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SUMMARY OF DEVELOPMENT AND APPLICATION OF DRAFT BUFF INDICATOR

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PROJECT MEMORANDUM

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ABSTRACT

This memorandum summarizes the development and use of the Draft Buff Indicator, a prototype system for sensing, recording, and displaying freight train "slack action" or inter-car movement. The prototype, developed by the Transportation Systems Center as part of the International Government Industry Research Program on Track Train Dynamics, has been use-tested by four major railroads. This memorandum describes the basic design of the system, the railroads' experiences with it, and the prognosis for future use.

PREFACE

This memorandum summarizes DOT's efforts in the development and use of the Draft Buff Indicator through the fall of 1977. A more detailed description of the system may be found in Report No. DOT/ORD-77-53 entitled "Development of a System to Display and Record Slack Action in Freight Trains." The memorandum also summarizes material originally published in the report entitled "Enginemen's Sensitivity Studies" published by the "International Government Industry - Research Program on Track Train Dynamics", April 1976. The work described in this memorandum was performed as part of TSC's work in train handling, under the sponsorship of the Federal Railroad Administration and in cooperation with the International Government-Industry Track-Train Dynamics program, (Task Four).

The following people assisted by providing technical and practical suggestions, access to railroad properties for testing, and aid in conducting experiments.

Association of American Railroads: E.D. Lind
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Denver and Rio Grande Western: W.A. Henderson
General Motors Corp., Electro-Motive Division: N.L. MacDonald
Southern Pacific Transportation Company: D.D. Grissom, R.D. Pigg, E. Thomas, and R. Austill.

The following individuals made significant technical contributions to the DBI at the Transportation Systems Center: D. Gosselin, J. Vrable*, D. Ofsevit*, C. Hoppin, J. Owens, and A. Wichansky.

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* Presently employed by the MITRE Corporation.

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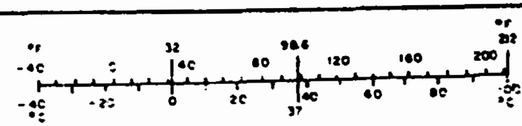
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
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)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
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)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
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		
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)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
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	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

As part of the first phase of the Government Industry Track Train Dynamic Program (TTD) a working group on engineer performance was formed. Research was undertaken to identify and develop techniques and devices which would aid the locomotive engineer in the safe and efficient operation of the train. Consideration of the train handling process led to the conclusion that the engineer could profit by more and better real-time information about the intercar motion of the cars in the train. This intercar movement, generally referred to as "slack action," is due to train acceleration and deceleration, changes in grade, and other factors.

The action is often manifested as a traveling shock wave within the train. This motion is possible due to draft gear compliance and wear related coupler slack. Because such slack action is often the cause of damage to rolling stock lading and track structures and is believed to be the cause of many derailments, its control was given a high priority in the TTD program. Prior efforts at control of slack action have involved improvements in draft gear to absorb the slack induced shocks, and improvements in the operating procedures to reduce the level and frequency of occurrence of these shocks.

Further improvements in the draft gear, while of course possible, were beyond the scope of the behavioral scientists, training, and operating personel involved in this portion of the TTD program. The working group's efforts were concentrated on developing methods to reduce the occurrence and severity of these shocks through improved displays which could be used to develop and execute improved procedures. The group's efforts were directed at the improvement of the engineer's knowledge of the train's dynamic characteristics and its dynamic behavior. A technique was developed to provide the engineer with a "hard copy" chart of the train's makeup immediately before its departure. Instrumentation was developed to provide the engineer with real-time estimates of the total force exerted on train by the power consist. These two developments were pursued by Southern Pacific Railroad (SP) and the General Motors Electromotive Division (EMD) respectively. At TSC a system was designed, fabricated, and use tested which displayed and recorded the slack or draft/buff condition of the train. This system (the subject of this report) was called the DBI or Draft Buff Indicator.

In this technical memorandum, the DBI development efforts are summarized, the nature of slack action is described, prior techniques are discussed, the DBI is described, and the applications of the DBI to date are discussed.

2. REQUIREMENTS FOR DBI

The DBI was developed to provide real-time information on destructive and potentially dangerous "slack actions" which occur during normal freight operations. Although originally envisioned as an aid for the engineer its major use has been in the analysis of handling problems and the development of new train handling techniques. In this section slack action is discussed in non-quantitative terms and prior attempts to measure and analyze it are described.

