT  16.591 FPS
END SIM., CP SECS. =     .125, PTS. ADDED TO TABLE =   104, ENDING CODE =  0, STOP CODE =  2
```

```
PROFYL CALLED WITH BASE ROLL. RES. = 21.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 14.341 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.605 FPS, TARGET VEL. OUT =  41.820 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  19.605 FPS, TARGET VEL. OUT  41.820 FPS, ACHIEVED VEL. OUT  20.066 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.711 FPS, TARGET VEL. OUT =  23.406 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  20.711 FPS, TARGET VEL. OUT  23.406 FPS, ACHIEVED VEL. OUT  21.401 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  21.401 FPS, TARGET VEL. OUT  23.406 FPS, ACHIEVED VEL. OUT  21.309 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  22.991 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  15.929 FPS, TARGET VEL. OUT  22.991 FPS, ACHIEVED VEL. OUT  15.640 FPS
END SIM., CP SECS. =    .129, PTS. ADDED TO TABLE =   105, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 22.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 15.007 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.397 FPS, TARGET VEL. OUT =  43.670 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  19.397 FPS, TARGET VEL. OUT  43.670 FPS, ACHIEVED VEL. OUT  19.824 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  20.318 FPS, TARGET VEL. OUT =  23.854 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  20.318 FPS, TARGET VEL. OUT  23.854 FPS, ACHIEVED VEL. OUT  20.997 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  20.997 FPS, TARGET VEL. OUT  23.854 FPS, ACHIEVED VEL. OUT  20.888 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  23.536 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  14.987 FPS, TARGET VEL. OUT  23.536 FPS, ACHIEVED VEL. OUT  14.630 FPS
END SIM., CP SECS. =    .125, PTS. ADDED TO TABLE =   107, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 23.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 15.675 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.186 FPS, TARGET VEL. OUT =  45.734 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  19.186 FPS, TARGET VEL. OUT  45.734 FPS, ACHIEVED VEL. OUT  19.578 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.916 FPS, TARGET VEL. OUT =  24.323 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  19.916 FPS, TARGET VEL. OUT  24.323 FPS, ACHIEVED VEL. OUT  20.584 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  20.584 FPS, TARGET VEL. OUT  24.323 FPS, ACHIEVED VEL. OUT  20.458 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  24.068 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  13.978 FPS, TARGET VEL. OUT  24.068 FPS, ACHIEVED VEL. OUT  13.543 FPS
END SIM., CP SECS. =    .131, PTS. ADDED TO TABLE =   110, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 24.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 16.341 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.972 FPS, TARGET VEL. OUT =  48.055 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  18.972 FPS, TARGET VEL. OUT  48.055 FPS, ACHIEVED VEL. OUT  19.329 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.507 FPS, TARGET VEL. OUT =  24.815 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  19.507 FPS, TARGET VEL. OUT  24.815 FPS, ACHIEVED VEL. OUT  20.163 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  20.163 FPS, TARGET VEL. OUT  24.815 FPS, ACHIEVED VEL. OUT  20.018 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  24.589 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  12.890 FPS, TARGET VEL. OUT  24.589 FPS, ACHIEVED VEL. OUT  12.358 FPS
END SIM., CP SECS. =    .140, PTS. ADDED TO TABLE =   113, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 25.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 17.009 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.756 FPS, TARGET VEL. OUT =  50.683 FPS
RET. GRP   1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  18.756 FPS, TARGET VEL. OUT  50.683 FPS, ACHIEVED VEL. OUT  19.077 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  19.089 FPS, TARGET VEL. OUT =  25.333 FPS
RET. GRP.  2, TRK. SEC. 13, RET    0.000 FT., VEL. IN  19.089 FPS, TARGET VEL. OUT  25.333 FPS, ACHIEVED VEL. OUT  19.733 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  19.733 FPS, TARGET VEL. OUT  25.333 FPS, ACHIEVED VEL. OUT  19.569 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  25.099 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  11.703 FPS, TARGET VEL. OUT  25.099 FPS, ACHIEVED VEL. OUT  11.050 FPS
END SIM., CP SECS. =    .142, PTS. ADDED TO TABLE =   116, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 26.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 17.675 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.538 FPS, TARGET VEL. OUT =  53.689 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  18.528 FPS, TARGET VEL. OUT  53.638 FPS, ACHIEVED VEL. OUT  18.822 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.661 FPS, TARGET VEL. OUT =  25.883 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  18.661 FPS, TARGET VEL. OUT  25.883 FPS, ACHIEVED VEL. OUT  19.293 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  19.293 FPS, TARGET VEL. OUT  25.833 FPS, ACHIEVED VEL. OUT  19.109 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  25.599 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN  10.376 FPS, TARGET VEL. OUT  25.599 FPS, ACHIEVED VEL. OUT   9.559 FPS
END SIM., CP SECS. =    .147, PTS. ADDED TO TABLE =   120, ENDING CODE =  0, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 27.500 LB/T
 TRACK SECTIONS 13 - 50 ROLL. RES. = 18.342 LB/T
RET. GRP.  1 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.317 FPS, TARGET VEL. OUT =  57.160 FPS
RET. GRP.  1, TRK. SEC.  4, RET.   0.000 FT., VEL. IN  18.317 FPS, TARGET VEL. OUT  57.160 FPS, ACHIEVED VEL. OUT  18.563 FPS
RET. GRP.  2 WABCO TARGET TRAVEL TIME CALCULATIONS - VEL. IN =  18.223 FPS, TARGET VEL. OUT =  26.468 FPS
RET. GRP.  2, TRK. SEC. 13, RET.   0.000 FT., VEL. IN  18.223 FPS, TARGET VEL. OUT  26.468 FPS, ACHIEVED VEL. OUT  18.843 FPS
RET. GRP.  2, TRK. SEC. 14, RET.   0.000 FT., VEL. IN  18.843 FPS, TARGET VEL. OUT  26.468 FPS, ACHIEVED VEL. OUT  18.638 FPS
RET. GRP.  3 DIST. TO CPL. CALCS. - TARGET CPL. VEL.   5.867 FPS, RETARDER LET OUT VEL.  26.089 FPS
RET. GRP.  3, TRK. SEC. 27, RET.   0.000 FT., VEL. IN   8.860 FPS, TARGET VEL. OUT  26.039 FPS, ACHIEVED VEL. OUT   7.795 FPS
END SIM., CP SECS. =    .152, PTS. ADDED TO TABLE =   125, ENDING CODE =  0, STOP CODE =  2

SIMULATION PHASE COMPLETE.  CP SECS. =     4.656


STARTING PAIRWISE COMPARISONS

PAIRWISE COMPARISONS COMPLETE.  CP SECS. =     17.328
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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

LEGEND FOR PAIRWISE COMPARISON CODE MATRICES PRINTED ON THE FOLLOWING PAGES --

 STOP CODES --

  CODE      ----------------EVENTS----------------

    0        CAR COUPLED IN DESIRED SPEED RANGE ( 2.0 TO 6.0 MPH)
    1        CAR STOPPED SHORT OF TANGENT POINT
    2        CAR STALLED IN BOWL TRACK BEFORE COUPLING
    3        CAR COUPLED UNDER  2.0 MPH (UNDERSPEED COUPLING)
    4        CAR COUPLED OVER  6.0 MPH (OVERSPEED COUPLING)
   -1        NOT ANALYZED DUE TO ASSOCIATED ROLLING RESISTANCE PROBABILITY BEING ZERO
```

```
PAIRWISE COMPARISON CODES --

 CODE     -----------EVENTS OCCURRING-----------
          COUPLE   CATCH-UP  CATCH-UP  CORNERING
          BEFORE      IN        AT       AFTER
          TAN.PT.  RETARDER   SWITCH    SWITCH

   0        NO        NO        NO        NO
   1        YES       NO        NO        NO
   2        NO        YES       NO        NO
   3        YES       YES       NO        NO
   4        NO        NO        YES       NO
   5        YES       NO        YES       NO
   6        NO        YES       YES       NO
   7        YES       YES       YES       NO
   8        NO        NO        NO        YES
   9        YES       NO        NO        YES
  10        NO        YES       NO        YES
  11        YES       YES       NO        YES
  12        NO        NO        YES       YES
  13        YES       NO        YES       YES
  14        NO        YES       YES       YES
  15        YES       YES       YES       YES
  -1        NOT ANALYZED DUE TO ONE OR BOTH ASSOCIATED ROLLING RESISTANCE PROBABILITIES BEING ZERO
  -2        NOT ANALYZED DUE TO NO CONSTRAINING POINTS FOUND
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

MATRIX OF PAIRWISE COMPARISON CODES
   LEAD CAR TRACK FULLNESS LEVEL, PCT.          = 50.00
   LEAD CAR ROLL. RES. TRANSF. FAMILY           =  1
   FOL. CAR TRACK FULLNESS LEVEL, PCT.          = 50.00
   FOL. CAR ROLL. RES. TRANSF. FAMILY           =  1

BASE
LB/T >FOL.CAR>  .50   2.50   4.50   6.50   8.50  10.50  12.50  14.50  16.50  18.50  20.50  22.50  24.50  26.50
  V  +-------+--+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+---
LEAD I  STOP
 CAR I  CODE >  4  0  0  0  0  0  0  0  0  0  0  0  0  0  2  2  2  2  2  2  2  2  2  2  2  2  2  2
  V  I   V   +--+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+--
  .50I   4   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 2.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 4.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 6.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 8.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
10.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
12.50I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   0   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
14.50I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
16.50I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
18.50I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
20.50I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
22.50I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I   2   I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
24.50I   2   I  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  0  0  0  0  0  0  0  0
     I   2   I  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  2  2  2  0  0  0  0  0
26.50I   2   I  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  3  3  3  2  2  2  0  0  0
     I   2   I  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  3  3  3  2  2  0
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SUMMARY OF PROBABILITIES OF UNDESIREABLE EVENTS FOR SINGLE CARS (ONLY TRACK SECTIONS WHERE SUCH EVENTS OCCURRED ARE LISTED) --

 PROBABILITIES ASSOCIATED WITH HOW A SINGLE CAR STOPS OR COUPLES IN BOWL --

 TRACK SECTION I.D.              PROB. ON        PROB. WEIGHTED
                                 SIMULATED      TO APPROXIMATE
                                ROUTE ONLY       OVERALL YARD

 TOTAL STALLS BEF. TAN. PT.    0.                0.
 STALLS IN BOWL BEF. CPL.       .94087E-03        .30108E-01
 UNDERSPEED CPL.(< 2.0 MPH)    0.                0.
 OVERSPEED CPL. (> 6.0 MPH)     .10642E-04        .34054E-03

 COUPLING SPEED DISTRIBUTION --

                               ------INCLUDING STALLS------           ----STALLS ADJUSTED OUT-----
 SPEED RANGE MPH                PROB. ON       PROB. WEIGHTED          PROB. ON       PROB. WEIGHTED
                                SIMULATED      TO APPROXIMATE          SIMULATED      TO APPROXIMATE
                               ROUTE ONLY       OVERALL YARD          ROUTE ONLY       OVERALL YARD

