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ORIGINAL

Decision No. 81248

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Investigation on the Commission's own
motion into the safety appliances and
procedures of the SAN FRANCISCO BAY
AREA RAPID TRANSIT DISTRICT.

Case No. 9445
(Filed October 3, 1972)

Malcolm Barrett and Thomas Jackson, Attorneys at
Law, for San Francisco Bay Area Rapid Transit
District, respondent.

Levy C. Van Bourg, by Barry J. Williams, Attorney
at Law, for Ely Palmer, and Hon. John A. Nejedly,
State Senator, for himself, interested parties.

John P. Mathis, Richard D. Gravelle, and
Walter Kessenick, Attorneys at Law, for the
Commission staff.

INTERIM OPINION

The Commission's Order Instituting Investigation in Case
No. 9445 reads as follows:

"The Commission having been given safety
jurisdiction over the San Francisco Bay Area
Rapid Transit District (BART) pursuant to
Section 29047 of the Public Utilities Code; and

"An accident having occurred on October 2, 1972,
at the BART Fremont Terminus, at which the train
failed to make the proper stop;

"IT IS ORDERED that an investigation is hereby
opened on the Commission's own motion into the
automatic train control system of BART and into
all other safety appliances and procedures of
BART which are subject to the Commission's
regulation. While the subject matter of this
investigation will focus on the incident of
October 2, 1972, the Respondent is placed on
notice that the Commission may wish to expand
this investigation."

The accident which occurred on October 2, 1972 is described in detail in the following opinion. It involved a two-car BART train running through Fremont Station into a sand pile at the end of the tracks. No serious injuries were incurred by passengers or operating personnel.

Public hearing in Case No. 9445 was held before Commissioner Vukasin and/or Examiner Mallory at Oakland on October 10 and 11, 1972 and at San Francisco on December 4, 5, and 6, 1972. The hearing was limited to an inquiry into the causes of the October 2 accident and to determine what steps should be taken to prevent recurrence of a similar type of accident. At the conclusion of this inquiry the investigation was temporarily removed from the calendar.

Evidence concerning the events directly involved in the accident was submitted by the operator of the train, by a Commission staff member who was riding the train as part of his assignment to investigate BART operations, and by four members of the public who were aboard the train at the time of the accident.

Five technical or engineering personnel and three train operators employed by BART explained the general operation of the BART system, the events leading to the accident, and the steps taken by BART after the accident.

BART's assistant general manager for operations and engineering placed in evidence the report on BART's investigation into the accident, and the conclusions reached therein with respect to the cause of the accident.

An analyst employed by the office of the Legislative Analyst for the California Legislature presented in evidence a report on BART's operations and financing prepared for presentation to the Joint Legislative Budget Committee, a joint committee of the California State Legislature.

Testimony concerning the causes of the accident and the remedies which may be taken to prevent similar accidents was received from two independent engineers. These witnesses also testified with respect to BART's automatic train operations (ATO) systems.

A staff member from the Commission's Transportation Division, Operations and Safety Section, presented exhibits containing a report on train operation failures occurring on a two-day period subsequent to the accident and staff recommendations designed to prevent future accidents at Fremont Station similar to the October 2 accident.

BART'S SYSTEM

The San Francisco Bay Area Rapid Transit District is a public corporation organized to provide rail rapid transit service between points in Alameda, Contra Costa, and San Francisco Counties. The system, when completed, will provide service on three separate lines in Alameda and Contra Costa Counties, and between points on those lines, and San Francisco and Daly City. At the time of the hearing only the line between MacArthur Station (Oakland) and Fremont was in revenue operation.

COMMISSION SAFETY REGULATIONS

General Order No. 127, effective September 15, 1967, contains regulations governing the construction, maintenance, and operation of automatic train control systems with respect to train detection and separations, route interlocking, speed enforcement, and right-of-way hazard protection, on rail rapid transit systems.