2.1 Description of "Slack Action"

Freight cars on North American railroads are attached together using automatic type couplers. The couplers are attached to both ends of the cars and locomotives by spring loaded, friction damped, draft gear. The draft gear allows the couplers to move relative to the car body.

With standard draft gear, movements of up to 6 inches are possible under strong compression (buff) or tension (draft). In trains of 120 cars, which are not uncommon, the train may be 100 feet longer under full draft than it is under full buff. The fact that the train may have this relatively large amount of slack is quite important. It is very helpful, for instance, in starting the train. A large freight train may weigh 10,000 tons. It would be extremely difficult for a locomotive consist to exert and transmit sufficient force through its couplings to overcome the inertial and frictional loads of the train at rest and move the entire 10,000 tons simultaneously. The elasticity of draft gear allows the engineer to start the train by applying force to each car in sequence, putting it in motion, and using its inertia to start the next car moving. However, the slack action permitted by elastic and/or worn draft gear can present serious handling problems. If the intercar movement permitted by the draft gear becomes heterogeneous, traveling shock waves (run-ins) can occur which place great compressive loads on the coupling and this may be translated into lateral forces causing derailments. When such forces are not translated into lateral forces they are often the cause of severe shocks to the cars resulting in damage to the cars and lading. Similarly extensive forces resulting in shocks (run-outs) may be the cause of damage to the coupler knuckle of draft gear and may cause train separation.

To counteract the undesirable effects of slack action engineers use a number of strategies. They may "bunch" the train or eliminate slack when reaching a downgrade by a brief air brake application. This is done to avoid run-ins. When operating in territory with frequent changes in grade they may stretch the train and maintain it in tension by power or stretch braking. In this manner the train is operated with the train brakes continually set and the locomotive pulling against the brakes.

Often more complex slack control procedures are used to accomplish special manuvers dictated by specific train and terrain conditions. The successful development and application of such slack control techniques is dependent on feedback or knowledge of the effect of the specific technique on train handling.

2.2 Prior State of the Art

The techniques for empirically determining the effect of slack control maneuvers have been relatively crude. "Seat-of-the-pants" feel by the engineer and reports on "run-ins" by the conductor from the caboose are the most commonly used. These are severely limited as the engineer is isolated from the train by the trailing locomotives in the power consist and it is often difficult for him to correlate reports of run-ins and run-outs from the caboose with control actions taken minutes before. Further, in long trains the possibility of severe shocks in the center portion of the train exists. This action is very difficult to detect and interpret by train crew members stationed at the ends of the train.

To develop better strategies and techniques for train handling empirical studies of slack action have been undertaken. Empirical methods of determining the effects of the control inputs have ranged from observation by staff members positioned on car sills to measurement of intercar movement using extensiometers. In almost all cases the opportunities for the observation of the effects of slack action in real-time have been severely limited if not impossible.

The other methods used for developing slack control techniques were basically analytical. These techniques range from calculation of the influence on slack of lead and trailing power consists, based on estimated and tractive effort at different horsepower levels, to highly sophisticated computer simulations of entire trains, based on known dynamic characteristics of rolling stock and track. Such simulations provide valuable inputs for the development of train handling procedures. Without techniques for directly determining the effects of control inputs, validation of the procedures must rely on observed reductions in train separations and derailments. While such reductions are of course the goal of the development of train handling techniques, this validation technique is insensitive in the extreme. This lack of sensitivity can lead to the spurious rejection of valuable techniques and strategies.

Due to the need for improved train handling techniques, and the lack of real-time information on the dynamic response of the train to new control strategies, it was decided to develop a system which could depict the Draft or Buff state of the train in "real-time". This system would display the coupler state at various points in the locomotive cab, so that changes in it could be correlated with train motion and simultaneously recorded for future study.