     STALLS                     .94087E-03       .30108E-01
  0    TO     1                0.               0.                    0.              0.
  1    TO     2                0.               0.                    0.              0.
  2    TO     3                 .35807E-03       .11458E-01            .36918E-03      .11814E-01
  3    TO     4                 .25254E-01       .80813E+00            .26038E-01      .83322E+00
  4    TO     5                 .44853E-02       .14353E+00            .46245E-02      .14798E+00
  5    TO     6                 .20094E-03       .64302E-02            .20718E-03      .66298E-02
  6    TO     7                 .10642E-04       .34054E-03            .10972E-04      .35111E-03
  7    TO     8                0.               0.                    0.              0.
  8    TO     9                0.               0.                    0.              0.
  9    TO    10                0.               0.                    0.              0.
 10    TO    11                0.               0.                    0.              0.
 11    TO    12                0.               0.                    0.              0.
 12    TO    13                0.               0.                    0.              0.
 13    TO    14                0.               0.                    0.              0.
 14    TO    15                0.               0.                    0.              0.
 15    TO   INF.               0.               0.                    0.              0.
                                ----------       ----------            ----------      ----------
  TOTAL                         .31250E-01       .10000E+01            .31250E-01      .10000E+01
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - SRI HYP. YRD., TRACK 31, PRODUCTION RUN 1: 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SUMMARY OF PROBABILITIES OF UNDESIREABLE EVENTS FOR PAIRS OF CARS (ONLY TRACK SECTIONS WHERE SUCH EVENTS OCCURRED ARE LISTED) --

 PROBABILITIES OF COUPLING BEFORE TANGENT POINT --

 TRACK SECTION I.D.             PROB. ON      PROB. WEIGHTED
                                SIMULATED     TO APPROXIMATE
                               ROUTE ONLY      OVERALL YARD

 SECTION 25                    .60327E-06       .19304E-04
 SECTION 27, RETARDER  4       .11450E-06       .36640E-05
 SECTION 28                    .29600E-06       .94720E-05
 OVERALL                       .10138E-05       .32440E-04

 PROBABILITIES OF CATCH-UP IN RETARDER(S) --

 TRACK SECTION I.D.             PROB. ON      PROB. WEIGHTED
                                SIMULATED     TO APPROXIMATE
                               ROUTE ONLY      OVERALL YARD

 SECTION 27, RETARDER  4       .90883E-06       .29083E-04
 OVERALL                       .90883E-06       .29083E-04

 PROBABILITIES OF HEADWAY PROBLEM AT SWITCH(S) --

 TRACK SECTION I.D.             PROB. ON      PROB. WEIGHTED
                                SIMULATED     TO APPROXIMATE
                               ROUTE ONLY      OVERALL YARD

 OVERALL                       0.              0.

 PROBABILITIES OF A CORNERING COLLISION AFTER CARS ARE SWITCHED APART --

 TRACK SECTION I.D.             PROB. ON      PROB. WEIGHTED
                                SIMULATED     TO APPROXIMATE
                               ROUTE ONLY      OVERALL YARD

 OVERALL                       0.              0.
```

Exhibit 2

SAMPLE SPEEDCON DEMONSTRATION RUN FOR A DOWTY YARD

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SIMULATION CONTROL PARAMETERS FOR THE RUN --

 SIMULATION TIME STEP, DELTA T, SEC.                                      1.000
 INTERVAL OF SIMULATED CAR HISTORY TABLE, SEC.                            1.000
 SIMULATE CARS IN BOWL TRACKS (1. = SIM.)                                 1.
 PERFORM PAIRWISE COMPARISONS (1. = PERFORM)                              1.
 COMPARISON CODE MATRICES OUTPUT SWITCH (1. = PRINT)                      1.
 CAR HISTORY TABLE OUTPUT SWITCH (1. = PRINT)                             0.
 COLLAPSE TRACK FULLNESS DIMENSION (I>0 = COLLAPSE INTO CELL I)           0.

PHYSICAL PARAMETERS FOR THE RUN --

 HUMP SPEED, MPH                                                          2.270
 LENGTH OF SIMULATED CARS, FEET                                          55.000
 WEIGHT OF SIMULATED CARS, TONS                                          60 000
 EXTRA WEIGHT OF CARS DUE TO WHEEL ROTATION, TONS                         2.870
 CRITICAL HEADWAY AT SWITCHES, FEET                                      50.000
 SPEED BELOW WHICH COUPLINGS ARE UNDERSPEED, MPH                          2.000
 SPEED ABOVE WHICH COUPLINGS ARE OVERSPEED, MPH                           6.000
 CONTINUOUS CONTROL UNIT LENGTH, FEET                                      .750
 TRUCK WHEELBASE, FEET                                                    5.500
 CENTER TO CENTER TRUCK SPACING, FEET                                    45.000
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR CLASS TRACK PERCENT FULLNESS --

   RANGE    FREQ.
   (PCT.)    IN
            1000
----------- ----

                 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   0.- 100. 1000 +*************************************************************************************************************
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR BASE ROLLING RESISTANCE       --

   RANGE    FREQ.
   (LB/T)    IN
            1000
----------- ----

                 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
   0.-   1.    1 +*
   1.-   2.    6 +****
   2.-   3.   31 +********************
   3.-   4.   82 +***************************************************
   4.-   5.  144 +*****************************************************************************************
   5.-   6.  177 +*************************************************************************************************************
   6.-   7.  165 +******************************************************************************************************
   7.-   8.  127 +*******************************************************************************
   8.-   9.   88 +*******************************************************
   9.-  10.   58 +************************************
  10.-  11.   38 +************************
  11.-  12.   25 +****************
  12.-  13.   17 +***********
  13 -  14.   11 +*******
  14.-  15.    8 +*****
  15.-  16.    6 +****
  16.-  17.    4 +***
  17.-  18.    3 +**
  18.-  19.    2 +*
  19 -  20.    2 +*
  20.-  21.    1 +*
  21.-  22.    1 +*
  22 -  23.    1 +*
  23.-  24.    1 +*
  24.-  25.    1 +*
  25.-  26.    1 +*
  26.-  27.    1 +*
  27.-  28.    1 +*

NOTE -- SOME CELLS ABOVE HAVE BEEN ROUNDED TO 1 RATHER THAN 0 TO MAKE THEM APPARENT
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

HISTOGRAM OF DISTRIBUTION INPUT FOR ROLL. RES. TRANSFORMATIONS    --

  TRANSF.   FREQ.
  FAMILY     IN
    NO.     1000
----------- ----

                 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
       1.   1000 +*************************************************************************************************************
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

ROLLING RESISTANCE LINEAR TRANSFORMATIONS FROM BASE ROLLING RESISTANCE (TRANSFORMATION FAMILY  1) --

          SECTIONS                       TRANSFORMATION
          --------     ---------------------------------------------------------

          11 - 50      ROLL. RES.(TRANSF.) =  .6670 * ROLL. RES.(BASE) + 0.0000

          NOTE -- ANY TRACK SECTIONS FOR WHICH A TRANSFORMATION IS NOT SPECIFIED WILL USE THE BASE ROLLING RESISTANCE VALUES.
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

 TRACK     LENGTH    CUM.     PERCENT   HORIZ.   SWITCH     DIST.      MAX.    NUMBER    SPEED     PROB.        DESCRIPTION
SECTION    (FEET)   LENGTH     GRADE    CURVE     LOSS     END SW.    RETAR-     OF     SETTING    CAR
NUMBER              (FEET)              RESIS.   (FT OF   TO CLEAR    DATION   CONTIN.  CONTIN.    USES
                                        (LB/T)    HEAD)     POINT     (FT OF   CONTROL  CONTROL   TRACK
                                                           (FEET)     HEAD)     UNITS    UNITS   SECTION
                                                                                         (MPH)

   1        53.5      0.0      2.64     -0.00     -0.00     -0.0      -0.00      -0.     -0.00   1.0000 CREST AREA
   2        53.8     53.5      3.57     -0.00     -0.00     -0.0      -0.00      66.      7.83   1.0000
   3       115.1    107.3      1.10     -0.00     -0.00     -0.0      -0.00     140.      7.83   1.0000
   4         1.0    222.4      1.10      4.28       .06    126.0      -0.00      -0.     -0.00    .5000 SWITCH 1
   5        74.3    223.4      1.10      4.28     -0.00     -0.0      -0.00      59.      7.83    .5000 DELTA 3D 34' 35" - 1
   6        75.3    297.7      1.10      4.28     -0.00     -0.0      -0.00      53.      7.83    .5000 DELTA 3D 34' 35" - 2
   7         1.0    373.0      1.10      6.59       .06    110.0      -0.00      -0.     -0.00    .1250 SWITCH 2
   8        23.0    374.0      1.10      6.59     -0.00     -0.0      -0.00      -0.     -0.00    .1250 DELTA 7D 09' 10" - 1
   9        73.7    397.0      1.10      6.59     -0.00     -0.0      -0.00      54.      7.83    .1250 DELTA 7D 09' 10" - 2
  10        46.9    470.7      1.10     15.92     -0.00     -0.0      -0.00      30.      7.83    .1250 DELTA 16D 36' 10": BEF.RR.CHG.
  11        46.9    517.6      1.10     15.92     -0.00     -0.0      -0.00      30.      7.83    .1250 DELTA 16D 36' 10": AFT.RR.CHG.
  12        68.2    564.5      1.10     -0.00     -0.00     -0.0      -0.00      53.      7.83    .1250
  13       162.7    632.8      1.10     11.16     -0.00     -0.0      -0.00      99.      7.83    .1250 DELTA 20D 10' 46"
  14        30.3    795.5      1.10     -0.00     -0.00     -0.0      -0.00      23.      7.83    .1250
  15         1.0    825.8      1.10     -0.00       .06    116.0      -0.00      -0.     -0.00    .0625 SWITCH 3
  16        23.0    826.8      1.10     -0.00     -0.00     -0.0      -0.00      -0.     -0.00    .0625
  17        73.8    849.8      1.10     -0.00     -0.00     -0.0      -0.00      59.      7.83    .0625
  18        15.0    923.6      1.10     -0.00     -0.00     -0.0      -0.00      18.      7.83    .0625
  19         1.0    938.6      1.10     -0.00       .06    126.0      -0.00      -0.     -0.00    .0313 SWITCH 4
  20        23.0    939.6      1.10     -0.00     -0.00     -0.0      -0.00      -0.     -0.00    .0313
  21        74.3    962.6      1.10     -0.00     -0.00     -0.0      -0.00      59.      7.83    .0313
  22        82.0   1036.9      1.10     11.78     -0.00     -0.0      -0.00      68.      7.83    .0313 DELTA 10D 43' 45" TO TAN. PT.
  23        77.2   1118.9       .30     -0.00     -0.00     -0.0      -0.00      95.      5.59    .0313 DECEL. ZONE - 1
  24        65.8   1196.0       .30     -0.00     -0.00     -0.0      -0.00      81.      3.35    .0313 DECEL.ZONE-2 TO START CAR STOR
  25      -507.0   1261.9       .30     -0.00     -0.00     -0.0      -0.00     130.      3.35    .0313 START CAR STORAGE TO END DOWTY
  26     -1081.0   1768.9       .10     -0.00     -0.00     -0.0      -0.00      -0.     -0.00    .0313 BOWL
  27      -500.0   2849.9      -.50     -0.00     -0.00     -0.0      -0.00      -0.     -0.00    .0313 UPGRADE
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

RETARDER LOGIC INPUT PARAMETERS FOR WABCO TARGET TRAVEL TIME ALGORITHM -

NO RETARDER SECTIONS SPECIFIED


INPUT/INITIALIZATION COMPLETE.  CP SECS. =      3.529
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SIMULATION LOG FOR PERCENT FULLNESS OF CLASS TRACKS = 50.00    (1044.00 FEET FROM TANGENT POINT TO COUPLING POINT)
ROLLING RESISTANCE TRANSFORMATION FAMILY  1


PROFYL CALLED WITH BASE ROLL. RES. =   .500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =   .334 LB/T
END SIM., CP SECS. =     2.541, PTS. ADDED TO TABLE =   270, ENDING CODE =  0, STOP CODE =  4

PROFYL CALLED WITH BASE ROLL. RES. =  1.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  1.001 LB/T
END SIM., CP SECS. =     2.533, PTS. ADDED TO TABLE =   276, ENDING CODE =  0, STOP CODE =  4

PROFYL CALLED WITH BASE ROLL. RES. =  2.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  1.668 LB/T
END SIM., CP SECS. =     2.540, PTS. ADDED TO TABLE =   283, ENDING CODE =  0  STOP CODE =  4

PROFYL CALLED WITH BASE ROLL. RES. =  3.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  2.335 LB/T
END SIM., CP SECS. =     2.617, PTS. ADDED TO TABLE =   292, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  4.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  3.002 LB/T
END SIM , CP SECS. =     2.546, PTS. ADDED TO TABLE =   304, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  5.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  3.669 LB/T
END SIM., CP SECS. =     2.566, PTS. ADDED TO TABLE =   321, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  6.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  4.335 LB/T
END SIM., CP SECS. =     2.570, PTS. ADDED TO TABLE =   350, ENDING CODE =  0, STOP CODE =  0

PROFYL CALLED WITH BASE ROLL. RES. =  7.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  5.002 LB/T
CAR  1 STOPPED ON TRACK AT TIME  359.51 SEC.
VEL =   -.00 MPH, DIST = 2162.50 FT, TIME ON TRACK =   359.51 SEC.
END SIM., CP SECS. =     2.592, PTS. ADDED TO TABLE =   386, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. =  8.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  5.669 LB/T
CAR  1 STOPPED ON TRACK AT TIME  330.38 SEC.
VEL =    .00 MPH, DIST = 1987.13 FT, TIME ON TRACK =   330.38 SEC.
END SIM., CP SECS. =     2.566, PTS. ADDED TO TABLE =   357, ENDING CODE =  1, STOP CODE =  2
```

```
PROFYL CALLED WITH BASE ROLL. RES. =  9.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  6.337 LB/T
CAR  1 STOPPED ON TRACK AT TIME  319.94 SEC.
VEL =     .00 MPH, DIST = 1862.70 FT, TIME ON TRACK =  319.94 SEC.
END SIM., CP SECS. =   2.580, PTS. ADDED TO TABLE =  346, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 10.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  7.004 LB/T
CAR  1 STOPPED ON TRACK AT TIME  391.01 SEC.
VEL =   -.00 MPH, DIST = 1752.02 FT, TIME ON TRACK =  391.01 SEC.
END SIM., CP SECS. =   2.605, PTS. ADDED TO TABLE =  417, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 11.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  7.671 LB/T
CAR  1 STOPPED ON TRACK AT TIME  275.03 SEC.
VEL =     .00 MPH, DIST = 1486.08 FT, TIME ON TRACK =  275.03 SEC.
END SIM., CP SECS. =   2.580, PTS. ADDED TO TABLE =  301, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 12.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  8.337 LB/T
CAR  1 STOPPED ON TRACK AT TIME  224.93 SEC.
VEL =   -.00 MPH, DIST = 1371.47 FT, TIME ON TRACK =  224.93 SEC.
END SIM., CP SECS. =   2.547, PTS. ADDED TO TABLE =  250, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 13.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  9.005 LB/T
CAR  1 STOPPED ON TRACK AT TIME  195.14 SEC.
VEL =   -.00 MPH, DIST = 1302.47 FT, TIME ON TRACK =  195.14 SEC.
END SIM., CP SECS. =   2.561, PTS. ADDED TO TABLE =  221, ENDING CODE =  1, STOP CODE =  2

PROFYL CALLED WITH BASE ROLL. RES. = 14.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. =  9.671 LB/T
CAR  1 STOPPED ON TRACK AT TIME  177.33 SEC.
VEL =   -.00 MPH, DIST = 1261.70 FT, TIME ON TRACK =  177.33 SEC.
END SIM., CP SECS. =   2.496, PTS. ADDED TO TABLE =  202, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 15.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 10.339 LB/T
CAR  1 STOPPED ON TRACK AT TIME  170.97 SEC.
VEL =   -.00 MPH, DIST = 1237.14 FT, TIME ON TRACK =  170.97 SEC.
END SIM., CP SECS. =   2.423, PTS. ADDED TO TABLE =  195, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 16.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 11.005 LB/T
CAR  1 STOPPED ON TRACK AT TIME  171.00 SEC.
VEL =   -.00 MPH, DIST = 1213.43 FT, TIME ON TRACK =  171.00 SEC.
END SIM., CP SECS. =   2.373, PTS. ADDED TO TABLE =  195, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 17.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 11.673 LB/T
CAR  1 STOPPED ON TRACK AT TIME  172.98 SEC.
VEL =     .00 MPH, DIST = 1190.02 FT, TIME ON TRACK =  172.98 SEC.
END SIM., CP SECS. =   2.325, PTS. ADDED TO TABLE =  196, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 18.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 12.339 LB/T
CAR  1 STOPPED ON TRACK AT TIME  178.17 SEC.
VEL =     .00 MPH, DIST = 1178.34 FT, TIME ON TRACK =  178.17 SEC.
END SIM., CP SECS. =   2.344, PTS. ADDED TO TABLE =  202, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 19.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 13.007 LB/T
CAR  1 STOPPED ON TRACK AT TIME  180.86 SEC.
VEL =     .00 MPH, DIST = 1167.82 FT, TIME ON TRACK =  180.86 SEC.
END SIM., CP SECS. =   2.279, PTS. ADDED TO TABLE =  204, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 20.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 13.673 LB/T
CAR  1 STOPPED ON TRACK AT TIME  186.65 SEC
VEL =   -.00 MPH, DIST = 1158.44 FT, TIME ON TRACK =  186.65 SEC.
END SIM., CP SECS. =   2.268, PTS. ADDED TO TABLE =  210, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 21.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 14.341 LB/T
CAR  1 STOPPED ON TRACK AT TIME  193.49 SEC.
VEL =   -.00 MPH, DIST = 1150.57 FT, TIME ON TRACK =  193.49 SEC.
END SIM., CP SECS. =   2.308, PTS. ADDED TO TABLE =  217, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 22.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 15.007 LB/T
CAR  1 STOPPED ON TRACK AT TIME  210.06 SEC.
VEL =   -.00 MPH, DIST = 1143.51 FT, TIME ON TRACK =  210.06 SEC.
END SIM., CP SECS. =   2.224, PTS. ADDED TO TABLE =  234, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 23.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 15.675 LB/T
CAR  1 STOPPED ON TRACK AT TIME  143.02 SEC.
VEL =   -.00 MPH, DIST =  743.72 FT, TIME ON TRACK =  143.02 SEC.
END SIM., CP SECS. =   1.424, PTS. ADDED TO TABLE =  157, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 24.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 16.341 LB/T
CAR  1 STOPPED ON TRACK AT TIME   84.67 SEC.
VEL =     .00 MPH, DIST =  551.46 FT, TIME ON TRACK =   84.67 SEC.
END SIM., CP SECS. =   1.072, PTS. ADDED TO TABLE =   96, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 25.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 17.009 LB/T
CAR  1 STOPPED ON TRACK AT TIME   74.56 SEC.
VEL =   -.00 MPH, DIST =  511.97 FT, TIME ON TRACK =   74.56 SEC.
END SIM., CP SECS. =    .973, PTS. ADDED TO TABLE =   85, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 26.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 17.675 LB/T
CAR  1 STOPPED ON TRACK AT TIME   73.77 SEC.
VEL =   -.00 MPH, DIST =  488.22 FT, TIME ON TRACK =   73.77 SEC.
END SIM., CP SECS. =    .931, PTS. ADDED TO TABLE =   84, ENDING CODE =  1, STOP CODE =  1

PROFYL CALLED WITH BASE ROLL. RES. = 27.500 LB/T
 TRACK SECTIONS 11 - 50 ROLL. RES. = 18.342 LB/T
CAR  1 STOPPED ON TRACK AT TIME   76.59 SEC.
VEL =   -.00 MPH, DIST =  465.44 FT, TIME ON TRACK =   76.59 SEC.
END SIM., CP SECS. =    .880, PTS. ADDED TO TABLE =   86, ENDING CODE =  1, STOP CODE =  1

SIMULATION PHASE COMPLETE.  CP SECS. =     63.435
```

```
STARTING PAIRWISE COMPARISONS

PAIRWISE COMPARISONS COMPLETE.  CP SECS. =     13.027
```