Prior to the commencement of revenue operations by BART, the Commission adopted Resolution No. S-1358 dated August 31, 1972, which stated that final approval could not be given at that time to the full utilization of BART's automatic train control system, and therefore ordered the following:

"IT IS ORDERED that approval for use of automatic train control in the operation of trains in revenue service is hereby granted subject to the following conditions:

- "1. Train revenue operations utilizing automatic train control shall be limited to the district between Fremont Station and MacArthur Station between the hours of 6 am and 8 pm, Monday through Friday.
- "2. The train control system shall be supplemented by manual override consisting of a trained operator at the controls of each train with a backup of supervisory personnel at key stations to provide positive train control in accordance with rules to be agreed upon and filed with this Commission prior to the commencement of revenue service.
- "3. Operation of trains utilizing automatic train control beyond the district specified in Condition 1 hereof shall be conducted in accordance with Condition 2 unless prior to that time final approval for the full utilization of the control system has been given by the Commission.
- "4. Further necessary testing of the train control system to prove reliability and conformity to General Order No. 127 shall be limited to times of nonrevenue service.
- "5. BART shall keep a full record of tests made in accordance with Condition 4 hereof and shall make said record available to the Commission or its representatives. Said records shall be kept on file for at least one year after the date hereof or until final approval of the system has been given by the Commission."

Revenue operations of BART were being conducted under the foregoing conditions at the time of the accident under investigation. Resolution No. S-1365 dated January 16, 1973 amended Condition 1 of Resolution No. S-1365 as follows:

"Train revenue operations utilizing automatic train control shall be limited to the district between Fremont Station and Richmond Station, Mondays through Fridays."

All other conditions of Resolution No. S-1358 remain in effect:

BART'S ATO SYSTEM

BART's trains are designed for fully automatic operations. A train attendant is assigned to each train. Under fully automatic operations the train attendant's duties would consist of monitoring train functions, announcing the approach to stations, and furnishing disembarking instructions. However, fully automatic operations were not permitted under the Commission Resolution reproduced above as the Commission had determined that the ATO system could not always detect the location of trains and imposed the manual override system described in Condition 2.

At the time of the accident BART's ATO system was in operation only insofar as to starting, operating speeds, and stopping was concerned. Speed instructions to trains are transmitted from each station by means of signals through the running rails and received by trains through antennae mounted over the running rails. Modifications of speed commands can be made by BART Central. The positioning of the trains at stations is accomplished by transmission of speed signals through antennae attached to the side of the trains. The maximum permissible speed is 80 mph. The speed control detection system aboard trains is designed to recognize speeds of 80, 70, 50, 36, 27, 18, 6, and 0 mph.

BART trains are equipped with two separate braking systems, an electro-hydraulic system and a dynamic system. Full service braking is designed to decelerate the train at the rate of 2.7 to 3.3 mph per second. At that rate, approximately 1,100 feet is required to reduce train speed from 70 mph to 20 mph.

The front car in each train contains a console consisting of a bank of signal lights, a set of manual operating controls, a digital speedometer, and a stop button. Braking by the attendant can be accomplished by placing the train in manual operation or by pressing the stop button. Activation of the braking system by either method stops the train at the aforementioned rate of about 3 mph per second. Train speeds are automatically controlled; however, the train operator can place the train in manual operation and run at a reduced speed. The maximum speed under manual operation is 25 mph.

FREMONT STATION

Fremont Station is the southern terminus of BART in Alameda County. The station north of Fremont is Union City. Train speed from Union City to Fremont is 80 mph up to a point either approximately 4,400 feet or 2,500 feet north of the south end of the platform at Fremont.

BART's operations are conducted over two parallel tracks throughout its system. Fremont Station consists of a center platform with tracks on either side. The platform is 700 feet in length. Approximately 48 feet from the south end of the platform is a sand pile. Tracks run into the sand pile.

At the time of the accident, trains approaching Fremont Station could enter either side of the platform. The track on the western side of Fremont Station is designated by BART as its TM-1 zone and on the eastern side as its TM-2 zone. Trains entering the

TM-2 zone would change from the westerly to the easterly track by means of a crossover switch located approximately 480 feet from the near end of the platform (1,180 feet from the far end of the platform). The train attendant would not know whether the train would enter the TM-1 or TM-2 zone until the train passed by or through the crossover.