3. DESCRIPTION OF THE DRAFT BUFF INDICATOR

The DBI is a telemetry system which senses, transmits, displays, and records intercar motion and relative displacement at various points in the train. Bi-stable sensors are installed between five pairs of freight cars within the trains. Information derived from these sensors is transmitted through radio transceivers (which are paired with the sensors) to a radio tranceiver which is part of the receiver decoder display unit. The radio transmissions are coded in audio frequency tones which are then decoded and displayed, and may also be stored in coded form for later display and analysis. The information is displayed through 5 sets of paired lights, one light in each pair indicating slack and the other buff for a single sensor transmitting station at a given part of the train.

3.1 Sensors

The sensors are "two-state hysteresis" devices which are self-adjusting and indicate only whether the coupling is relatively extended (in draft) or relatively compressed (in buff). The absolute determination of the displacements is not possible due to variations in coupler type and condition. The sensors are mounted between the sills of selected freight car pairs. The selection of the car pairs is critical to developing the particular type of data required. If exact determination of a power node is required then a clustering of the sensors about the predicted node is necessary; if the study of the propagation of rear end run-ins is required a wider distribution of the sensors with a concentration toward the end of the train is required.

3.2 Transceiver

The transceiver portions of the system have been adapted from hand-held commercial transceivers. There is a transmitter in each of the five coupler stations and a receiver at the head end receiver-decoder display unit. The condition of the sensor (draft or buff) and its position in the train are indicated by audio tones. Each transceiver can send two distinct tones. Ten tones are required to indicate the two possible states for each of the five transmitter sensor stations. The audio tone is encoded as a frequency modulated radio frequency signal and decoded by a transceiver-decoder display system. Encoding the draft-buff positions as audio transmitter-frequencies tones has two basic advantages: general purpose radios can be used allowing significant economy in the construction of prototypes; and the signal, as received in the receiver decoded display system, may be recorded on an inexpensive audio tape recorder.

In practice, the transmitter system operates in two modes: a periodic update mode and an interrupt update mode. In the periodic update mode, each transmitter sends a signal in turn indicating that its sensor is either in a buff or in a draft condition. In the override mode, a change in the coupler and sensor state causes an immediate transmission of the signal representing the new state. The receiver decoder display system senses and decodes transmissions from each station and displays the results. If no transmission is received for a given station for two periodic update cycles (requiring a total of approximately twenty seconds) the display for that station is turned off until a new signal is received. The use of the two transmission modes allows for immediate display of a new signal and elimination of spurious information due to signal loss. The transceivers are operated by internal batteries contained in robust weatherproof housings which are readily mounted on the freight car ladders. The TSC prototypes operate on a frequency of 162.675 mHz, but this frequency is not critical and any voice communication frequency available to the railroads is suitable.

3.3 Receiver-Decoder Display

The state of each of the instrumented couplers or coupler stations is represented on a display consisting of five pairs of lights. Each pair represents one coupler, the yellow or upper light in each pair represents the draft condition and the blue or lower light represents the buff condition. The display may be directly attached to the receiver decoder unit or attached to it by a flexible cable. The display itself is equipped with a magnetic fastener permitting easy installation of the display within the user's field of view while at the same time, allowing the bulkier receiver-decoder unit to remain on the floor out of the way. The display also incorporates a rheostat allowing adjustment of the light level of the light pairs to the illumination requirements of the user. The receiver and the display are powered by internal batteries but have provision for operating from an external 12 volt DC power source.

3.4 Recorder

Because the signals are encoded as acoustic tones they may be recorded prior to decoding on a standard magnetic tape recorder. In TSC's prototypes, battery operated cassette type recorders were used. They were chosen because of the economies involved in using commercial units and the simplicity they afforded the user. The recorder and the decoder display section of the receiver-decoder-display unit are connected in parallel allowing simultaneous recording of the signal and use of the display. To replay the signal, the recorder output is played through the decoder unit which in turn activates the display. Annotation of the record is made possible by an interrupt switch which allows the user to place verbal comments and data such as location, time and train operation conditions directly on the tape.