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SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

LEGEND FOR PAIRWISE COMPARISON CODE MATRICES PRINTED ON THE FOLLOWING PAGES --

 STOP CODES --

  CODE     ----------------EVENTS----------------

    0        CAR COUPLED IN DESIRED SPEED RANGE ( 2.0 TO 6.0 MPH)
    1        CAR STOPPED SHORT OF TANGENT POINT
    2        CAR STALLED IN BOWL TRACK BEFORE COUPLING
    3        CAR COUPLED UNDER  2.0 MPH (UNDERSPEED COUPLING)
    4        CAR COUPLED OVER  6.0 MPH (OVERSPEED COUPLING)
   -1        NOT ANALYZED DUE TO ASSOCIATED ROLLING RESISTANCE PROBABILITY BEING ZERO

 PAIRWISE COMPARISON CODES --

  CODE     -----------EVENTS OCCURRING-----------
          COUPLE   CATCH-UP  CATCH-UP   CORNERING
          BEFORE      IN        AT        AFTER
          TAN PT.  RETARDER   SWITCH     SWITCH

    0        NO         NO         NO         NO
    1        YES        NO         NO         NO
    2        NO         YES        NO         NO
    3        YES        YES        NO         NO
    4        NO         NO         YES        NO
    5        YES        NO         YES        NO
    6        NO         YES        YES        NO
    7        YES        YES        YES        NO
    8        NO         NO         NO         YES
    9        YES        NO         NO         YES
   10        NO         YES        NO         YES
   11        YES        YES        NO         YES
   12        NO         NO         YES        YES
   13        YES        NO         YES        YES
   14        NO         YES        YES        YES
   15        YES        YES        YES        YES
   -1        NOT ANALYZED DUE TO ONE OR BOTH ASSOCIATED ROLLING RESISTANCE PROBABILITIES BEING ZERO
   -2        NOT ANALYZED DUE TO NO CONSTRAINING POINTS FOUND
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

MATRIX OF PAIRWISE COMPARISON CODES
   LEAD CAR TRACK FULLNESS LEVEL, PCT.             = 50.00
   LEAD CAR ROLL. RES. TRANSF. FAMILY              =  1
   FOL. CAR TRACK FULLNESS LEVEL, PCT.             = 50.00
   FOL. CAR ROLL. RES. TRANSF. FAMILY              =  1