Maximum speeds for trains entering Fremont Station TM-2 zone when using the crossover are as follows:

80 mph	approaching	4,444'	from	sand pile
50 mph	4,444'	to	3,627'	from sand pile
36 mph	3,627'	to	2,522'	from sand pile
27 mph	2,522'	to	415'	from sand pile
18 mph	415'	to	231'	from sand pile
6 mph	231'	to	60'	from sand pile
0 mph	60'			from the sand pile

Maximum speeds for trains entering Fremont Station TM-1 zone when not using the crossover are as follows:

80 mph	approaching	2,522'	from	sand pile
50 mph	2,522'	to	1,486'	from sand pile
36 mph	1,486'	to	798'	from sand pile
27 mph	798'	to	415'	from sand pile
18 mph	415'	to	231'	from sand pile
6 mph	231'	to	60'	from sand pile
0 mph	60'			from the sand pile.

About 700 feet from the sand pile the program-stop feature of the ATC system takes control over the stopping of trains, so that the trains will stop near the center of the platform regardless of the length of the train.

THE ACCIDENT

On October 2, 1972, BART Train No. 307 heading southbound from Union City to Fremont ran through Fremont Station and into the sand pile at the end of the tracks. The first car of the two-car train plowed through the sand pile and came to rest with its front lying in the adjacent parking lot.

The testimony of the train attendant, the staff engineer aboard the train, the public witnesses, BART technical personnel, and the BART's report of its investigation serve as a basis for the following summary of facts concerning the accident.

Train No. 307, consisting of two cars, was routinely dispatched from the Hayward yard at 8:28 a.m. on October 2, 1972. It made one trip south to Fremont and was making its second trip when the accident occurred.

The train was dispatched from MacArthur Station at 9:21 a.m., arriving at Union City at 9:51 a.m. The train was held at Union City until the preceding train vacated the TM-2 zone at Fremont. The train proceeded south in automatic operation at 9:52 a.m. The train achieved an operating speed of 80 mph approaching Fremont. The train was scheduled to enter the TM-2 zone at Fremont. The train attendant had no knowledge of the TM zone to be used.

The train attendant made his routine announcement that the train was entering Fremont Station. The attendant first recognized that operations were not normal when the train entered the crossover (to bring it into the TM-2 zone) without materially decreasing its speed. The train attendant immediately pushed the "stop" button several times, and then placed the train selector lever in the off position and removed his key.

The testimony of the persons aboard the train establishes that the train was moving at approximately 66 mph at the time it started through the crossover. Estimates made by a BART technician indicated that the train had slowed down prior to striking the sand pile. The witness developed that the approximate train speed when striking the sand pile was 26 mph.^{1/} The sand pile absorbed the

^{1/} This estimate was disputed in the Legislative Analyst's testimony presented in connection with Exhibit 14, the Report of the Legislative Analyst Into the Operations of BART.

greater portion of the impact energy of the train. The lead car of the train came to rest with its head end 70 feet from the point of impact with the sand pile.

The lead car (Car 143) sustained minor damage to its shell at the head where impact was made with the sand pile; the frame of the car was sprung because of the drop from the sand pile to the parking lot; and under-car equipment was severely damaged because of impact with the sand pile. Car 143 had no broken windows, nor were any seats damaged. The second car (Car 118) remained on the track and suffered only a broken coupler.

Twenty-five persons were aboard the train. The attendant and four passengers were taken to the hospital and released. No apparent permanent injuries were sustained.

The technical witnesses for BART described in detail the investigations made by BART subsequent to the accident, and the Report of BART's Board of Inquiry was introduced into evidence as Exhibit 11.^{2/} The substance of this evidence was that the following occurred as Train 307 approached Fremont Station: At Mile Post 23.31, the train received a wayside command to decelerate to 27 mph. The train responded erroneously by accelerating, achieving a speed of approximately 66 mph at the time it crossed the interlock switch at the crossover while approaching Fremont Station. The train attendant

^{2/} The Board of Inquiry consisted of D. G. Hammond, BART's Assistant General Manager-Operations and Engineering; C. E. Keiser, retired Manager of Operations, Chicago Transit Authority; and C. Kalkof, Superintendent, Maintenance of Way, New York City Transit Authority.

pushed the "stop" button at approximately the point where the train entered the crossover. The brakes functioned in a normal manner, but the speed of the train was too great to permit normal braking to stop it within the limits of the station.