3.5 Analysis Techniques

The data may be interpreted directly in real time by engineers or other railroad personnel en route, but TSC and railroad experiences have revealed that analysis after the "run" by individuals familiar with the route and handling strategies often yields more useful information. In practice, track sections of interest are chosen and identified on the tape. The train of interest is equipped with a draft buff indicator system and then operated over the chosen track sections. During analysis the track sections of interest are identified from the tape and then the percentage of time that each of the five stations is in draft and in buff over selected sections are tabulated. Figure 1 illustrates a plot of the recorded data from a train ascending a grade with helper in service. The horizontal axis of the figure depicts the position of the sensor station within the train; the vertical axis, the percent of time the station registers draft or buff. As the draft buff indicator can detect and display only draft or buff, the percentage of time that the coupler is in buff on any section is the complement of the percentage of time that it is in draft. Plotting smoothed curves through both points, however, allows the ready visualization of the power node or point on the train where the influence of the helper and the lead units are balanced. Further, the shape of the plots yield important information with regard to the train's stability. The steeper the slopes of the lines going through the power node the fewer the changes in state experienced by the various stations in the train, and the more stable the train on the particular section.

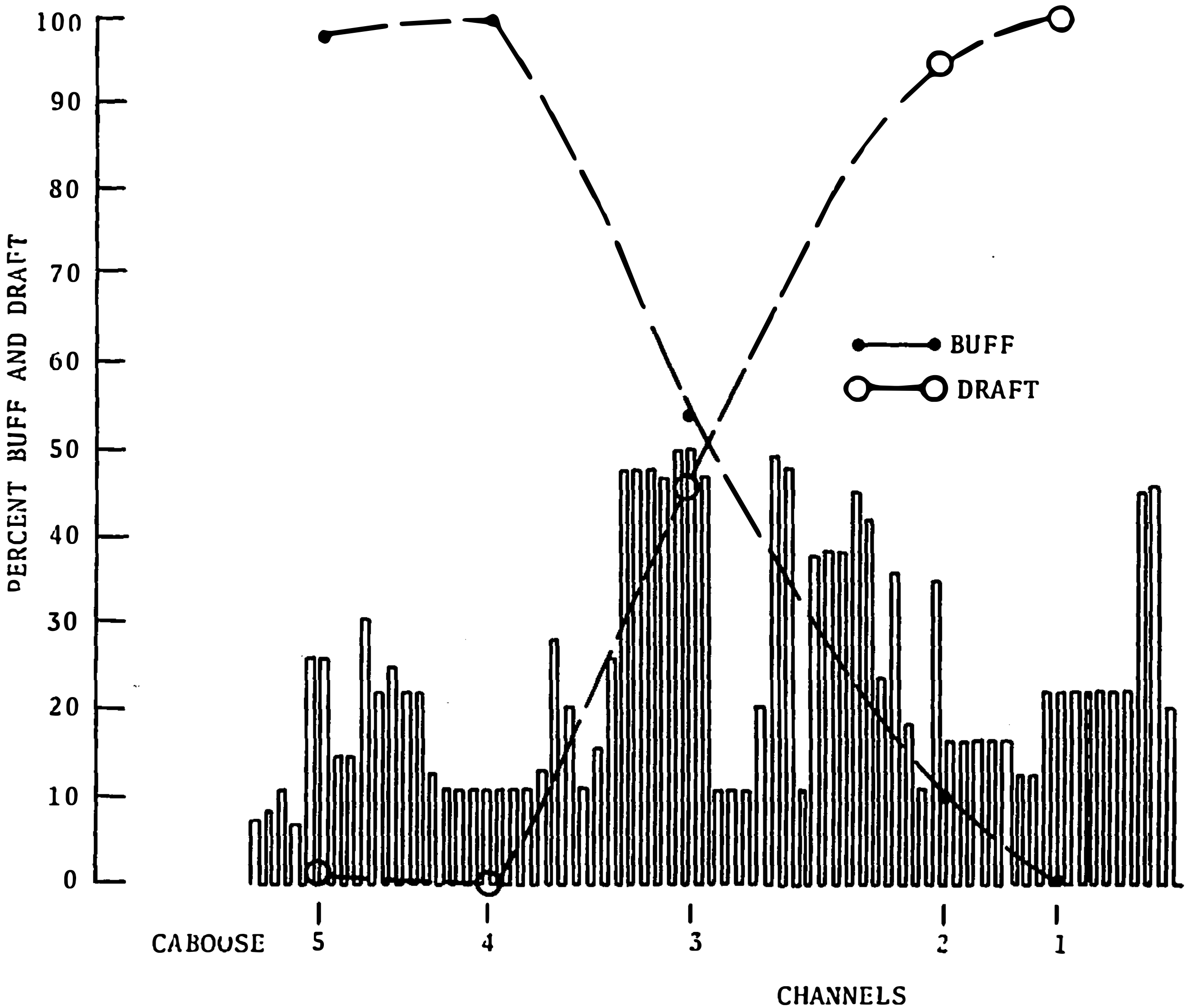


FIGURE 1 DBI TIME-IN-STATE GRAPH - SLACK ACTION ON ASCENDING GRADE, STRAIGHT TRACK (With Helper Locomotives)