BASE
LB/T >FOL.CAR>   .50   2.50   4.50   6.50   8.50  10.50  12.50  14.50  16.50  18.50  20.50  22.50  24.50  26.50
  V  +-------+--+------+------+------+------+------+------+------+------+------+------+------+------+---
LEAD I  STOP
 CAR I  CODE >  4  4  4  0  0  0  0  2  2  2  2  2  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  V  I   V    +--+------+------+------+------+------+------+------+------+------+------+------+------+---
  .50I    4  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    4  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 2 50I    4  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    0  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 4.50I    0  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    0  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 6.50I    0  I  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    2  I  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 8.50I    2  I  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    2  I  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
10.50I    2  I  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    2  I  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
12.50I    2  I  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
     I    2  I  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0
14.50I    1  I  9  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0
     I    1  I  5  5  5  5  5  5  9  9  9  9  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0
16.50I    1  I  5  5  5  5 13 13  5  5  5  5  5  5  5  5  5  5  1  1  1  1  1  0  0  0  0  0  0  0
     I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  1  1  1  1  1  1  0  0  0  0  0
18.50I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  1  1  1  1  0  0  0  0  0
     I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  1  1  1  0  0  0  0  0
20.50I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  1  1  0  0  0  0  0
     I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  1  0  0  0  0  0
22.50I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  0  0  0  0  0
     I    1  I  9  9  9  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0
24.50I    1  I  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  1  1  1  1  1  1  1  0  0
     I    1  I  5  5  5  5  5  5  5  5  5  5  5  9  9  9  9  9  9  9  9  9  9  9  9  9  9  9  1  1
26.50I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  9  9  9  9  9  9
     I    1  I  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  9
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SUMMARY OF PROBABILITIES OF UNDESIREABLE EVENTS FOR SINGLE CARS (ONLY TRACK SECTIONS WHERE SUCH EVENTS OCCURRED ARE LISTED) --

 PROBABILITIES ASSOCIATED WITH HOW A SINGLE CAR STOPS OR COUPLES IN BOWL --

 TRACK SECTION I.D.                PROB. ON     PROB. WEIGHTED
                                   SIMULATED    TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD

 STOPS IN SECTION   9              .35056E-04     .28045E-03
 STOPS IN SECTION  10              .95151E-04     .76121E-03
 STOPS IN SECTION  11              .63852E-04     .51081E-03
 STOPS IN SECTION  13              .80127E-04     .64102E-03
 STOPS IN SECTION  23              .31707E-03     .10146E-01
 STOPS IN SECTION  24              .55526E-03     .17768E-01

 TOTAL STALLS BEF. TAN. PT.        .11465E-02     .30108E-01
 STALLS IN BOWL BEF. CPL.          .11387E-01     .36439E+00
 UNDERSPEED CPL.(< 2.0 MPH)       0.             0.
 OVERSPEED CPL. (> 6.0 MPH)        .11822E-02     .37830E-01

 COUPLING SPEED DISTRIBUTION --

                                  ------INCLUDING STALLS------           ----STALLS ADJUSTED OUT-----
 SPEED RANGE MPH                   PROB. ON     PROB. WEIGHTED            PROB. ON      PROB. WEIGHTED
                                   SIMULATED    TO APPROXIMATE            SIMULATED     TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD            ROUTE ONLY      OVERALL YARD

     STALLS                        .12534E-01     .39450E+00
   0   TO     1                   0.             0.                      0.             0.
   1   TO     2                   0.             0.                      0.             0.
   2   TO     3                    .51557E-02     .16498E+00              .85147E-02     .27247E+00
   3   TO     4                    .55316E-02     .17701E+00              .91356E-02     .29234E+00
   4   TO     5                    .44853E-02     .14353E+00              .74075E-02     .23704E+00
   5   TO     6                    .25672E-02     .82151E-01              .42398E-02     .13567E+00
   6   TO     7                    .97061E-03     .31059E-01              .16030E-02     .51295E-01
   7   TO     8                    .21159E-03     .67708E-02              .34944E-03     .11182E-01
   8   TO     9                   0.             0.                      0.             0.
   9   TO    10                   0.             0.                      0.             0.
  10   TO    11                   0.             0.                      0.             0.
  11   TO    12                   0.             0.                      0.             0.
  12   TO    13                   0.             0.                      0.             0.
  13   TO    14                   0.             0.                      0.             0.
  14   TO    15                   0.             0.                      0.             0.
  15   TO   INF.                  0.             0.                      0.             0.
                                   ----------     ----------              ----------     ----------
   TOTAL                           .31456E-01     .10000E+01              .31250E-01     .10000E+01
```

```
SRI RAILYARD SPEED CONTROL EVALUATION PROGRAM - DOWTY-SRI HYP. YRD., OUTER TRK., PROD. RUN 1, 28 RESISTANCES, 1 FULLNESS, 1 FAM.

SUMMARY OF PROBABILITIES OF UNDESIREABLE EVENTS FOR PAIRS OF CARS (ONLY TRACK SECTIONS WHERE SUCH EVENTS OCCURRED ARE LISTED) --

 PROBABILITIES OF COUPLING BEFORE TANGENT POINT --

 TRACK SECTION I.D.                PROB. ON     PROB. WEIGHTED
                                   SIMULATED    TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD

 SECTION  6                        .42453E-04     .84905E-04
 SECTION  9                        .13541E-04     .10833E-03
 SECTION 10                        .17201E-04     .13760E-03
 SECTION 11                        .13363E-04     .10690E-03
 SECTION 12                        .16018E-04     .12815E-03
 SECTION 13                        .46493E-04     .37194E-03
 SECTION 14                        .34930E-04     .27944E-03
 SECTION 17                        .11676E-04     .18682E-03
 SECTION 18                        .19246E-05     .30794E-04
 SECTION 21                        .34440E-05     .11021E-03
 SECTION 22                        .88050E-05     .28176E-03
 SECTION 23                        .51388E-04     .16444E-02
 SECTION 24                        .72324E-04     .23144E-02
 OVERALL                           .33356E-03     .57856E-02

 PROBABILITIES OF CATCH-UP IN RETARDER(S) --

 TRACK SECTION I.D.                PROB. ON     PROB  WEIGHTED
                                   SIMULATED    TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD

 OVERALL                          0.             0.

 PROBABILITIES OF HEADWAY PROBLEM AT SWITCH(S) --

 TRACK SECTION I.D.                PROB. ON     PROB. WEIGHTED
                                   SIMULATED    TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD

 SECTION  7, SWITCH     2          .94263E-04     .18853E-03
 SECTION 15, SWITCH     3          .82389E-04     .65911E-03
 SECTION 19, SWITCH     4          .32450E-04     .51920E-03
 OVERALL                           .20910E-03     .13668E-02

 PROBABILITIES OF A CORNERING COLLISION AFTER CARS ARE SWITCHED APART --

 TRACK SECTION I.D.                PROB. ON     PROB. WEIGHTED
                                   SIMULATED    TO APPROXIMATE
                                  ROUTE ONLY     OVERALL YARD