TESTS MADE BY BART

On October 2 and 3, a team of persons employed by BART and its consulting engineers and suppliers conducted tests on the train equipment involved in the accident, and the wayside equipment in the area of the accident.

The tests on the wayside equipment disclosed no adverse or abnormal conditions. Tests of the aboard-train propulsion equipment were also made. No exceptions were taken to the ATO equipment of Car 118 nor to the electro-hydraulic or dynamic braking systems on either car. Although hydraulic lines on Car 143 were bent and flattened in several locations, they still operated properly. The stop button circuits on both cars were tested and they also functioned properly. However, when testing the ATO equipment from Car 143, the crystal designed to transmit a signal representing a 27 mph speed command did not oscillate at the proper rate.

The ATO equipment from Car 143 was then placed in Car 110 for the purpose of testing under road conditions. Test equipment capable of duplicating wayside signals was placed aboard the train and tests were conducted between Union City and Fremont.

The ATO equipment in Car 110 functioned properly except when given the 27 mph speed command. Every time this signal was given, the train would immediately accelerate to speeds between 40 and 80 mph. The stop button was used during these tests and although it functioned properly, it was noted that hard blows could unseat the button from its mounting. The ATO equipment was then removed

from Car 110 and X-ray equipment was used to look into the sealed crystal boxes. These crystal circuits oscillate upon specific wayside signal commands which cause one of the crystals to oscillate and send a signal to the master oscillator crystal. The master oscillator compares this signal with the wheel rotation and signals the propulsion to either accelerate or brake. All of the crystals appeared normal except for the one designed to receive and transmit the signal for 27 mph. This crystal appeared to be mounted at one end of the box instead of in the middle.

The 27 mph crystal circuit was sent to Bulova, the subcontractor responsible for assembling the crystals, for observation and testing. Examination of the circuit disclosed that the crystal was mounted in such a way that it was capable of shorting intermittently. A complete short in this circuit would have transmitted no signal which would have been interpreted as a zero speed command. However, the intermittent shorting caused the crystal to transmit an abnormal signal, in this case a signal for speeds higher than 27 mph.

THE CAUSE OF THE ACCIDENT

The investigation by BART established that the proximate cause of the accident was a defective crystal which controlled an oscillator in the speed decoding network in the automatic train protection sub-system aboard Car 143. The malfunction of the defective crystal caused the decoding equipment on board the car to misinterpret the 27 mph speed command transmitted from wayside as a 70 mph command, resulting in the train attempting to achieve that speed in response to the faulty command.

Following a determination that a faulty crystal was the proximate cause of the accident, BART examined all speed decoding circuits which contain similar crystal controlled oscillators and found no evidence of existing or potential defects.

OPERATING PROCEDURES

The investigation by BART and by the Commission staff determined that certain operating procedures should be undertaken to prevent future run-throughs at Fremont Station. The following corrective measures in operating procedures were instituted by BART as a result of the staff and BART investigations to prevent similar accidents. These corrective measures are as follows:

1. Stop buttons at both ends of the train are to be tested every day prior to revenue service even though there has been no evidence of a malfunction.
2. Speed profiles for A-90-TM1 (southbound track at Fremont) have been changed to coincide with the speed profiles for A-90-TM2.
3. Speed signs have been placed to the right of track approximately 200 feet beyond the point of maximum permissible speed zones for southbound trains entering the crossover at Fremont and train attendants have been advised to depress the stop button should their train exceed the posted speed.

LEGISLATIVE ANALYST'S REPORT

The report of the Legislative Analyst (Exhibit 14) is an investigation of BART with particular reference to safety and contract administration.^{3/} The portion of Exhibit 14 involving safety was developed in response to a legislative request that the Legislative Analyst determine what problems affecting the safety of passengers carried by BART still remain unsolved, and in what manner can the Legislature assure that proper steps will be taken to resolve such problems. Of necessity the scope of the Legislative

^{3/} The portion of the report dealing with contract administration is not embraced within the issues raised in this proceeding.