4. APPLICATIONS

Four prototype DBI systems have been provided to railroads and used in various applications including; accident investigation, survey of current practices, and development of new procedures.

4.1 Accident Investigation

Two applications have been reported by the Southern Pacific Railroad. The first was in an investigation of unexplained freight car derailments occurring on mainline track. The accident investigators suspected undetected slack action was a possible cause. During the investigation freight trains operating over the problem area were equipped with draft buff indicator systems and their slack actions recorded and analyzed. The results did not demonstrate a significant level of slack action and the test personnel explored alternative hypotheses. The derailments were later related to the occurrence of violent "truck-hunting."

In the second example, the cause of derailments occuring on ore trains operating from mineheads to mainline track was sought. Data gathered with the draft buff indicator suggested that slack action was probably involved. Study of and analysis of recorded data using the DBI resulted in a development of new procedures aimed at increasing the train's resistance to slack-action shocks and the elimination of maneuvers which might cause or initiate slack-action shocks. Among these changes were requirements for heavily loaded ore cars to follow directly behind the lead power units, the use of air brakes to "bunch the train" prior to any use of the dynamic brake, and maintenance of uniform and low speeds in order to minimize maneuvers which will initiate slack action.

4.2 Survey of Current Practice

An example of use of the DBI to survey railroad practices was provided by CONRAIL. Members of the CONRAIL staff monitored the DBI display during operations requiring stretch braking. They noted that the release of the train brakes at the customary point was accompanied by a shift from draft to buff at the trailing DBI sensor station. This was quickly followed by changes from draft to buff at the next two sensor stations indicating a run-in. The observers suspected that the stretch braking was terminated too early which allowed the cars at the rear of the train (which were still on the grade) to run-in to the rest of the train. Based on this observation, it was decided to change the operating procedures and to postpone the termination of the stretch braking maneuver thereby allowing more of the train to leave the grade prior to brake release. While such a shift in the braking point will result in greater fuel consumption and train brake wear it can reduce the possibility of run-in induced damage.

Subsequent to the decision to make the change, but before it could be communicated to the train crews, a train similar to that observed in the DBI tests, descended the same grade. During the descent a derailment was observed near the rear of the train. As a result of the investigation of the derailment, which included consideration of the crews' reports, the physical evidence and the information previously developed using the DBI, the CONRAIL staff members concluded that the derailment could be attributed to an early stretch braking release.

4.3 Development of New Procedures

An example of the use of the DBI in the development of railroad operating procedures was provided by the Southern Pacific Railroad. The railroad operating staff was investigating procedures for increasing the efficiency of helper operations. The use of helper units or helper consists is a long established procedure in railroading. Helper units are simply locomotives which provide extra traction and braking effort; however they are not attached to the lead power consist. They are coupled within the train towards or at the rear. Simply adding locomotives to the lead consist would result in the imposition of excess forces on the draft gear of the cars at the front of the train which could in turn cause train separations and/or derailments. The helper units are therefore remote from the lead engine and lead engineer, and are controlled either by a radio telemetry link to the lead engine cab (on railroads so equipped) or by a helper engineer who provides manual control.

There are many strategies for helper operation. A common one is to operate the part of the train directly influenced by the helper consist as a separate train which is coordinated with the movement of the train section pulled by the lead units. Placement of the helper units within the train is determined by calculations which relate the theoretical horsepower of the helpers to the number of cars that they can control on the "ruling" or most severe grade on the particular run. The placement of the helper consist is calculated so that it pushes one third of its cars and it pulls the remaining two thirds. The control sections are then calculated to achieve the "one third-two thirds" effect.