 CLEAR PT.,   SWITCH    2          .53192E-04     .10638E-03
 CLEAR PT.,   SWITCH    3          .10284E-04     .82269E-04
 CLEAR PT.,   SWITCH    4          .48644E-05     .77830E-04
 OVERALL                           .68340E-04     .26648E-03
```

D.3.3 SPEEDCON Input

This section describes the exact nature of the input data required to run the SPEEDCON program. Specifications are given regarding the nature of every input parameter, and each parameter's specific location within each field on every input card (or line). Nearly every field in SPEEDCON is 10 columns (i.e., characters) wide; this facilitates input preparation considerably.

The specific input parameters and formats required to run SPEEDCON are enumerated in Table D-4. Since this table is quite detailed and self-explanatory, only a few comments will be made here. The input to SPEEDCON can be thought of as consisting of 4 parts:

- General simulation parameters (card types 1 through 3).
- Distributions of car characteristic random variables* (card types 4 through 9).
- Track section geometry (card type 10).
- Retarder logic parameters (card type 11).

The retarder logic-modules, and therefore their input, can be replaced by user-supplied routines, if necessary. Table D-4 shows two alternate inputs for the two logics currently available in SPEEDCON. Both modules--WABCO Target Travel Time (Section D.2.1.2.1) and Magic X (Section D.2.1.2.2)--share the same distance to couple target shooting logic (Section D.2.1.2.3). The appropriate module--WABCO Target Travel Time and Magic X--is selected by including its source with the SPEEDCON source to be compiled, or by linking it at the load time of the binary object decks.

D.4 APPLICATION OF SPEEDCON TO A COMPARISON OF A CONVENTIONAL YARD VERSUS A DOWTY YARD

D.4.1 Introduction

In this section SPEEDCON is applied to the performance comparison of a conventional yard versus a Dowty yard. The yard designs used in this comparison are hypothetical. The conventional yard was designed by SRI, the Dowty yard by Dowty using SRI-provided specifications (see Section 5). The conventional yard was a tangent point retarder design. The master and group retarders were assumed to be controlled by the WABCO Target Travel Time Algorithm (Section D.2.1.2.1), the tangent point retarders by a target shooting logic (Section D.2.1.2.3). The comparison of the two yards was made on the basis of event probabilities weighted to reflect the entire yard.

The entire set of runs was replicated twice. The first uses an extreme hard rolling car of 28 lb/ton† base rolling resistance and may be considered a conservative rolling resistance assumption; the second set uses an extreme hard rolling car of 19 lb/ton base rolling resistance and may be considered an optimistic rolling resistance assumption (see Appendix F).

D.4.2 Input Data and Assumptions

The basic physical and simulation parameters used in the runs are identical for the two yards; these are shown in the first pages of both Exhibits 1 and 2 in Section D.3.2. It will be noted that the program logic switch to simulate cars in the bowl tracks is "off" for the conventional yard, but "on" for the Dowty yard. This is because the car's bowl track behavior is easily calculated for the conventional yard without recourse to detailed simulation,‡ while the simulation must be extended into the bowl tracks to calculate the Dowty yard car behavior.

The hump speed, car weight, car length, car wheelbase, and truck wheelbase are typical values and conform to the specifications used to design the hypothetical yard. The critical headway of 50 ft at switches, the smallest coupler-to-coupler headway for which two consecutive cars may be switched apart, is also a typical value, commonly used in design analysis with the PROFILE model. The 0.75 ft length of a continuous control unit (here meaning a Dowty unit) was taken not as the actual physical size of the unit, but as the distance a car moves while in contact with the unit.

In deciding on the specification of the distributions of the three car-related random variables, the tradeoff between cost and accuracy had to be kept in mind. In Section D.2.2.3 it was explained that the computer costs of SPEEDCON run are dominated by a term which is proportional to the square of the product of the number of cells used in each of the histograms that approximate these distributions. It was finally decided to use three classification track fullness levels, 19 base rolling resistance levels, and three base rolling resistance transformation families. These decisions will be discussed in more detail below.

In a further economy, the pairwise comparisons were made with only one classification track fullness level, reducing the cost of this phase by a factor of 9. In a deterministic sense, this simplification causes no problem. With the distance to couple target shooting logic used in SPEEDCON (Section D.2.1.2.3), for the conventional yard all the sensitivity to track fullness level occurs only after the tangent point retarders--which is beyond the point where the pairwise comparisons are performed.§ The hypothetical pure Dowty yard has no sensitivity to the track fullness level in the switching area--the area where the pairwise comparisons are performed.

As mentioned above, three fullness levels, each assumed to have an equal probability (i.e., 1/3) of occurrence, were used to assess probabilities associated with single car events. While three fullness levels can certainly be considered a coarse representation of a continuous random variable, in light of the modeling assumptions and approximations and of the accuracy of available data used in this and other portions of the speed control study, this representation is felt to be quite adequate. The equal probability assumption is also felt to be reasonable considering the empirical data SRI has obtained as a part of a different project from Union Pacific's Hinkle Yard.

Nineteen base rolling resistance levels were used in all runs. As mentioned above, two base rolling resistance distributions were used in two sets of runs (see Appendix F). The first distribution had

---

*Including the specification of the transformations of the base rolling resistances.

†Actually 28.5 lb/ton.

‡The trajectory table, needed only for the pairwise comparisons, must extend only as far as the tangent point, the end of the pairwise comparisons.

§Note that when the target shooting is performed by a group retarder, the varying track fullness levels of adjacent classification tracks can have a significant impact on the pairwise performance.

TABLE D-4.-SPEEDCON INPUT FORMATS

End-of-Group cards are used as separators and terminators at several points in the program and for convenience are designated as Card Type 0 (i.e., zero). For simplicity, their format is defined once immediately below; however, they are used only where explicitly called for in the card type definitions starting with Card Type 1.

Card Type 0--End of Group Card

Columns	Variable	Type	Description
6-10	--	I	The numbers "99999" in columns 6 to 10 inclusive.

Card types 1 through 3, as a group, supply general parameters to the model.

Card Type 1--Title Card

Columns	Variable	Type	Description
1-80	TITLE	A	Any title information for the run.

Card Type 2--Simulation Control Parameters

Columns	Variable	Type	Description
1-10	XDELT	F	Simulation time step, Δt, seconds.
11-20	TABINT	F	Time interval of data in stored trajectory table, sec.
21-30	RUNBWL	F	Switch determining whether to simulate bowl tracks (0. = Do not simulate, 1. = Simulate).
31-40	PFPAIR	F	Switch determining whether to perform the pairwise comparisons portion of the analysis (0. = Do not perform, 1. = Perform).
41-50	PRCMAT	F	Switch determining printing of pairwise comparison code matrices (0. = Do not print, 1. = Print).
51-60	PRTABL	F	Switch determining printing of car history (trajectory) tables with interval TABINT (0. = Do not print, 1. = Print),
61-70	COLLFL	F	Switch to collapse all track fullness levels into one cell for pairwise comparisons (0. = Do not collapse, I > 0 = Collapse into cell I).

Card Type 3--Simulation Physical Parameters

Columns	Variable	Type	Description
1-10	HUMPV	F	Velocity of hump, miles per hour.
11-20	CARLEN	F	Length of simulated cars, feet.
21-30	WTTONS	F	Weight of simulated cars, tons.
31-40	EXTRAW	F	Equivalent rotational weight of all the wheels, tons.
41-50	HCRIT	F	Critical headway determining misswitching at switches, feet.
51-60	VCPLL0	F	Speed below which couplings are considered underspeed, miles per hour.
61-70	VCPLHI	F	Speed above which couplings are considered overspeed, miles per hour.
71-80	CCULEN	F	Effective length of each individual continuous control unit (if C.C.U.'s are present), feet.

Table D-4 (Continued)

Card Type 3--Continuation Card

Columns	Variable	Type	Description
1-10	WBT	F	Truck wheelbase (required only if C.C.U.'s are present), feet.
11-20	TSP	F	Center to center truck spacing (required only if C.C.U.'s are present), feet.

Note: Card Type 3 continuation card must be followed by an End-of-Group card (i.e., Card Type 0 card).

Card types 4 and 5, as a group, describe the track fullness level distribution to the model.

Card Type 4--Track Fullness Distribution Datum

Columns	Variable	Type	Description
1-10	STARTD	F	Starting value for left edge of track fullness level histogram, in percent fullness.
11-20	STEPD	F	Step size for track fullness level histogram cells, in percent fullness.

Card Type 5--Track Fullness Distribution Relative Frequencies

Columns	Variable	Type	Description
1-10	PROBD(1)	F	Relative frequency or probability in cell 1 of the histogram.
11-20	PROBD(2)	F	As above, cell 2.
21-30	PROBD(3)	F	As above, cell 3.
31-40	PROBD(4)	F	As above, cell 4.
41-50	PROBD(5)	F	As above, cell 5.

Note: An additional Card Type 5 continuation card may be used to specify cells 6 through 10, up to a maximum of 10 cells. If it is not necessary to fill a Card Type 5 through field 41-50, the unneeded fields should be left blank. An End-of-Group (Card Type 0 card) must follow the one or two Card Type 5 cards.

Card types 6 and 7, as a group, describe the base rolling resistance distribution to the model.

Card Type 6--Base Rolling Resistance Distribution Datum

Columns	Variable	Type	Description
1-10	STARTR	F	Starting value for left edge of base rolling resistance histogram, lbs. per ton.
11-20	STEPR	F	Step size for base rolling resistance histogram cells, lbs. per ton.

Card Type 7--Base Rolling Resistance Distribution Relative Frequencies

Columns	Variable	Type	Description
1-10	PROBR(1)	F	Relative frequency or probability in cell 1 of the histogram.
11-20	PROBR(2)	F	As above, cell 2.
21-30	PROBR(3)	F	As above, cell 3.
31-40	PROBR(4)	F	As above, cell 4.
41-50	PROBR(5)	F	As above, cell 5.

Table D-4 (Continued)

Card Type 7 (Continued)

Note: Additional Card Type 7 continuation cards may be used to specify cells 6 through 10, 11 through 15, etc. up to a maximum of 40 cells. If it is not necessary to fill a Card Type 7 through field 41-50, the unneeded fields should be left blank. An End-of-Group (Card Type 0 card) must follow the last Card Type 7 card.

Card type 8 describes the number and frequency of occurrence of the transformation families to the model (a distribution datum card is not required, since the numbering of the families is arbitrary, and so is assumed to start at 1).

Card Type 8--Rolling Resistance Transformation Families Relative Frequencies

Columns	Variable	Type	Description
1-10	PROBT(1)	F	Relative frequency or probability in cell 1 of the histogram.
11-20	PROBT(2)	F	As above, cell 2.
21-30	PROBT(3)	F	As above, cell 3.
31-40	PROBT(4)	F	As above, cell 4.
41-50	PROBT(5)	F	As above, cell 5.

Note: An additional Card Type 8 continuation card may be used to specify cells 6 through 10, up to a maximum of 10 cells. If it is not necessary to fill a Card Type 8 through field 41-50, the unneeded fields should be left blank. An End-of-Group (Card Type 0 card) must follow the one or two Card Type 8 cards.

Cards of type 9 describe the actual transformations to be applied to the base rolling resistances for each of the rolling resistance transformation families.

Card Type 9--Rolling Resistance Transformations

Columns	Variable	Type	Description
1-10	ITSEC1	I	First track section to which the transformation specified on this card applies.
11-20	ITSEC2	I	Last track section to which the transformation specified on this card applies.
21-30	ATRAN	F	Multiplicative constant involved in the transformation.
31-40	BTRAN	F	Additive constant involved with the transformation.

Note: Up to four such transformation cards may be specified for each transformation family. Each transformation family must be terminated by an End-of-Group (Card Type 0 card). As many transformation families must be specified as there were cells (up to 10) specified on the Card Type 8 cards. If no transformation of base rolling resistance is desired, at least one transformation family must be specified, with one completely blank Card Type 9 being entered.

Cards of type 10 describe the track geometry from the hump through the bowl. These are described to the model as a series of track sections, with one pair of type 10 cards (i.e., Card Type 10 and Card Type 10 continuation) per track section.

Card Type 10--Track Section Geometry

Columns	Variable	Type	Description
1-10	SECLEN	F	Track section length in feet. Bowl tracks must be indicated by coding their length as negative.
11-20	PCTGRD	F	Track section percent grade; downgrades taken positive.
21-30	CURVR	F	Horizontal curve resistance, in lbs. per ton (if the section is on a curve).

Table D-4 (Continued)

Card Type 10 (Continued)

Columns	Variable	Type	Description
31-40	SWITL	F	Switch loss, in feet of velocity head (if the section is a switch). If zero loss is desired, a very small value should be entered, to indicate this as a switch section to SPEEDCON.
41-50	CLEARD	F	Distance to the clearance point of the switch, measured in feet from the end of the switch section (if the section is a switch).