Analyst's investigation is broader than that defined in our order.

The Legislative Analyst's report contains the following recommendation specifically directed to safety matters involving the accident at the Fremont Station: "BART should take all steps necessary to provide sufficient terminal track extensions and emergency restraining structures with adequate safety factors at the terminal end of each line."

The witness presenting Exhibit 14 also recommended that this Commission should examine in depth the need for a backup manual control and signal system. The witness testified that if the train operator had seen a visual speed command signal at the same time that the failure occurred in the crystal oscillator in the speed control system, the train attendant would have immediately recognized that the train had not responded to the speed command. This added information would permit the train attendant to override the ATO system if it appeared that the ATO system is not functioning correctly.

It is the view of this witness that a manual override of the fail-safe system is required for BART, and that full operations using the transbay tube should not be inaugurated until such a system is adopted. The specific recommendation in Exhibit 14 is the following:

"BART and this Commission should perform a thorough reevaluation of a trackside signal system or an internally mounted cab signal system to inform the train operator in advance of all speed zone changes, and changes in vital routing information which are important to assure safe operations. The need for additional manual control functions available to the train operators should also be evaluated in order to assure essential human intervention under conditions of automatic control failures."

OTHER TECHNICAL WITNESSES

A witness, whose technical background is in digital computer system design, testified that there are basic flaws in the design of BART's ATO system, and that an additional redundant signal system is required to make sure the ATO system is functioning properly.

An electronic engineer, who had previously been employed as a train control engineer for BART, testified that in the course of his employment he had developed computer programs and system designs for BART's central control system. The witness testified that the failure of the particular crystal oscillator was the result of an incredible coincidence of factors which probably will never happen again. The witness stated, however, that there are countless other possibilities for failures in the ATO system. The witness stated that BART equipment is not as safe as equivalent equipment on other rail rapid transit systems which perform essentially the same functions because of the complexity of BART's signal system. Other rail rapid transit systems employ a relatively simple analog signalling system which has been in use over a period of years and has been proven to be adequate and safe for automatic train operations. The witness testified that the more complex system developed for BART cannot be determined to be safe until it has been subjected to actual operating conditions over a span of many months. Because of the larger number of components in BART's digital system as compared with the simpler analog systems, there are many more chances for failures to occur. The witness recommended that reliability studies should be made of the ATO system developed for BART, and that redundant circuits should be added as a guard against component failures to insure that the trains actually obey the speed signals received.

ADDITIONAL DATA

A Commission staff safety engineer introduced Exhibit 12, which contained a report of train operations over a two-day period following the accident. This report showed, among other things, that upon entering stations train attendants frequently had used the stop button to override the program-stop function of the ATO system, and that other malfunctions occurred which caused trains to operate improperly. The staff witness described such malfunctions as operational problems, rather than safety problems. The frequent manual override of the ATO system by train operators to prevent potential station run-throughs was also described by the witness as an operational problem. The several types of incidents where malfunctions occurred, as shown in the staff report, indicated to the witness that many operational difficulties exist with respect to BART's ATO system which require the continued use of the operating rules set forth in Commission Resolution S-1358 (supra).

The Commission finds:

1. On October 2, 1972 a BART Train 307 consisting of Cars 143 and 118 ran through Fremont Station and through the sand pile at the end of the tracks at that station. Car 143 continued through the sand pile and ultimately stopped with its nose resting in the adjacent parking lot. Car 118 stayed on the rails. Car 143 sustained substantial damage to the equipment carried under the car, the frame was bent and the car shell at the head end was damaged from impact with the sand. Damage to Car 118 was limited to a broken coupler. Twenty-five persons were aboard the train. Five persons in Car 143 were hospitalized and released. No permanent injuries appear to have been incurred by passengers or BART employees.

2. Investigations of the cause(s) of the accident show that the proximate cause of the accident was the failure of a crystal oscillator in the train-speed control equipment on board Car 143 to respond properly to the speed command issued to it by wayside equipment.