There are serious drawbacks to this type of operation. The possibility of derailment of cars towards the front of the train due to lead locomotive emergency braking is increased and the possibility of train separation of trailing cars pulled over the crest of grades is also relatively high. Perhaps the most significant problem is the time and effort required to calculate the helpers position, insert them into the train and "set them out" when they are no longer needed. In practice helpers are inserted just before entering difficult territory and set out after leaving this territory. The insertion and set out times cause significant delays and are particularly bothersome because they tie up mainline track. A procedurally simpler strategy is to place the helpers at the rear of the train just before the caboose, and then maintain a high power setting so that the helpers are always pushing against the head end units.

While such a procedure would simplify train assembly, it was important to determine what sort of effect it might have on train stability prior to adoption for any particular terrain. To investigate this the Southern Pacific railroad performed a series of tests of various helper placements and control stratagies using the DBI. The results of the tests indicated that placing the helpers at the rear of the train and pushing would enhance both efficiency and stability of the operation and so this strategy has been adopted.

5. PROPOSED USES

A number of other uses have been proposed for the DBI. Among the most important of these are the training of new engineers and the provisions of real-time feedback in special operation situations.

5.1 Training

The device could be used to demonstrate the nature of slack action to novice engineers. This would probably improve their understanding of trains in action. The DBI could also be used to help new engineers to learn the control responses needed to operate various train types on the territory which would later make up their assignments.

5.2 Special Operations

The device could be used to provide direct feedback to engineers operating high speed unit-trains. In such applications the DBI units could be permanently installed or built into the freight cars and locomotives. The device could also be used to provide immediate feedback to individuals involved in operating trains carrying hazardous materials or trains which were particularly unstable due to slack action.

6. POSSIBLE FUTURE DEVELOPMENTS

6.1 Limitations of Draft Buff Indicator

The draft buff indicator systems remains a relatively sophisticated piece of equipment for general railroad use. Its repair and maintenance requires skilled electronic technicians. This, however, is not the major drawback of the system; rather the time required to install the draft-buff indicator sensor transceiver stations remains a major problem in using the system. Installation of the stations requires access to the train as it is being made up. This is often almost impossible in normal operations and extremely difficult in automated freight yards.

Another limitation on the device is the need for the training of the engineers who use it. At this time, there are no rules or procedures by which the engineer may interpret the information provided by the DBI into control changes which could enhance train handling. Such rules must be generated through use of the device and this generation will only follow the familiarization of training and operating personnel within its operation.

6.2 New Railroad Developments

A number of new railroad developments would enhance the value of the DBI including increased train length, the increased use of radio control or "RC" helper units and the increased use of floating sill cars. Increased train length is likely to increase the problems associated with slack action and make its control more critical. The increased use of radio control helpers would make use of the draft buff indicator more important because in the current operation of the rear helpers the engineer has absolutely no information as to the helpers' effects on the slack action on the train. The draft buff indicator would provide him with direct information on the slack conditions within the train. Finally, the increased use of floating sill cars (using long stroke hydraulic draft gear) would make the use of the draft buff indicator more important as such cars increase the sensitivity of the train to slack action even though they decrease the sensitivity of the individual cars to shocks resulting from slack action.

Conversely, maintenance improvements, the use of shorter trains, and improved coupler systems would decrease the problems associated with slack action and the need for the Draft Buff Indicator.

7. CONCLUSIONS

7.1 System Demonstration

The feasibility of the development and application of a prototype device (the Draft Buff Indicator) to directly display and record slack action within the train has been demonstrated. This device has been used on five major railroads in both special tests and in revenue service and has proved robust against weather and general railroad operation conditions. The problems involved in further application of the device are procedural and include the time required to install the system prior to train departure and the need for training procedures which allow the engineer to directly use the information provided by the draft buff indicator.

In the work to date, four systems were provided to the railroads by the Department of Transportation. One of these prototype units revealed many technical improvements. However, the basic design of the prototype units was demonstrated to be sound and, through improvements are possible, would probably remain the same in production units.

7.2 Applications

Because of the problems noted above the applications for the draft buff indicator remain limited. Its best applications are in the investigation of slack action related accidents, the development of improved operating procedures, and training. It is highly unlikely that the draft buff indicator in its present form would ever be required for all trains as a standard operating tool. However, it is likely that a number of changes in operations, such as increases in train length, would vastly enhance the value of the use of the draft buff indicator.