51-60	RMAX	F	Maximum retardation capability of the retarder, in feet of velocity head (if the section is a retarder).
61-70	NSCCCU	I	Number of continuous control units (C.C.U.'s) in the section, if any.
71-80	VCRIT	F	Common speed setting of all C.C.U.'s in the track section, in miles per hour (if any C.C.U.'s are present).

Card Type 10--Continuation Card

Columns	Variable	Type	Description
1-10	PRBOCC	F	Probability that a randomly selected car at the hump will pass through this track section.
11-40	DESCR	F	Any desired descriptive information identifying the track section.

Note: Up to 40 Card Type 10 pairs (i.e., track sections) may be entered. The specification must extend through the end of the bowl track. The last Card Type 10 pair must be followed by an End-of-Group (i.e., Card Type 0) card.

The remaining card types describe the parameters of the retarder logic system. Since the retarder logics that might be used with SPEEDCON are many and varied, the program has been designed to allow the user to code the retarder logic in separate subroutines: RETPAR (to input the logic parameters), and RETLOG (to execute the logic on-line to the simulation). The user must link subroutines of the above names implementing his desired logic to the program. Two logics have been pre-programmed: (1) The WABCO Target Travel Time Algorithm, and (2) The "Magic X" Algorithm. The inputs for these two algorithms are described below.

Card Type 11 (for WABCO Target Travel Time Algorithm)--Retarder Logic Parameters

Columns	Variable	Type	Description
1-10	RFPTUP	I	Upstream reference point for the retarder (track section number at whose end the reference point is located) initiating a sequence of track sections for which the algorithm will attempt to equalize the travel times of all cars to that of a reference car.
11-20	RFPTDN	I	Downstream reference point for the retarder group (track section number at whose end the reference point is located) terminating the sequence of track sections initiated by RFPTUP.
21-30	TTREF	F	Travel time for the reference car between the two reference points specified by RFPTUP and RFPTDN, in seconds.
31-40	GDADJA	F	Additive constant applied in adjusting the effective grade between the end of the retarder group and the point RFPTDN. Constant must be in units of percent.

Card Type 11 (Continued)

Columns	Variable	Type	Description
41-50	GDADJB	F	Multiplicative constant applied in adjusting the effective grade between the end of the retarder group and the point RFPTDN.
51-60	RRADJA	F	Additive constant used in computing predicted rolling resistance after the current retarder group from measured rolling resistance(s) immediately upstream of each retarder group. Constant must be in units of lbs. per ton.
61-70	RRADJB	F	Multiplicative constant used in computing predicted rolling resistance after the current retarder group from the measured rolling resistance immediately upstream of the 1st retarder group.
71-80	VDTOC	F	Target coupling velocity in the bowl track, in miles per hour. Applicable only if this is the farthest downstream retarder group from the hump (otherwise can be blank).

Note: A set of Card Type 11 cards must be specified for every retarder group. A retarder group (not to be confused with "group retarder") is defined as a retarder track section, or as two contiguous retarder track sections. No more than two retarder sections can be contiguous. Card Type 11 cards are specified by retarder groups, not by individual retarder track sections. No more than four retarder groups can be specified. The program will automatically read the Card Type 11 sets in the manner specified here using information obtained by scanning the track section geometry cards (Card Type 10). For the first retarder group, the set of cards of Card Type 11 consists simply of one card. For the second retarder group, the set of cards of Type 11 consists of two cards, the first card containing all the parameters specified above, the second card containing only the parameter RRADJB (in columns 61-70) to be applied to the rolling resistance measured immediately upstream to the second retarder group. Similarly, the set of cards of Type 11 for the third and fourth retarder groups consist of (for example, for the fourth retarder group):

1st card--Full set of parameters specified above, including RRADJB upstream of retarder group 1.
2nd card--RRADJB upstream of retarder group 2.
3rd card--RRADJB upstream of retarder group 3.
4th card--RRADJB upstream of retarder group 4.

Card Type 11 (for WABCO Magic X Algorithm)--Retarder Logic Parameters

Columns	Variable	Type	Description
1-10	VEIN	F	Entry speed of the easy rolling reference car at this retarder group, miles per hour.
11-20	VEOUT	F	Let out speed of the easy rolling reference car at this retarder group, miles per hour.
21-30	VEDTOC	F	Target coupling speed for easy rolling reference car (if this is the farthest downstream retarder group from the hump--blank otherwise), miles per hour.
31-40	VHIN	F	Entry speed of the hard rolling reference car at this retarder group, miles per hour.
41-50	VHOUT	F	Let out speed for hard rolling reference car at this retarder group, miles per hour.
51-60	VHDTOC	F	Target coupling speed for hard rolling reference car at this retarder group (if this is furthest downstream retarder group from the hump--otherwise blank), miles per hour.

Note: One Card Type 11 card must be specified for every retarder group. A retarder group (not to be confused with "group retarder") is defined as a retarder track section, or as two contiguous retarder track sections. No more than two retarder sections can be contiguous. Card Type 11 cards are specified by retarder groups, not by individual retarder sections. No more than four retarder groups can be specified. The program will automatically read each Card Type 11 using information obtained by scanning the Track Section Geometry cards (Card Type 10).

an extreme hard rolling resistance of 28 lb/ton, the second distribution had an extreme hard rolling resistance of 19 lb/ton.* In each case, a smooth, interpolating distribution function was fitted to the empirical histogram shown in Appendix F. The base rolling resistance distribution for the first set of runs is given in Table D-5. To use 19 levels, each group of three cells in Table D-5 was aggregated into a single cell for the SPEEDCON evaluation runs. This gave a base rolling resistance distribution in 1.5 lb/ton increments for the first set of runs, and in 1.0 lb/ton increments for the second set of runs.† The distribution in Table D-5 was simply truncated at the 28.5 lb/ton level.

As mentioned in Section D.2.2.1, the rolling resistance transformation families in SPEEDCON can serve two purposes: (1) To effect a deterministic change in rolling resistance--say a reduction as is assumed in design, and (2) to introduce a change to the rolling resistance "unknown" to the retarder control logic.‡ To simulate cars rolling easier as they get further from the hump, all base rolling resistances were reduced at the group retarder by a factor of 1/3 (i.e., the multiplicative factor used was 2/3). This reduction was also applied to the rolling resistances in the Dowty yard, at a distance from the crest equal to that of the group retarder in the conventional yard. This rolling resistance assumption is discussed more fully in Appendix F.

The problem of rollability measurement errors for the conventional retarder yard was addressed by introducing additional changes in rolling resistance "unknown" to the retarder control algorithm. This was effected by employing three base rolling resistance transformation families, each with an equal probability (i.e., 1/3) of occurrence. In the first family, the base rolling resistance was decreased by 19% (i.e., a multiplicative factor of 0.81) at the master retarder, and was held at this level to the group retarder, where the product of the 2/3 factor discussed above and the 0.81 factor was applied, giving a combined multiplicative factor of 0.54. This factor applied through the end of the class tracks. For the second family, the base rolling resistances were unchanged at the master retarder, having only the deterministic multiplicative factor applied at the group retarder. The third family was symmetrical to the first family--the base rolling resistances were increased by a factor of 1.19 at the master retarder, and a combined factor of 1.19 × 2/3 = 0.79 was applied at the group retarder. The ±19% changes are based on some limited but realistic yard data. Figure D-11 shows the overall rolling resistances used, normalized to a base rolling resistance of 1.

The retarder control algorithm was assumed to "know" about the deterministic rolling resistance factor of 2/3 at the group retarder. It was felt that in a real yard, such a systematic change in rolling resistance would be accounted for in "tuning" the yard. For this reason, the multiplicative factor used in the control algorithm that <u>predicts</u> a car's rolling behavior was set at 2/3. The additional changes of ±19% were withheld from the algorithm. Mechanically, this was accomplished by having all three retarders derive their rollability "measurements" from a test section immediately preceding the master retarder. At that point, all cars are moving at their expected rolling resistance values. The rollability "measurements" were used without adjustment in the master retarder control logic, and the 2/3 factor was applied for the control logics at the group and tangent point retarders. See the "Retarder Logic Input Parameters" section for the conventional yard in Exhibit 1.

These same three rolling resistance transformation families were also applied to the Dowty yard, the rolling resistance jump corresponding to that at the master retarder being made at a distance from the crest equal to that of this retarder in the conventional yard. The Dowty system, of course, has no on-line rollability measurement. The Dowty system's continuous control of speed automatically adjusts for any changes in car rollability within the bounds of the system's design.

The selected reference points for the WABCO Target Travel Time Algorithm for the conventional yard were located at the entrances of the group and tangent point retarders. This is in accordance with common practice. Preliminary values for the arrival time of the reference car at these points were taken from PROFILE runs used in designing the hypothetical yard; the design hard rolling car was used. These initial target times were then adjusted as follows:

- If cars had too low a velocity at a reference point (e.g., as shown by stalls), then the ΔT_{ref} was decreased.§
- If the cars had too high a speed at a reference point, then ΔT_{ref} was increased.

The above process is, in fact, quite analogous to the process by which such a parameter would be adjusted to "tune" the yard in real-life.

The final portion of the input data to be discussed here is the design of the hypothetical yards themselves. This information is contained in quantitative form in the geometric data input to SPEEDCON; this data may be seen for the conventional yard in Exhibit 1, and for the Dowty yard in Exhibit 2. Details of these designs were given in Section 5.

D.4.3 Results of Evaluations

The various event probabilities obtained from the SPEEDCON runs discussed above are shown in Table D-6 for the 28 lb/ton hardest roller, and in Table D-7 for the 19 lb/ton hardest roller.

Generally speaking, the results observed in the previous comparison between Exhibits 1 and 2 also obtain here. However, it is surprising how well the conventional retarder system still performs (compare to Exhibit 1 results) even when its "knowledge" of a car's rollability is degraded. This is because the WABCO target travel time algorithm tends to be "self-correcting." For example, if the rolling resistance "seen" by the retarder logic at the master retarder is higher than the car's actual effective rolling resistance, the car will be under-retarded. This will cause the car to arrive at the group retarder ahead of the

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*The second base rolling resistance distribution is the first distribution's rolling resistances scaled by a multiplicative factor of 2/3.

†SPEEDCON uses the base rolling resistance at the midpoint of each cell in the simulation phase.

‡This could be caused by the car changing its rolling resistance in some random manner after measurement; or by an error in the rolling resistance measurement itself.

§ΔT_{ref} is the difference between the car's arrival time at a reference point, and its arrival time at the previous reference point.

TABLE D-5.-HYPOTHETICAL YARD-BASE ROLLING RESISTANCE DISTRIBUTION FOR 28 LB/TON EXTREME HARD-ROLLING CAR

Zone, rolling resistance, pound/ton		Probability function[a]	Cumulative distribution function[b]
from	to		
0.000	0.500	0.002	0.002
0.500	1.000	0.032	0.034
1.000	1.500	0.162	0.196
1.500	2.000	0.480	0.676
2.000	2.500	1.078	1.753
2.500	3.000	2.023	3.776
3.000	3.500	3.322	7.098
3.500	4.000	4.880	11.978
4.000	4.500	6.483	18.461
4.500	5.000	7.847	26.309
5.000	5.500	8.715	35.023
5.500	6.000	8.958	43.981
6.000	6.500	8.618	52.599
6.500	7.000	7.854	60.453
7.000	7.500	6.865	67.318
7.500	8.000	5.819	73.137
8.000	8.500	4.828	77.965
8.500	9.000	3.951	81.916
9.000	9.500	3.208	85.124
9.500	10.000	2.595	87.719
10.000	10.500	2.097	89.816
10.500	11.000	1.698	91.514
11.000	11.500	1.378	92.892
11.500	12.000	1.123	94.015
12.000	12.500	0.919	94.934
12.500	13.000	0.756	95.690
13.000	13.500	0.625	96.315
13.500	14.000	0.519	96.834
14.000	14.500	0.433	97.267
14.500	15.000	0.364	97.631
15.000	15.500	0.307	97.937
15.500	16.000	0.260	98.197
16.000	16.500	0.221	98.418
16.500	17.000	0.189	98.607
17.000	17.500	0.162	98.769
17.500	18.000	0.140	98.909
18.000	18.500	0.121	99.029
18.500	19.000	0.105	99.134
19.000	19.500	0.091	99.225
19.500	20.000	0.080	99.305