3. Train 307 (operating under a speed command of 36 mph) received a speed command at Mile Post 23.31 to decelerate to 27 mph. Due to the faulty crystal oscillator responding incorrectly to this speed command, the train accelerated to a speed of approximately 66 mph.

4. The train operator aboard Car 143 responded to the increase in speed by punching the stop button and then placing the car under manual control, the two methods available to him to stop the train.

5. The train responded to the actions of the train operator by decelerating at the braking speed designed for BART's system, that is, at a speed between 2.7 and 3.3 miles per hour per second.

6. The aforementioned rate of deceleration was not sufficient to stop the train in the area of the station.

7. No evidence exists to indicate that there is any other physical cause of the accident beyond the failure of the crystal oscillator in the speed control system aboard the car.

8. Additional operating rules to bring trains to a slower speed before entering the crossover leading to the TM2 zone of Fremont Station were developed by the Commission staff and BART and immediately placed into effect following the accident.

9. BART has instituted a procedure for testing all crystals in its speed control system and on its cars. At the time this hearing was concluded, no additional defective crystals had been found.

10. There will be no reasonable likelihood of a similar accident occurring again if BART continues the procedures described in Findings 8 and 9.

11. BART has experienced many day-to-day operating problems with respect to its ATO system (such as station run-throughs) and to the operation of automatic equipment aboard its trains (such as failure of doors to open). The evidence indicates that BART has not yet achieved a desirable level of reliability for its ATO system or for its aboard-car equipment. However, none of the operating problems described in the record will result in unsafe operations as long as the current restrictions imposed by Resolution No. S-1358 are continued in effect.

12. BART should immediately modify its train control panel to provide a visual indication to the train operator of the speed command being received by the trains's ATO system.

The Commission concludes:

1. Resolutions Nos. S-1358 and S-1365 should be continued in effect until BART has demonstrated that its ATO system is reliable and is functioning properly.

2. BART should continue in effect the operating rules established to control train speeds and to inform train attendants of changes in train speeds entering Fremont Station, until further order of the Commission.

3. With the continuation of the aforementioned operating rules, it will not be necessary to modify the terminal tracks at Fremont or to modify the emergency restraining structure (sand pile) at that station.

4. No extension of BART's revenue service involving merging, diverging, or crossing of trains should be authorized until BART has satisfactorily shown its ATO system will be reliable and in conformity to General Order No. 127. Any application for such service shall be filed at least 90 days prior to the commencement of such service.

5. BART should modify its trains in conformity with Finding 12.

6. The proceeding should be kept open for the receipt of additional evidence with respect to the safety of operations of BART's ATO system.

INTERIM ORDER

IT IS ORDERED that:

1. The provisions of Resolutions Nos. S-1358 and S-1365 shall remain in full force and effect with respect to revenue operations of the San Francisco Bay Area Rapid Transit District until further order of the Commission.

2. The following operating rules shall remain in effect with respect to revenue operations of the San Francisco Bay Area Rapid Transit District until further order of the Commission:

- (a) Speed profiles for A-90-TM1 (southbound track at Fremont) shall coincide with the speed profiles for A-90-TM2.
- (b) Speed signs shall be placed to the right of the track approximately 200 feet beyond the point of maximum permissible speeds for southbound trains entering the crossover at Fremont Station. Train attendants shall be instructed to depress the stop button should the train exceed the posted speed at that point.

- (c) In addition to all other tests conducted by the train attendant, stop buttons at both ends of trains shall be tested each time the train is placed in revenue service.

3. BART shall take the necessary steps to immediately install on its train a visual indication of the speed signals being received by the trains's ATO system.

4. Any application of BART for service involving merging, diverging, or crossing of trains shall be filed with the Commission at least 90 days prior to the commencement of such service.

5. Further hearings shall be scheduled to receive additional evidence at a time and place to be determined.

The effective date of this order shall be twenty days after the date hereof.

Dated at San Francisco, California, this 10th
day of APRIL, 1973.

Vernon L. Stinger
President
William Symons, Jr.
[Signature]
[Signature]
Commissioners

Commissioner J. P. Vukasin, Jr., being necessarily absent, did not participate in the disposition of this proceeding.