20.000	20.500	0.070	99.375
20.500	21.000	0.061	99.436
21.000	21.500	0.054	99.491
21.500	22.000	0.048	99.539
22.000	22.500	0.043	99.581
22.500	23.000	0.038	99.619
23.000	23.500	0.034	99.653
23.500	24.000	0.030	99.683
24.000	24.500	0.027	99.710
24.500	25.000	0.024	99.734
25.000	25.500	0.022	99.756
25.500	26.000	0.020	99.775
26.000	26.500	0.018	99.793
26.500	27.000	0.016	99.809
27.000	27.500	0.015	99.824
27.500	28.000	0.013	99.837
28.000	INFIN	0.163	100.000
		100.000	

Equation for cumulative distribution F(R): $F(R) = 1 - \frac{1}{1 + a(\frac{R}{10})^b}$ $a = 7.14$ $b = 4.32$

[a] Percent of cars.

[b] Cumulative percent to upper zone boundary.

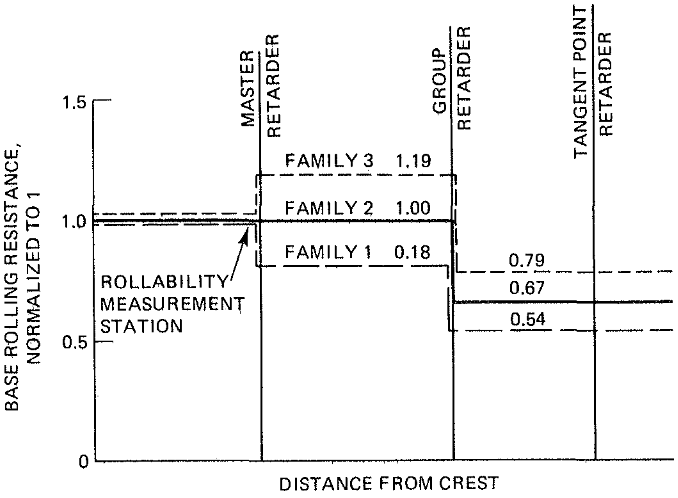

Figure D-11. Rolling Resistance Transformations Used in SPEEDCON Yard Comparison Evaluation Runs

TABLE D-6.-SPEEDCON RESULTS, 28 LB/TON HARDEST ROLLER

	Conventional design	Dowty design
Probability of coupling before tangent point[a] (%)	3.74×10^{-3}	0.65
Probability of catch-up in retarder[a] (%)	3.71×10^{-3}	NA
Probability of misswitch[a] (%)	5.45×10^{-4}	0.15
Probability of cornering collision after switch[a] (%)	1.15×10^{-3}	0.03
Probability of how car stops or couples:[b]		
Stalls before tangent point (%)	0.03	3.00
Stalls in bowl (%)	15.82	41.14
Couples in speed range:		
0-1 mph (%)	0.02	1.63
1-2	4.33	4.48
2-3	6.71	5.81
3-4	39.99	9.33
4-5	13.79	17.77
5-6	12.35	13.83
6-7	6.94	2.50
7-8	0.02	0.51
8-∞	0	0

[a] For consecutive cars over hump only.

[b] Couplings under 2 mph were considered underspeed, and over 6 mph overspeed.

TABLE D-7.-SPEEDCON RESULTS, 19 LB/TON HARDEST ROLLER

	Conventional design	Dowty design
Probability of coupling before tangent point[a] (%)	0	0.18
Probability of catch-up in retarder[a] (%)	0	NA
Probability of misswitch[a] (%)	0	0.02
Probability of cornering collision after switch[a] (%)	0	5.40×10^{-3}
Probability of how car stops or couples:[b]		
Stalls before tangent point (%)	0	0.46
Stalls in bowl (%)	7.86	22.56
Couples in speed range		
0-1 mph (%)	0	0.26
1-2	3.73	2.72
2-3	9.10	6.73
3-4	36.48	7.93
4-5	24.19	20.26
5-6	14.36	29.15
6-7	4.21	8.60
7-8	0.07	1.33
8-∞	0	0

[a] For consecutive cars over hump only.

[b] Couplings under 2 mph were considered underspeed, and over 6 mph overspeed.

reference car's schedule. The group retarder logic will integrate the car's earliness with whatever (possibly erroneous) rolling resistance is measured; the resulting retardation selected will at least include a component of additional retardation in an attempt to force the car back to the reference car schedule.

The relatively poor performance of the Dowty system was already commented upon in Section D.3.2. There it was mentioned that this performance is not inherent in the Dowty system per se, but is due to the fact that the Dowty hypothetical yard was designed using a much easier rolling design hard roller: 12 lb/ton for the Dowty hypothetical yard as opposed to 18 lb/ton for the conventional hypothetical yard. See Section 5 for further discussions comparing the performance of the conventional and Dowty yards.

D.4.4 Conclusion

This section has demonstrated the utility of SPEEDCON to compare two alternative speed control systems. The model can also be used for yard design activities of a more extensive and detailed nature than can the pre-existing PROFILE model. Although its cost is larger than that for using the PROFILE model, SPEEDCON's utility can be great. In situations in which the entire yard is to be designed as one unified system--the geometry together with the retarder system design (and logic, if applicable)--SPEEDCON can be a highly valuable tool.

Appendix E

SURVEY OF SPEED CONTROL ALGORITHMS

E.1 INTRODUCTION

The layout and overall operation of a classification yard using an advanced clasp retarder speed control system is described elsewhere in this report. The speed control system is composed of both hardware--retarders, wheel detectors, radars, and computers, and software--the algorithms used by the computers to control the retarders and switches based on sensor inputs.

One of the objectives of this project is to evaluate algorithms that are currently being used to control retarders in class yards to see if the performance of existing or new yards might be improved by using more precise algorithms. The first step toward this objective was an exhaustive study of the existing algorithms. This algorithm survey is summarized in this Appendix. Several conclusions concerning possibilities for improvements are also presented.

We believe that this Appendix discusses all the important algorithms which have been publicly disclosed. In particular, algorithms described in König's 1969 paper (reference 7) and those used by WABCO [as revealed in their patents (references 5 and 8)] and GRS [as revealed in their patents (references 9 through 12)] are described. WABCO and GRS are the two major suppliers of class yard equipment in the United States. Two algorithms proposed by Peter Wong (references 13 and 14) are also described. The König paper is important because it seems to represent the best of the algorithms then in use in Europe (1969).

E.2 CATEGORIES OF ALGORITHMS

For the sake of simplicity and organization, the algorithms have been separated into the following categories based on what task the algorithm is intended to perform, rather than how the task is performed:

- Master and Group Retarder Algorithms--These algorithms are used to control the master and/or group retarders in a conventional class yard. Inputs to these algorithms typically consist of car velocities (from doppler radar, for example), car presence signals (from wheel detectors), predicted rolling resistance of the car, car weight, and cut list information (often from a central computer). The output of the algorithm is a "desired exit speed" from the retarder(s) being controlled.
- Tangent Point Retarder Algorithms--These algorithms are used for the control of tangent point retarders. Inputs are typically car velocities, car presence signals, predicted rolling resistance of the car, and "distance to couple" measurements. The output of the algorithm is the "desired exit velocity" from the tangent point retarder.
- Deceleration Algorithms--These algorithms are used to achieve the "desired exit velocity" which is the output of the above algorithms. Inputs to these algorithms are typically car weight or weight class, car velocity signals, car presence signals, and the "desired exit velocity." The outputs of the algorithm are the retarder control signals. These are typically "open" and "close" commands and heavy, medium, or light pressure commands.
- Rollability Prediction Algorithms--These algorithms are used to predict the rollability (or rolling resistance) of a car. This information may be used as input by the algorithms above. Inputs to these algorithms are typically car velocity and presence signals.

It should be apparent that at least one algorithm from each of the first three categories above is needed for the control of a conventional automated class yard. Some yards may also use an algorithm(s) from the fourth category. This list of categories need not be exhaustive, however. New categories may be added in the future to cover new or unconventional algorithms which do not fit into one of the present categories.

Below, several algorithms which are described in the literature are discussed. To facilitate subsequent discussion and comparison of the algorithms, a unique name has been assigned to each algorithm discussed.

E.3 MASTER AND GROUP RETARDER ALGORITHMS

E.3.1 Two Delta V

This algorithm is called "2 · DELTV" by König (reference 15). It is similar to an algorithm which has been called the "Magic X" by some WABCO personnel. Variables are identified as follows:

V_{ein} = car speed at the entrance to the retarder

V_m = a reference speed (equal to "the mean speed of the slowest-runner in the zone of the valley brake")

ΔV = a speed difference, see below

F = a "deflection factor" which is determined by "trial and error" for a given yard. Typically, F = 2

V_{aus} = desired exit speed from retarder.

The exit speed is determined as follows:

$$\Delta V = V_{ein} - V_m$$
$$V_{aus} = V_{ein} - (F)\Delta V.$$

E.3.2 Siemens Running Time

This algorithm is only vaguely described in the reference. Apparently it is similar in results to the above algorithm, however, this algorithm uses the running time of each car from the crest to the retarder entrance rather than V_{ein} as an input.

E.3.3 WABCO Target Time

This algorithm is described in great detail in the Budway and McGlumphy patent (reference 16). Basically, the retarders are controlled to achieve a certain target time for the travel of each car from the crest to several reference points along the tracks in the switching area. These target times are precomputed parameters. A different set of target times would be used if the humping speed were changed.

Variables are defined as follows:

T_T = target time from crest to reference point below retarder being controlled.

T'_0 = measured travel time between crest and entrance of retarder being controlled.

V_E = measured entrance speed to retarder.

V_X = desired exit speed from retarder.

A_R = average deceleration in the retarder.

G'_3 = average grade (equivalent acceleration) between exit of retarder and the reference point downstream.

R_3 = predicted average rolling resistance of the car (equivalent acceleration).

S_T = distance from the exit of the retarder to the downstream reference point.

L_R = length of the retarder.

L_C = length of the car.

The basic equation used by this algorithm is given in reference 17. In a slightly simplified form the equation is:

$$T_T - T'_0 = \frac{1}{V_X}\left[\frac{L_R + L_C}{1.467} + \frac{\left(V_X - V_E\right)^2}{0.219\ A_R}\right] + \frac{2\ S_T}{1.467\left[V_X - \sqrt{V_X^2 + (G'_3 - R_3)S_T}\right]} \qquad (1)$$

Making the simplifying assumptions that

$$L_R = L_C = 0 \quad \text{and} \quad V_X = V_E \quad ,$$

the above equation can be rearranged to give

$$S_T = (1.467)\ V_X\ (T_T - T'_0) + \left[\frac{1.467}{2}\right]^2 (G'_3 - R_3)\ (T_T - T'_0)^2 \quad . \qquad (2)$$

This relation is similar to the well-known relation for uniformly accelerating motion

$$x = v_o t + 1/2\ at^2 \quad . \qquad (3)$$

Presumably, this similarity is not coincidental, but arises because the WABCO algorithm is incorporating this well known relationship, together with "fudge factors" and/or other coefficients.

Solution of the basic equation to determine the desired exit speed is done by iteration because a closed-form solution presumably is not available. A flow chart for the iteration procedure is given in reference 18.

E.3.4 GRS Modifier

This algorithm is described in two patents by Auer, et al. (references 19 and 20). The later patent is the more general of the two and will be discussed below. The algorithm has certain similarities to the Two Delta V algorithm discussed above.

The desired exit speed from the master retarder is obtained from a table of precomputed values. Inputs to the look-up procedure are the car weight and the settings of two manual controls called the "yard speed manual modifying control" and the "light car modifying control" (reference 20). The algorithm for determining the values in the table is only qualitatively described, for example:

> "It has been determined experimentally, for example, that light cars tend to be very hard rolling under low temperature conditions. To overcome this effect, it is at times desirable to release lightweight cars from the hump retarder at a higher speed" (reference 20).

The actual (as opposed to the desired) exit speed from the master retarder is determined from sensors in the yard. Based on the actual exit speed from the master retarder, a "reference entering speed," V_{re}, is computed which corresponds to the speed that a car would have upon entering the group retarder if it were an easy roller. A "reference leaving speed," V_{rl}, is obtained from a table based on car weight and the route the car will take through the yard. (However, the fullness of the particular class track concerned is not used here.) A (positive) "multiplying factor," K, is found from a table based on the car's intended route through the yard and the position of a manual adjustment known as the "group manual modifying control." (It is claimed that the group manual modifying control can be used to account for different track fullness levels, but since there is only one such control for each group retarder, only the average track fullness for that group retarder can be used.) According to the patent (reference 21), the value of K is determined based on a linear fit to a higher-order function. The actual entering speed at the group retarder, V_{ae}, is determined from sensors in the yard. The desired exit speed from the group retarder, V_{de}, is then determined from

$$V_{de} = V_{rl} + (V_{re} - V_{ae})K \quad . \qquad (4)$$

The above equation is implemented by a device known as the "modifier."

E.4 TANGENT POINT RETARDER ALGORITHMS

E.4.1 Energy Equation Target Speed

The earliest reference to this algorithm that we have seen is a GRS patent (reference 9); it also appears in numerous other references (22 through 25). The algorithm uses the well known energy equation to predict the retarder exit velocity which will result in a desired coupling velocity. Variables are defined as follows:

V_C = desired coupling velocity

V_X = computed retarder exit velocity

R = predicted rolling resistance of the car (in units of force)

S = distance from tangent point retarder exit to coupling point

g = acceleration due to gravity

Δh = elevation change between retarder and coupling point

m = mass of the car

The equation for V_X is then:

$$V_X = \sqrt{V_C^2 + \frac{2RS}{m} - 2g\Delta h} \qquad (5)$$

E.4.2 Straight Line Theory

This algorithm is based on an unexplained "straight line of theory" of car behavior (reference 26). The parameter, K_D, is related to the rolling resistance (see E.6.3 below). The desired exit speed from the tangent point retarder is computed from:

$$V_X = V_C + 0.00747\ K_D S \quad . \tag{6}$$

E.5 DECELERATION ALGORITHMS

E.5.1 Retardation at Earliest Moment (König)

König is responsible for coining the name of this algorithm (reference 27), but it is widely used (references 28 and 29). The retarder is commanded to close as the car enters the retarder. The retarder is then commanded to open after the velocity of the car has reached the desired exit velocity.

E.5.2 Retardation at Last Moment (König)

König also named this algorithm (reference 30). It relies on a prediction of the retarding capability of the retarder. Based on this prediction, the time of retarder actuation is computed which will result in the car leaving the retarder with the desired exit velocity and the retarder being actuated at the last possible moment.

E.5.3 Retardation with Constant Deceleration (Wong)

In this algorithm (reference 31), unlike the two above, the retarder is commanded to open and to close more than once (typically several times) for each car. This is done to approximate the case of constant deceleration through the retarder. Due to the relatively slow response time of conventional retarders, the constant-deceleration velocity curve cannot be achieved exactly. The algorithm also contains a special feature to account for the slow response time and achieve accurate exit speed despite departure from the ideal constant-deceleration velocity curve.

E.5.4 Retardation with Constant Deceleration (Berti)

This algorithm (reference 32) is similar to the one above in that the goal is to obtain constant deceleration along the length of the retarder. In this algorithm, it is assumed that there is a means for continuous control of the retardation force exerted by the retarder. The retarder is commanded to exert that retardation force which will result in the desired exit speed with constant deceleration through the retarder.

E.5.5 Retardation with Constant Deceleration (Brockman)

This algorithm is also similar to E.5.3 above. In the Brockman patent (reference 11), the retarder can be controlled to three different retardation states, heavy retardation, light retardation, and no retardation. The retardation rate called heavy retardation is selected based on car weight. Heavy retardation is applied when the car velocity exceeds the desired velocity profile by a certain amount. When the car velocity approaches the desired profile, light and no retardation are used alternately to match the desired profile.

E.5.6 Retardation with Constant Deceleration (Di Paola)

This algorithm (reference 12) is similar to those described in E.5.3, E.5.4, and E.5.5 above in that its goal is relatively constant deceleration through the retarder. Unlike the above algorithms (E.5.3 and E.5.5), this algorithm does not rely on a sensor in the yard to determine the actual car velocity in the retarder. Instead, a table is computed which contains the clamping force to be applied by the retarder as a function of time or distance, the computed values being based on the previously-measured behavior of the retarder.

The computed clamping forces are applied regardless of the actual behavior of the car in the retarder. In other words, this is an open loop control system. The advantage claimed for this approach is the elimination of speed sensors in the yard, thus reducing overall cost for the speed control system.

E.6 ROLLABILITY PREDICTION ALGORITHMS

E.6.1 Single Test Section

This algorithm has as input the velocity of each car at the entrance and at the exit of a section of track called the test section. Normally, the test section would be part of the track between the hump and the retarder being controlled. Rolling resistance is calculated using an energy equation such as the one given in Section E.4.1 above. (In this case, V_X and V_C would be the entrance and exit speeds from the test section.)

$$R = (V_X^2 - V_C^2 + 2g\ \Delta h)\ \frac{m}{2S} \tag{7}$$

E.6.2 Multiple Test Section, Linear Regression

In this algorithm (reference 33), rollability is measured on two or more test sections between the hump and the retarder being controlled. In each case, the rollability is determined as described in Section E.6.1 above. If the several rollabilities determined for a given car are denoted by $R_1, R_2, R_3, \ldots$, then the predicted rollability, R_P, is given by:

$$R_P = a_1 R_1 + a_2 R_2 + a_3 R_3 + \ldots \tag{8}$$

where $a_1, a_2, a_3, \ldots$ are regression coefficients. These regression coefficients would be determined separately for each yard after testing with a statistically-significant number of cars.

E.6.3 Single Test Section Velocity-Dependent Linear Regression

This algorithm is discussed in the WABCO patent (reference 34) in conjunction with the retarder control algorithm discussed in Section E.4.2 above. The algorithm is based on the assumption that rolling resistance varies linearly with velocity. Inputs to the algorithm include velocities at the entrance and exit of a single test section as in Section E.6.1 above. First the factor, K_U, is defined

$$K_U \equiv \frac{2}{V_1 + V_2}\left[G_r - \frac{66.9}{S}\,(V_1^2 - V_2^2)\right] \quad , \tag{9}$$

where:

V_1 = velocity at the entrance to the test section

V_2 = velocity at the exit of the test section

S = length of the test section

G_r = average grade of the test section

Next, the factor, K_D, which is akin to the rolling resistance, is computed:

$$K_D = A_T K_U + B_T \tag{10}$$

The constants A_T and B_T are obtained (presumably) by regression analysis from test data for a statistically-significant number of cars. Different values of A_T and B_T are used for each weight class. Presumably, A_T is approximately equal to the average exit velocity from the tangent point retarder for that weight class.

E.7 PREFERRED ALGORITHMS

E.7.1 Introduction

Based primarily on theoretical considerations, one algorithm was selected from each category which is believed to be the "best" (i.e., which maximizes yard throughput for a given level of misswitching and overspeed couplings). The performance of conventional yards which are currently using inferior algorithms could probably be improved if the preferred algorithms were installed. Of course installation of new algorithms in an existing yard would not be inexpensive, and the expected benefits must be weighed against this cost. In particular, the need to "tune" the algorithm after installation should be included in the installation cost estimates.

E.7.2 Master and Group Retarder Algorithm

The WABCO target time algorithm is the preferred algorithm for master and group retarders. This algorithm takes into account all the readily-measured parameters (rollability, car weight and length, and the intended path of the car through the yard) and uses a rational criterion (the target time) to pick the desired exit speed. The equations used by the algorithm are relatively complex, but this is because the fundamental laws of physics which govern car behavior have been used to develop the equations. Despite their complexity, the equations are solved relatively rapidly (compared to the time required to sample all the sensor inputs) by the yard control computer according to WABCO (reference 35).

Several runs of SPEEDCON have been performed to compare the effectiveness of the Two Delta V and the WABCO Target Time algorithms. The results support the conclusion that the later algorithm is superior. Incidentally, WABCO claims (reference 35) that they have incorporated measured wind velocity and direction as well as ambient temperature in recent versions of the algorithm.

E.7.3 Tangent Point Retarder Algorithm

The Energy Equation Target Speed algorithm is the preferred algorithm for tangent point retarders. This algorithm uses all the available information in a rational, physically justified equation to determine desired exit speed.

E.7.4 Deceleration Algorithms

The constant deceleration algorithms are preferred because the transit time of cars through the retarder is less than with the Retardation at Earliest Moment algorithm. This results in higher throughput in the yard. Retardation at Last Moment would give even shorter retarder transit times, but this algorithm is likely to result in a large number of cars leaving the retarders at speeds in excess of the desired exit speed because of the highly unrepeatable performance of conventional clasp retarders. Due to this unrepeatability of retarder performance, a "closed loop" algorithm such as Wong or Brockman is preferred to the open loop algorithms (Berti and DiPaola).

Among the closed loop algorithms with constant deceleration (Wong and Brockman) there is not a clearly superior alternative. These two algorithms are quite similar, and their differences are due to a desire to accommodate certain capabilities (multiple clamping forces) or limitations (slow response time) of particular retarders. Therefore, the choice between these two algorithms would depend on the characteristics of the particular retarder being controlled.

E.7.5 Rollability Prediction Algorithms

If some apparently reasonable assumptions are made about rollability statistics, probability theory indicates that the Multiple Test Section, Linear Regression algorithm is superior to the Single Test Section algorithm. Similar arguments can be made that the Single Test Section Velocity-Dependent Linear Regression algorithm is superior to the Single Test Section algorithm.

We do not have sufficient statistical rollability data to choose between the Multiple Test Section, Linear Regression and Single Test Section Velocity-Dependent Linear Regression algorithms. However, an algorithm incorporating features of both, multiple test sections and velocity-dependent linear regression, could be easily formulated. Such a hybrid algorithm should be somewhat superior to either of the algorithms separately.

E.8 SUGGESTIONS FOR FUTURE ALGORITHM DEVELOPMENT

All algorithms discussed above treat each car independently of the other cars in the yard (except for the use of distance-to-couple information in Section E.4.1 above). An algorithm which was designed to maintain a minimum headway between cars in the switching area can be envisioned (reference 36). The algorithm would require solution of equations similar to those used in the WABCO Target Time algorithm discussed above, but the equations would be more complex due to the inclusion of parameters for two or more cars.

To realize the full benefits of the envisioned headway control algorithm, it would be necessary to have the yard control computer control the speed of the hump locomotive in real time. Power and traction of the hump locomotive as it relates to the inertia of the cars being humped would also be an important consideration. Finally, there is a maximum hump speed which cannot be exceeded without requiring unreasonable performance of the pin puller. For example, at Southern Pacific's West Colton Yard, a maximum humping speed of about six mph is dictated, not by the limitations of the speed control system, but by the capabilities of the pin puller.

Appendix F

ASSUMPTIONS ON CAR ROLLING RESISTANCE

In the 1976 edition of the AREA yard design manual (reference 37) the hardest rolling car is recommended to be equivalent to a 1.4% grade i.e., 28 lb/ton) and the easiest rolling car is .08% grade (i.e., 1.6 lb/ton). Furthermore, the AREA manual indicates that the most frequent rolling resistance of loaded cars is a .2% grade (i.e., 4 lb/ton) and for empty cars .35% grade (i.e., 7 lb/ton). However, these values are not firmly based, and many railroads use other figures. In fact, the AREA itself has gone on record to recommend a research program to more fully understand and specify rolling resistance (see AREA Bulletin 650).

Much of the current data on rolling resistance is in private hands and is generally not available to the public. The two signal companies, GRS and WABCO, have probably the largest collection of data based on the accumulated experience of building many yards, but their data is considered proprietary.

SRI's experience in yard design indicates that the most "current model" for rolling resistance is to assume for design purposes that the rolling resistance becomes easier during a car's roll. For example, one set of rolling resistance values are assumed from crest to the position of the group retarder, and an easier set of rolling resistance values are assumed thereafter.

Because there is controversy over the exact range of the United States rolling resistance car population, and because these assumptions greatly affect the performance of the speed control systems, we decided to measure the performance of the speed control systems against two assumptions concerning the population of rolling resistance:

Conservative Rolling Resistance Assumption

- Between the crest and group retarder (or equivalent location) the rolling resistances of the car population is assumed to be that as shown in the Elkhart histogram (Figure F-1).
- After, the group retarder (or equivalent location), the rolling resistances become easier; the Elkhart histogram is used except that all rolling resistance values are reduced to two-thirds (2/3).

Optimistic Rolling Resistance Assumptions

- Between the crest and group retarder (or equivalent location), the rolling resistances of the car population is assumed to be that as shown in the Elkhart histogram (Figure F-1), except that all rolling resistance values are reduced to two-thirds (2/3).
- After the group retarder (or equivalent location), the rolling resistances become easier; the Elkhart histogram is used except that all rolling resistance values are reduced to four-ninths (4/9).

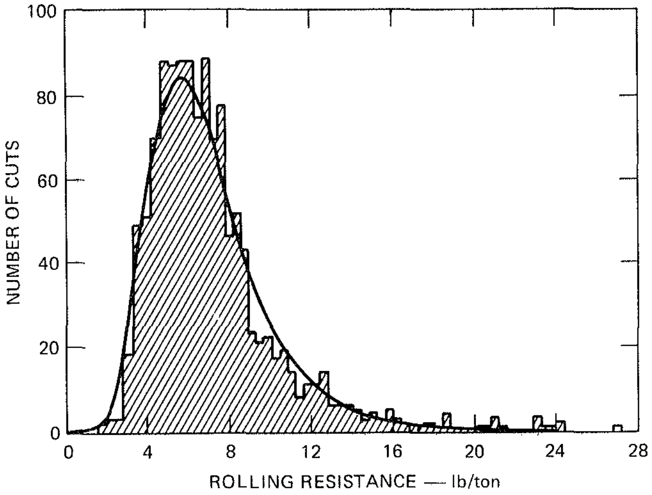

Figure F-1. Histogram of Rolling Resistance Data Supplied by CONRAIL (Elkhart Yard).

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